A Redesigned Reconstruction Kit for Rapid Collaborative Debugging and Designing of E-Textiles

Deborah A. Fields
ITLS
Utah State University
Logan UT U.S.A.
deborah.fields@usu.edu

Yuhan Lin
TLL
University of Pennsylvania
Philadelphia PA U.S.A.
jimmylin@upenn.edu

Gayithri Jayathirtha
TLL
University of Pennsylvania
Philadelphia PA U.S.A.
gayithri@gse.upenn.edu

Yasmin B. Kafai
TLL
University of Pennsylvania
Philadelphia PA U.S.A.
kafai@upenn.edu

ABSTRACT

In this paper, we present an iteration on a "reconstruction kit" for e-textiles, a flexible-state construction kit that allows for rapid deconstruction and reconstruction of sewn, programmable circuits. The reconstruction kit was redesigned to be more modular and was tested in more computationally and spatially challenging debugging and design situations by four pairs of students, familiar with e-textiles, in an introductory computer science course in a U.S. high school. Analyzing think-aloud protocols of the four sessions, we examined affordances and limitations of how students debugged and designed with the reconstruction kit and in which ways collaborative interactions were supported.

CCS CONCEPTS

• Social and professional topics ~ Professional topics ~ Computing education ~ Computational thinking • Social and professional topics ~ Professional topics ~ Computing education~K-12 education

KEYWORDS

Debugging, Computational Thinking, Making, Prototyping, Maker Education

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1 Introduction

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As maker activities expand into more and more educational spaces such as clubs, museums, libraries, and schools, many types of "construction kits" [7] have become available for teachers and students to support creative design among novices in robotics, electronic circuitry, and electronic textiles. While a majority of the focus has been on making and finalizing artifacts on and off the screen, much less attention has been given to the need for prototyping artifacts that provide students with opportunities to engage with troubleshooting, debugging, and iterating on their design ideas and prototypes [4]. In our recent work, we proposed the design of "reconstruction kit" to complement the making of electronic textiles (or e-textiles), by adding modular elements to a traditional e-textiles kit, transforming a fixed-state kit into flex-state one (see [4]). E-textiles construction kits [3] allow creators to design programmable, light-up textiles using conductive thread and sewable microcontrollers to components such as LEDs, buzzers, and switches. However, the fixed state of the sewing can cause two types of challenges. First, debugging e-textiles is often tedious and time-consuming since it involves ripping out and re-sewing stitches. Second, the nature of sewing with needle and thread means that, in general, deconstructing and reconstructing e-textiles circuits is a one-person job, potentially limiting the ability of two or more people to collaborate on problem solving or designing a circuit [5].

In this paper, we present the re-design and pilot testing of a revised version of an e-textile reconstruction kit to support designing and debugging e-textiles projects. We report on the changes to the kit components and describe two testing scenarios in which four student pairs familiar with e-textiles engaged in debugging and designing. We captured their interactions in think-aloud protocols [2], which we analyzed with two research questions in mind: What were affordances and limitations of the reconstruction kit for students' debugging and designing e-textiles? How were students' collaborations supported in debugging and designing e-textiles?

2 Revisions of Reconstruction Kit

The original "reconstruction kit" for e-textiles [4] (see Figure 1) was designed with strips of felt that could be used to quickly connect, disconnect, or reconnect the LEDs to the power sources in order to trace (by color) and fix circuitry problems without sewing, cutting, and resewing (See Figure 2). It embedded a microcontroller on a felt mat with hooks available for connections to five of the available pins (See Figure 3). It also included LEDs sewn onto small felt pieces with conductive hooks as well as long strips of felt in multiple colors with conductive stitching. In the revised kit we made several changes to allow for greater flexibility in design and debugging. First, we improved modularity by making the microcontroller moveable, adding safety pins to all components so that they could be affixed to any fabric surface (see Figure 1, center and right). This allowed for more spatially complex designs on a range of fabric artifacts. Second, we changed the microcontroller to the Adafruit Circuit Playground (CP) and pre-sewed hooks to every available pin. This allowed for a more expansive range of designs and problems since the CP has multiple onboard switches and sensors. Third, we included aluminum foil "touch sensor" patches, a vibration board, and more LEDs—each with hooks and safety pins for connective modularity. Finally, we also made the felt strips thinner to allow for less clunky attachments between the other electronic components.

