Perceptions of Productive Failure in Design Projects: High School Students' Challenges in Making Electronic Textiles

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Abstract. The concept of productive failure has emerged as one the key ideas for designing effective learning activities in well-defined problems. Here we report on moments of productive failure from an eight-week long workshop with 16 high school freshman (13-15 years) who engaged in an open-ended design problem, making an electronic textile. Using students' self reports, we found that students encountered failure mostly in the design and crafting of circuits, and in these exploration phases students generated a multitude of successful and unsuccessful solutions. Our findings indicate that students' design artifacts function as a source of within-task feedback supporting their persistence through failures. Additionally, our findings highlight a need for further research examining what Kapur's consolidation phase looks like in an open-ended design environment, particularly focusing on the development of canonical problems from design activities as a way to have students experience failure and success in constrained design contexts.

Keywords: electronic textiles, learning through making, productive failure, learning designs

Introduction

One of the current debates in the learning and educational sciences is the role of instructional supports in learning and problem solving. While one group argues for the "productive success" model by providing direct instruction and scaffolding (Kirshner, Sweller & Clark, 2006), others point to "productive failure" with delayed instruction as an equally promising direction for scaffolding student learning (Kapur, 2008; Kapur & Bielaczyc, 2012). Much like the proponents of productive success who see scaffolds and collaborations as essential in propelling students' learning forward, the supporters of productive failure focus on better understanding the role of multiple representations and solutions, their role in activating prior knowledge, and the nature of peer support during the generation phase to identify which dimensions are most productive for which students and under which conditions (Kapur & Rummel, 2012). Most of these studies, however, have focused on getting students to solve well-defined canonical problems, not examining the role that failure plays in solving open-ended design problems.

In open-ended design activities, failure plays a constant and prominent role in the overall learning process. In projects that involve designing software (e.g., Kafai & Ching, 2004), building car ramps (e.g., Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar & Ryan, 2003), or engineering bridges (e.g., Roth, 1998), students working in teams or alone constantly run into challenges as they imagine, then implement and iteratively cycle through the process on their way to product completion. For instance, in designing software, the process of debugging, or fixing the problems in the program code, is a constant part of programming and not just located in the beginning (Soloway & Spohrer, 1988). In fixing bridge structures, students learn not only about the qualities of materials but also about structural properties of different engineering designs (Roth, 1998). Identifying and addressing the small and big challenges in conceptualizing and implementing a design, whether physical or virtual, is what makes these design activities rich learning experiences. Could we consider the challenges and resolutions encountered in such design activities a form of productive failure? The answer to this question could provide the field of learning sciences with new insights and contexts in how to structure opportunities for productive failure for different kinds of learning activities.

We report on a study conducted with 16 high school freshmen ages 13-15 years who chose to participate in an eight-week long workshop in which they learned to design and program their own electronic textile using the LilyPad Arduino microcontroller (Buechley, 2006), sensors and actuators. Electronic textiles (hereafter: e-textiles) include microcontrollers, sensors for sound, touch and light and actuators such as LEDs and buzzers, that can be sewn into textiles to make interactive wearables and teach programming and engineering concepts (Buechley, Peppler, Eisenberg & Kafai, 2013). For our analysis, we focus on debriefing interviews conducted with all the students where we asked them specifically about periods of troubleshooting and debugging during their e-textile design processes. Our analysis was directed by two research questions: (1) What range of challenges do youth report encountering when crafting e-textiles? and (2) How do youth respond to and resolve these challenges? In the discussion we address what our findings from examining challenges and resolutions contribute to the growing work on designing for productive failure in educational settings.

Background

The idea that we can learn better through prior failure initially seems counterintuitive but has emerged as one of the new directions for designing effective learning activities. Productive failure defined by Kapur (2008) is first "engaging students in solving complex, ill-structured problems without the provision of support structures" (p. 379). Then, students are provided with instruction and tasked with solving canonical problems. Students who first solved ill-structured mathematics problems were significantly more successful at later solving well-structured mathematics problems compared to students who only solved well-structured mathematics problems (Kapur & Bielaczyc, 2012). The critical feature of productive failure—the use of ill-defined problems in an initial phase to achieve better problem solving performance of well-defined problems in a later phase (Kapur, 2008)—also provides promising connections to open-ended design activities. Integrating a "failure" phase into instruction during which students generate multiple representations and solution methods is instrumental in equipping those learners with more agile problem solving abilities and greater representation flexibility to later outperform students who only experienced direct instruction (Kapur 2012; Kapur & Bielaczyc, 2012). These research findings also highlight a central dimension of design learning where students turn an ill-defined into a well-defined problem by creating a solution in the form of a virtual or tangible artifact (Bielaczyc & Kapur, 2010; Kapur & Bielaczyc, 2012).