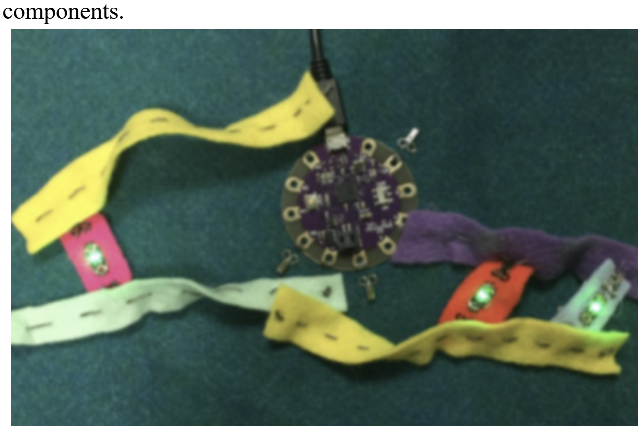

Figure 1: Original reconstruction kit (center) © Debora Lui

Figure 2: Revised reconstruction kit © Yuhan Lin

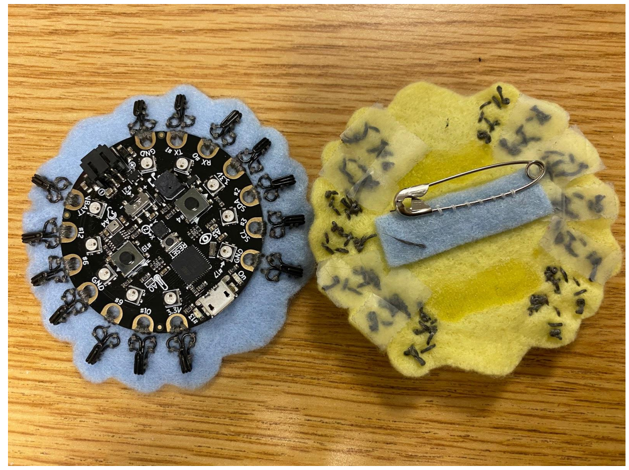

Figure 3: Close-up of Revised reconstruction kit Circuit Playground © Yuhan Lin

3 Methods

We conducted think-aloud sessions where pairs of students either debugged a pre-made, buggy e-textile project or prototyped a new project based on a prompt, both using the revised reconstruction kit. Students had already completed 6-8 weeks of the Stitching the Loop e-textile curriculum for Exploring Computer Science (http://exploringcs.org/e-textiles). Students were from an ethnically and socioeconomically diverse charter school in a large metropolitan city on the West coast of the United States. Pairs were randomly selected by the teacher. Three pairs of boys and one pair of girls were assigned to the two situations (two pairs each), each lasting a class period (~45 minutes of solving/designing with a 5-minute debrief).

In the debugging situation, students were tasked with solving intentionally designed bugs in two e-textile projects (one flat, one a pillow) created with the reconstruction kit. Students debugged first the circuitry then the code parts of the project (see [4, 6]). Circuitry problems included missing components (e.g., a ground line or a sensor patch), reversed polarity, and microcontroller pin connections that did not match code. Coding problems included undeclared pins on the microcontroller, missing input or output declarations, missing initializations, non-functional sensor ranges, missing delays (i.e., for lighting patterns), and missing components of conditional logic (i.e., missing "else" statements) (See Figure 4). In the design situation, students were tasked to design and program a new e-textile projects, either a belt or a jacket, to fulfill a design statement. For example, one design statement asked students to prototype a light-up hoodie: when the wearer touches conductive patches near their right and left palms (on the bottom of the sleeves), the hoodie needed to light up with students' choice of LED patterns. The other statement asked students to program a belt with two lighting patterns using one switch to control the patterns.

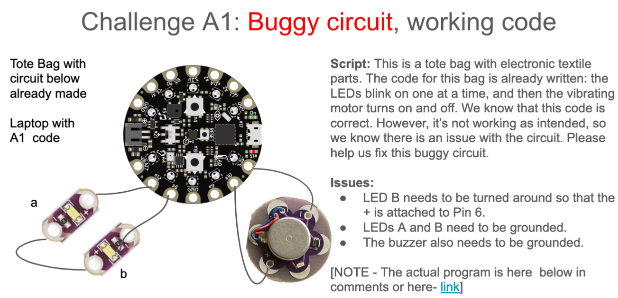

Figure 4: Example of an intentional task handout © Debora Lui

We draw from video data to answer our research questions: four 45-minutes think-aloud videos, two of students debugging and two of prototyping e-textiles design ideas [2]. To analyze the videos systematically and iteratively [1], we first divided the video into 5-minute snippets. For each snippet, we coded the video for several types of actions by the pairs of students (pairs were treated as a single unit of analysis). In the debugging situation, we recorded the tools used (e.g., reconstruction kit, pen & pencil, compiler, partner or one’s knowledge, labor and sense, etc.), how many times the group attempted to identify problems, phases of problem solving (e.g., hypothesis and solution generation, fixing), and verification or checks. For the design situations, we recorded the tools used, and the number and the sketch of major iterations. Any change in the circuit design or layout involving repositioning the circuit components was counted as an iteration.