One of the key distinctions of learning in open-ended design activities, however, is that failure is not an initial one-time generative phase followed by successful completion but rather a frequent occurrence possible at multiple time points throughout the design process (e.g., Kafai & Ching, 2001; Kolodner et al., 2003; Roth, 1996; Litts & Ramirez, 2014). Learners addressing design problems not only experience but also resolve multiple failures. Hybrid designs projects where students need to identify and solve problems in multiple, overlapping domains provide a rich context for experiencing and addressing failure. For instance, in the context of robotic design, students not only have to build motor-driven models with active sensors but also have to code the programs that operate motors and sensors independently in the field, without any human direction (Sullivan, 2009). In the context of designing e-textile wearables, students are learning about crafting, circuitry and coding. We found how these overlapping domains, where materials behave in unexpected ways, are rich spaces for student learning (Kafai, Searle, Fields, Lee, Kaplan, & Lui, 2014). Students had to learn and coordinate multiple representations, i.e. blueprints for circuit design and program code for the microcontroller. We observed how students' experiences with failure occurred not only within each respective domain (and thus would make them more comparable to the traditional productive failure studies), but also at the intersections between crafting and circuitry, coding and circuitry (Kafai, Fields, & Searle, 2014).

In this particular study, we were further interested in understanding how students themselves perceive moments of failure and resolutions as they are designing e-textiles. Such retrospective accounts are rare in the current research on productive failure, which has mainly focused on examining the impact of different conditions on students' learning outcomes. Understanding what students consider moments of failure in the design process, how and where they deal with failure provides critical insights for designing supports in learning tools and interactions. It is this particular dimension of design learning that potentially could inform not only the larger literature on productive failure but also the work on design projects that has emphasized success, i.e., getting students to complete a design project by providing scaffolds and tools. By looking at failure as a productive rather than counterproductive dimension of learning, we can shift pedagogical directions as well students' perceptions of such events that are inevitable in the design and learning process.

Context, participants, and data

Workshop participants and e-textile design activities

We conducted this study with 16 high school freshmen (7 boys, 9 girls, 13-15 years old) from a science magnet school in a metropolitan city in a US northeastern state. Students identified as follows: 56% Black, 19% Asian, 19% White, and 6% Multiracial. Participants selected our e-textiles workshop from a variety of workshop options as part of an immersion partnership between their school and a local science museum. The workshop spanned eight two-hour-long sessions at the museum and a ninth wrap-up session at the school. A researcher led the workshop and was supported by two graduate students who assisted with student projects and data collection. Students engaged in a series of three e-textile projects: 1) an introductory activity crafting a simple circuit with an LED, coin cell battery, and conductive thread; 2) a starter wristband project with two LED lights, coin cell battery, conductive thread, and snaps that closed the circuit; and 3) a more advanced 'human sensor project' where students programmed a LilyPad Arduino to activate a lighting pattern with 2-3 LED lights by touching two conductive patches that closed the circuit. While projects were scaffolded in that they built in complexity, students designed their own circuitry and remixed existing code. We focus on the students' design processes in the human sensor project. We framed this project as a "Logo Remix" in which students remixed an existing logo (e.g., their favorite sports team or brand) by making it interactive with up to 3 LED lights, touch sensors, and a LilyPad Arduino. Each student created his or her own Logo Remix, but many worked collaboratively. As part of the design process, we instructed students to create a circuit design blueprint, which we approved before they began sewing. All students uploaded their design blueprints and received feedback via an e-textile website (ecrafting.org) from graduate students who were more advanced in e-textiles.

Data collection and analysis

We collected a range of data on students' design processes focusing on challenges students encountered and resolution strategies they employed. In addition to photo documenting the progression of students' artifacts and code, we kept extensive field notes throughout the workshop and interviewed students after they completed their projects. Interviews were semi-structured and aimed at the challenges students encountered in their crafting, coding, and circuitry, and how they resolved each challenge they shared. Ten students were interviewed in pairs due to time constraints. Our main analysis focused on students' post-interviews, which we triangulated with field notes and photos of students' design processes. Two researchers coded all of the data and iteratively developed a coding scheme around challenges and resolutions. Researchers discussed and resolved disagreements or inconsistencies. Initially, researchers completed open line-by-line and in-vivo coding (Saldaña, 2009) to get an overall sense of the data. Inspired by the productive failure literature, researchers then coded through a four-phase process: (1) Identified points of iteration/challenge (95 total); (2) Generated and applied a coding scheme of the types of challenges (e.g., knots/tangles, polarity of LEDs, etc.) remaining open to adding new codes; (3) Determined whether and how the challenges were resolved: alone, with a peer, with a teacher, or not at all; (4) Clustered codes around larger themes. For instance, challenges like knots/tangles and stray ends are connected by the underlying challenge of crafting with conductive thread. One researcher applied the coding schemes for "challenges" and "resolutions" to the field notes to triangulate with the findings from the self-report interview. No new codes were generated, but the fieldnotes shed more light on resolution strategies to remedy challenges.

Findings

We present the findings of this data analysis in two parts: 1) outline the two most prevalent themes of challenges: crafting with conductive thread and designing spatial circuitry~~,~~ and 2) highlight the resolution strategies students' employed to overcome these two most challenging elements of the design process.

Encountering challenges within e-textile designs

Across the interviews, students listed two overarching challenges—crafting with conductive thread, and spatial circuitry—that accounted for 68 out of 95 (roughly 72%) of all statements. Every student reported encountering both of these challenges in making his or her e-textile project. Other observed challenges related to project time constraints and working in the programming environment, Arduino.

Crafting with conductive thread

Learning to craft with e-textiles is not just about crafting skills, which are challenging in their own right (Lee & Fields, 2013), but also about how these skills intersect with circuitry knowledge in a domain specific way (Peppler & Glosson, 2012). For novices who have not fully grasped the properties of conductive thread, however, it often appears that crafting and circuitry can be separated out as discrete entities, resulting in failure to complete a functional circuit. In our analysis, crafting with conductive thread accounted for 28% of the total challenges faced by students. Asked to recount some of her sewing challenges, Kerry remarked:

> Oh! Let's do all the problems I went through. Hey,...so when you wanna start [thread] the needle, it doesn't want to go in. And then when you finally get it in, you have to make a knot. And the knot doesn't wanna be formed. So then you finally make the knot and you're sewing, and sometimes...either the knot and the entire thread comes through and the needle just disappears and the the thread's left there alone, or, you know what happens? Knots come out of nowhere when you don't need them! It's like, hey, where were you when I was trying to knot you? (Int., 6/19/15, pp. 4-5).

In this reflection, Kerry highlights several of the ways in which she experienced failure in the process of crafting her e-textile project, including difficulty threading the needle, difficulty tying knots in appropriate places, and the propensity of the thread to tangle easily. Rhett, a novice sewer, experienced a different but related problem when he tried to connect components with one giant stitch rather than many small ones. He explained, "[o]ften times I forgot to do a running stitch and I would just put it straight there and that was frustrating because I had to cut it and try again" (Int., 5/11/2015, p.2). These large stitches were easily pulled loose and failed to hold the components in place. They could also move around and touch other lines of conductive thread, creating unanticipated circuitry problems. As Kerry and Rhett illustrate, these basic sewing challenges were especially frustrating and became even more frustrating for students when they realized that, because of the uninsulated, conductive nature of the thread, sewing mistakes and circuitry mistakes were often intertwined.