4 Methods

4.1 Rapid Designing and Debugging in Circuitry

One affordance to the revised reconstruction kit was the ability to make frequent and quick iterations to circuit designs. In the debugging situation both student pairs verified and/or changed circuits two to three times in the first few five-minute periods (10-15 minutes total for each group) they focused on debugging circuits. As an example of one circuitry fix, Aaron and Kala put their finger on the end of a thread close to an LED whose polarity was reversed. Kala said, "this one's supposed to be switched" as the original LED was connected in the opposite direction. The pair unhooked the LED, unpinned it from the fabric, flipped it to the correct polarity alignment, then reattached and re-hooked the LED, all in only 30 seconds. Likewise, the pairs in the design situations also engaged in several instances of rapid prototyping of circuit designs. The pair working on the spatially simpler belt made three major iterations on the circuitry while the group working on the more complex jacket completed six major iterations. One reason the jacket group completed six major iterations was because of the challenges of choosing where to put the microcontroller in relation to the jacket: on the front, on the inside back (See Figure 5), or on the outside back. After discussing several different means of reorienting their design, such as rotating one of the LEDs, they shifted the position of the CP to the outside back and had to reimagine the rest of the circuitry layout, reposition the LED, and redo the new connections. Further, during the design process, Ryan and David took advantage of the availability of electronic pins on the CP, using four different pins to circuit their LEDs. These examples illustrate that the revised kit provided more flexibility in designing and debugging connections to the microcontroller. Thus, the revised reconstruction kit provided greater facility and flexibility with rapid prototyping and fixes in circuitry, as evidenced by the number, frequency, and short length of time in the fixes across the two debugging and two design groups. As one student reflected, “it was easy because it was much quicker.”

Figure 5: Example of a design -- Microcontroller inside the zipper © Deborah Fields

4.2 Collaborative Debugging and Designing

The revised reconstruction kit also contributed to more direct collaboration on physical parts of the projects, in direct contrast to prior studies that have identified a tendency for students to split tasks between physical and virtual components (e.g., [5]). While pairs or small teams of students have been observed splitting the work between crafting and coding, as it is quite difficult for two people to sew on the same piece of fabric at the same time (e.g., [5]), this was not the case with any of the four pairs. In one of the debugging situations, Regis found that the connection of the LED should be to pin 9 of the CP instead of pin 6, while his partner, Steven, simultaneously checked on other parts of the circuit. Then both of them came up with a plan to unhook and hook the LED to the correct pin and coordinated their actions together to make the change (See Figure 6).

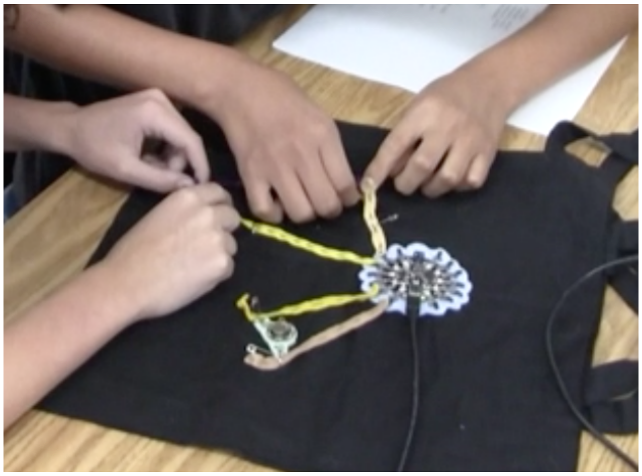

Figure 6: Collaboration between two students on the debugging challenges as both students were working the circuit at the same time

Students similarly coordinated their activities with design. For instance, Adi and Bhuvan actively worked together to lay out LEDs, CP, and threads for the belt they designed, rather than having one person manage the physical materials as is more common in e-textiles collaborations. In some instances, student pairs still split up tasks, but not into crafting (physical) versus coding (virtual). Instead they sometimes split tasks within crafting in coordinated ways. In one case, Steven identified a problem with an LED that needed to be moved because it was too close to a pin on the CP. Then Regis took over working on the circuit, while Steven helped her find all the needed materials. These instances illustrate that the revised reconstruction kit facilitated more direct, synchronized collaboration among students during the construction phase.

5 Discussion

Our goal in this study was to investigate the potential affordances of a revised reconstruction kit for e-textiles that would allow more rapid collaborative prototyping and debugging of e-textile circuitry and designs. The more modularized tool designs with hooks and safety pins for all electronic components (including the microcontroller) allowed for quick repositioning of various electronic parts. Further, the inclusion of hooks on every pin of the microcontroller allowed greater flexibility in re-design of the e-textile projects. The study also revealed constraints in the use of the reconstruction kit. For instance, sewing has a unique ability to cross from one side of a surface to another by passing a thread through fabric. In contrast, the threads sewn on pieces of felt (and similarly alligator clips or wires) cannot cross through material without cutting. Thus, as some students discovered, the reconstruction kit does not have all of the affordances of sewing circuits, even if it is malleable and attachable to fabric, leading to limitations in prototyping e-textiles designs.

Overall, this study presented the benefits for additional tool development that can support maker activities. Reconstruction kits may serve as unique tools in maker education for debugging and prototyping physical and digital artifacts that may be difficult to take apart at later stages of design. These kits might work particularly well at the early stages of spatially complex designs or in scenarios where students need practice in debugging. We noticed no effects on the coding aspects of e-textiles, perhaps not a surprise since the kit focuses on physical qualities rather than coded ones. While we have developed and studied reconstruction kits in the domain of e-textiles, we look forward to studies exploring the use of reconstruction kits in other areas of making.

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