All students had short circuiting issues in which their positive and negative threads tangled together or were connected by stray ends of thread and many students discussed having to repeatedly cut out and resew lines of thread because of incorrect or crossing circuitry. Taraji was an experienced sewer who liked the thicker feeling of the conductive thread and often mended her own clothing outside of school but even she admitted that, "getting to understand, like, sewing without making the thread in the back like touch, or going over other [threads]" was difficult (Int., 5/08/15, p.3). Similarly, Sabrina observed that "another challenge was connecting it to the wrong LilyPad circuit. I messed that up, like, I know when I first did it I didn't connect it to the negative and that messed up my whole project" (Int., 5/08/15, p.2). In these ways, students experienced multiple failures related to crafting with conductive thread in the context of their e-textiles projects. Though we did not measure their learning gains, anecdotally we can say that students developed a more robust knowledge of the properties of conductive thread and of key circuitry concepts (e.g short circuits) through their failures.

Designing spatial circuitry

In addition to experiencing failure related to an incomplete understanding of the properties of conductive thread as connected to circuit design, students also experienced failure related to *spatial circuitry*, the design and physical construction of the circuit. Spatial circuitry accounted for 43% of all challenges (41 out of 95). Spatial circuitry is not just about making sure that lines of conductive thread do not cross or that the whole project fits on a sheet of felt, but also takes into account making sure that the correct circuit components are connected to the correct ports on the LilyPad, since not all ports, for example, can read input from a sensor. Although we required students to first draw a paper and pencil representation of their design (including tracing the LilyPad and its ports and labeling the components) and to consult with one of the instructors before moving onto constructing their design, translating the design blueprint into a physical artifact proved challenging in terms of both functional and aesthetic considerations.

As Kerry recounted in her reflective interview, the placement of various design components often evolved through a degree of failure in the construction process (see Figure 1):

> When I did [my project], I had to switch [the patches] like four different times and I also had to switch my LEDs because the way that my design worked is...there wasn't a lot of space over here or through here [*pointing to top of her project*] so it was like, you had to try to cut through things and...hide some things but not a lot. And I was like trying to make everything be there but not touch and it was really confusing...LEDs had to switch and ideas had to switch" (Int., 5/08/15, p.11).

In this reflection, Kerry highlights several common aspects of spatial circuitry that challenged students, including the size, shape, and placement of their conductive patches and also an aesthetic desire to hide some of the circuitry while still having a functional project. Similarly, Taraji explained, "I didn't really estimate all the amount of space I would have on the felt [as opposed to the piece of paper]. So when I actually started sewing on the felt I had to like think, like before I got to put my conductive patches on I had to think like how big they could be, or where exactly they could fit" (Int., 5/08/15, p.4). Across projects, students experienced failure related to realizing their design goals within the constraints of their circuitry and coding knowledge.

Overcoming challenges within e-textile designs

Working with conductive thread and designing spatial circuitry were the two most common challenges students discussed-in their reflections of design processes. In post-interviews, 6 out of 16 students reported that they did not successfully complete their project (e.g., they had not finished sewing or did not upload their code to their Lilypad). Interestingly, though, all of the students employed various resolution strategies to overcome these two challenges. In this section, we outline the range of those resolution strategies according to who students reported they relied on to resolve the challenges: alone (55%, 52/95), teacher support (26%, 25/95), peer support (4%, 4/95), and unresolved (15%, 14/95).

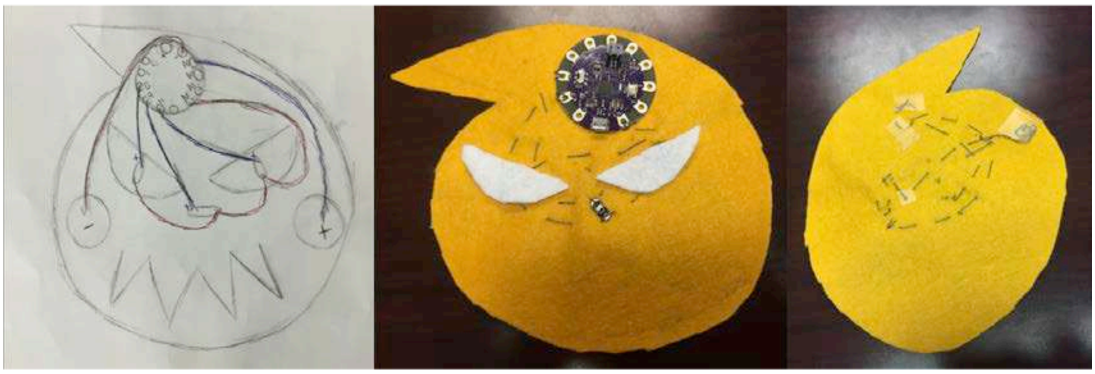

Figure 1. Kerry's circuitry blueprint and partially completed project, front (l) and back (r).

Crafting with conductive thread

A large part of resolving challenges of crafting with conductive thread is having the foresight to see how crafting causes short-circuiting. Students must understand that because the thread is conductive (and not insulated) it cannot cross and their stitches must be tight to ensure strong connections. Students largely worked by themselves (55.6%) to troubleshoot challenges of crafting with conductive thread, but some required teacher (29.6%) support, and a few solicited peer support (7.4%) or were not able to resolve their challenges (7.4%).

Working on his own, Mack realized the importance of solid connections, but struggled to sew accordingly, so he generated a creative resolution. He expounded, "The hardest part was connecting the LEDs to the thread, because if I would stick it in, I only did it single [thread] so it would pop [break] and then I had to restart" (Int., 5/08/15, p.2) In response, he sewed plastic beads behind the LEDs to guide his sewing on the back of his project and secure his components (see Figure 1). Other students resolved this particular challenge by taking more traditional approaches like trimming their stray ends to prevent short-circuiting with thread crossing in the back.

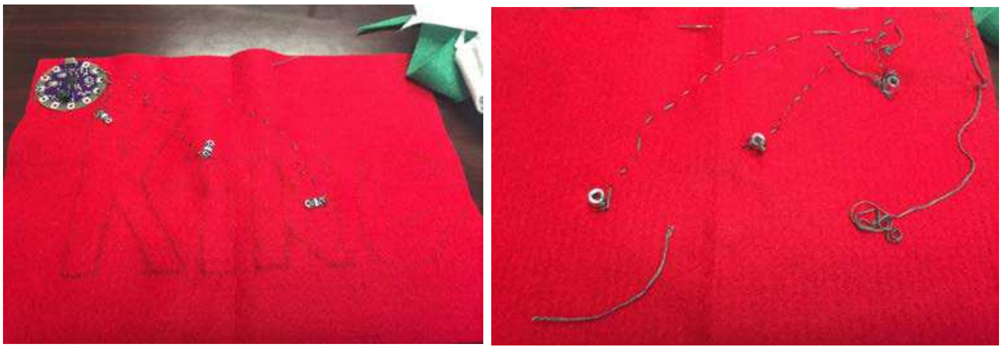

Figure 2. Mack's project partially complete, front with LEDs (left) and back with beads (right).

Likewise, Kerry described how she resolved the issue of short-circuiting caused by stray ends, "I did that on my own after I was given tape. Because I saw and I was like, oh, you know, this part is so long and then [the teachers] just placed tape down on the table and so I was like, ok and decided to tape things" (Int., 5/08/15, p.7). While Kerry believed that she resolved this challenge on her own, she also illustrates how minimal, implicit teacher support (placing the tape down on the table) structured her ability to do so. In contrast, Jonathan, needed direct teacher support to tackle a short circuiting issue he was having with stray ends. He recounted, "I had to trim down a bunch of stuff in the back so that they didn't cross over...I had to be told that's what I had to do" (Int., 5/08/15, p. 3).

In other cases, students solicited help from their peers. For instance, Kendra described how her friends helped her make a proper running stitch, "Well previously my threads were really far apart, and then my friends,...noticed that it could like really be easy to get loose...So they told me to make my threads tighter, so it'll be like difficult to [get] loose and they wouldn't be tangling. That was a helpful suggestion, so I just sewed tinier" (Int., 5/11/15, p. 6) Unlike traditional sewing where typically only one side of the project is important, both sides of e-textiles project are equally important for aesthetics and circuitry.

While we instructed students to secure their components by sewing the connection at least three times, several students still faced challenges with this technique. Kendra explained, "This [LED] is pretty loose. I didn't sew it tight enough, and it's pretty dull, too. So I don't know, those could be contributing factors [of] why…it doesn't really light up that much" (Int., 5/11/15, p. 2) Kendra struggled to understand *why* securing her components was important until she made the mistake herself, and though she left this problem unresolved, she articulated the most likely cause of her dim LED light in her reflective interview.

Designing spatial circuitry

In spite of the challenges students faced in translating their paper and pencil design blueprints into a physical reality, many referenced their original design blueprints or created multiple versions of their design blueprints in order to resolve challenges related to spatial circuitry. More than half of the students (58.5%) relied mostly on themselves to solve challenges related to spatial circuitry, but nearly one third (31.7%) requested teacher assistance to troubleshoot their circuitry. Only one student reported soliciting peer support (2.5%) and a few were unable to resolve their spatial circuitry issues (7.3%).

Students who worked alone to resolve their spatial circuitry problems often reported generating multiple design blueprints along the way. Taraji, for example, reported a careful planning process, "Before I would actually sew, I'd draw the pattern out and make sure none of them like crossed each other, and once I had that I'd just copy it off the paper and to the actual [felt]" (Int., 5/08/15, p. 3). Each time Taraji made changes to her design plan she modified her blueprint to match. Taraji's proficiency in using her design blueprint streamlined her overall design process, as she described, "I just followed each step that was listed on here and it was pretty simple" (Int., 5/08/15, p. 4). In contrast, Kerry attempted to work through spatial circuitry challenges in her design (see Figure 1) by making in-the-moment changes. In her reflective interview, she recalled:

> The touch sensors, they were supposed to be…I have this right here, I have the basic idea (*showing design blueprint*). My design never changed, it's just the way I did it, I switched it. Like I had these were gonna be the conductive touch sensors (*showing cheek on design blueprint*), because these were gonna be touch sensors and they were supposed to go right here on the edge (*pointing under the eyes*), but you see how close they are to the eyes and everything it made everything a lot harder to navigate so things got weird" (Int., 5/08/15, p. 11).

Since Kerry did not reflect the changes to her spatial circuitry on her design blueprint, she failed to realize that her design iterations would result in crossing negative and positive threads, which caused a lot of frustration, because she "had to do redo everything" (Int., 5/08/15, p. 12). Both Taraji and Kerry resolved their spatial circuitry challenges on their own, however they used different strategies and this resulted in different outcomes.

Students also requested teacher assistance to troubleshoot their spatial circuitry challenges. Eagan, for example, described her biggest mistake, "Well the circuiting obviously. Cuz I just kept messing on up, but yeah I had great teachers help me out" (Int., 5/08/15, p. 8). She further explained that with teacher support she tried rotating her Lilypad and that helped resolve a lot of of her issues connecting her LEDs and touch sensors to the Lilypad without crossing positive and negative lines. Another student, Jess, reported assisting her friend with connecting her LEDs to the Lilypad, "I was helping Lauren with stuff, because she didn't know where to connect it" (Int., 5/11/15, p. 5). Even though Jess struggled herself with the concept, she understood the challenge of thinking through, "how [the] design will fit into the circuitry… [and]... not to get the thread all tangled up in each other" (Int., 5/11/15, p. 6). A few students, like Mel, didn't reach out at all: "Since we don't know anything about this part, this Lilypad, I don't know where to put which…I don't know, where to put things and stuff. So, or how it works, cuz I don't know how this thing works… it's just really confusing" (Int., 5/11/15, p. 5). Even at the end of the project Mel still struggled to understand the importance of her design blueprint and the function of the Lilypad, but did not report asking for help to resolve her confusion with these concepts. While we might read students' spatial circuitry challenges and resolutions as just a lot of frustration, we argue that students learned valuable lessons about design processes and how to use resources to solve ill-defined problems.

Discussion

We examined students' perspectives on challenges and resolutions with the goal of better understanding how the idea of productive failure can apply within an open-ended design task. All students reported moments of failure with sometimes successful, and at other times unsuccessful responses. The majority of students reported working on their own to troubleshoot and debug their projects without direct instruction. While it is likely that students received more external help than they reported, what is important is that they persisted to overcome challenges even if they did not produce fully functioning and finished products. In the following sections, we discuss whether or not our findings of productive failure resonate with those observed in previous research and outline potential instructional applications.

Understanding the productivity of failure in open-ended design tasks

The productive failure literature introduces the "solution generation effect" meaning the more solutions students generate, the more they learn (Kapur, 2015) and illustrates that this occurs in two phases: exploration and consolidation. However, the bulk of this research has been conducted using math tasks where there exists a clear canonical solution to which students can compare and contrast their self-generated solutions. In this study, we identified two ill-structured exploration phases that exist in e-textile design: (1) crafting with conductive thread and (2) designing spatial circuitry. In these exploration phases, students generated multiple solutions, many of which were non-traditional. For instance, Mack's creative solution of using beads to guide his LEDs and secure his components illustrates the productive nature of repetitively making the same mistake. But in open-ended designs, there is not a parallel canonical solution to which students can compare their self-generated solutions. Instead, there are a range of design styles and techniques students can leverage to suit their project. Hence, it is difficult to model well-structured tasks like the ones used in productive failure studies. Though open-ended designs have multiple successful trajectories and a vague definition of failure, e-textiles designs require integration of knowledge from multiple domains (crafting, circuitry, and coding). In the next phase of examining productive failure in open-ended designs, we must more intentionally explore what a well-structured consolidation phase looks like.

In this study we collected students' perspectives rather than examining their learning outcomes. Students' reflections shed light on the role of feedback that physical artifacts can provide when persisting through iterative failure. A productive failure learning design builds from unguided (exploratory) to guided (consolidation) problem-solving conditions and wraps up with direct instruction (Kapur, 2015). In these studies the role of the teacher is to provide the scaffolding that guides learning. Our study suggests that the physical artifacts students make can guide their problem solving without teacher intervention by providing enough within-task feedback to support them to persist beyond their failures. With tangible, three-dimensional artifacts as a learning support, students were able to rapidly cycle through many failures before finding a solution that worked for their project and process. Unlike a math problem, e-textile designs can provide live feedback to a student through their function. For instance, when debugging a short circuit a student can check knots, stray ends, etc. and debug the project until the LED turns on. The feedback from physical artifacts perhaps introduces an additional form of guidance to consider in future productive failure learning designs.

Engineering productive failure in open-ended tasks

The findings from our research illustrate that students encounter many moments of failure among the process of completion, two of which we presented and discussed in more detail. Our argument is that failure is embedded in the design process rather than a separate pre-planned activity that sets the stage for later successful problem-solving. Observing and hearing about the multiple difficulties that students experience along the way suggest that we should consider the design of supports. In previous design studies such supports that have taken the form of reflections or design diaries (e.g., Kafai, 1995; Roth, 1998) to help novice designers with completion of their artifacts, alone or together. Perhaps the presentation of supports could also come in form of challenges or problems that mirror features of productive failure. For instance, we might present students with artifacts that have intentional problems built-in that they will be asked to fix. In the context of e-textiles this could actually mean that teachers or researchers design and make an e-textile that has faulty crafting, circuits, or code by design (See Figure 2). Based on what we know from observing students' challenges, we could incorporate intentional problems in an e-textile that we ask students to fix or debug (Fields, Searle, Kafai, & Min 2012).

Furthermore, we could think carefully about the time point in the design process when we would ask students to fix the problem. The later beginning phase when students have already some experience with crafting and circuit design seems like a reasonable time point. Indeed, this idea of providing students with faulty or buggy programs is not a new one and has been used in teaching novice programmers. For instance, the "Debug-me Studio" in Scratch presents students with a set of programs that have strategically planted bugs to help them better understand programming in playful way (Griffin, Kaplan & Burke, 2012). We see no reason why we cannot adopt the same approach for tangible artifacts such as e-textiles that often feature a larger and interconnected array of challenges cutting across the disciplinary boundaries of crafting, circuitry, and code.

We conclude our paper with a quote from a student, Eagan, who perhaps best highlights the benefits of working through multiple challenges, “Even though I never got one to light up (laughing)... I learned from my mistakes. I did just, ‘oh I made a mistake, ugh, give up,’ but I learned from my mistakes” (Int., 5/08/15, p. 8). Whether or not failure occurs and promotes learning in well-defined or open-ended problem settings, it is clear that mistakes which are often perceived as roadblocks can become stepping stones to success.

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