Tinkering with “Failure”: Equity, Learning, and the Iterative Design Process

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ABSTRACT

This paper attempts to reframe popular notions of “failure” as recently celebrated in the Maker Movement, Silicon Valley, and beyond. Building on Vossoughi et al.’s 2013 FabLearn publication describing how a focus on iterations/drafts can serve as an equity-oriented pedagogical move in afterschool tinkering contexts, we explore what it means for afterschool youth and educators to persist through unexpected challenges when using an iterative design process in their tinkering projects. More specifically, this paper describes: 1) how young women in a program geared toward increasing equitable access to quality science, technology, and engineering education for girls underrepresented in the field (Techbridge) make sense of their tinkering experiences while persisting through challenges in the iterative design process, 2) which pedagogical moves both Techbridge girls and educators value when persisting through frustrations, 3) what iterative design learning looks like in the afterschool program, and 4) how supporting iterative design processes over end-products can redefine notions of STEM ability and intelligence by inviting diverse learners into activities they find meaningful.

Keywords

Tinkering, Making, Iteration, Equity, Failure, Persistence, Learning, Pedagogy, Afterschool Education

1. INTRODUCTION – CELEBRATING “FAILURE” IN THE MAKER MOVEMENT

“Failure” has been highly celebrated within the Maker Movement. Drawing on Dweck’s [6] work regarding growth mindsets, Dougherty [4] emphasizes how the Maker Movement can help “creat[e] innovative thinkers and doers” by fostering a “maker mindset” that “tolerates risk and failure” (p. 9). Similarly, Martin [15] explains that this “maker mindset” includes being “failure-positive.” He describes *Make* magazine’s introduction of the “Most Spectacular Failure Award” upholding failure as the “new winning” [17]. In his study of young makers, Wagner [28] describes a key quality of innovators as the ability to “tolerate failure” (p. 12). This Maker Movement message has run parallel to Silicon Valley’s latest mantra: “fail fast, fail early, fail often” [1], “fail better” [18], and “fail forward” [12].

However, what does the word “failure” actually mean for youth? Are we trying to encourage children to “fail”? Is it something different from “failure” that we want to notice and celebrate?

If we are to believe that making can “reinvent education” [24] by creating more engaging, accessible, and equitable learning opportunities for *all* youth, then one must ask: why would children attending under-resourced schools in low-income communities *want* to fail when the opportunities to try again are few and far between in environments characterized by high-stakes testing and tracking?

Eason [7] highlights this tension in her complexification of the Maker Movement’s promotion of failure with youth, especially children from low-income or historically marginalized communities:

> [I]n America, when you’re poor, and when you lack privilege, the consequences of failure are different….When you give yourself permission to fail, the implicit assumption is that you have the resources—materials, time, reputation/social capital—to try again…When you’re poor, you don’t have resources…Risk aversion is often ultimately the more practical option. (par. 4-5)

Martin [15] also recognizes that “Failure is not a happy word in most educational circles, particularly when attached to schools, students, or initiatives” (p. 35). And while the Center Stage videos from Maker Faire Bay Area 2015 featured a video about “Epic Fails” with Jimmy Diresta, Bob Clagett, David Picciuto, and Mike Senese describing what they learned “when things go very wrong” (**http://makerfaire.com/bay-area-2015/video/**), few examples of failed projects were displayed at the Maker Faire in San Mateo this year; the majority of presentations featured peoples’ best and most successful creations.

We believe that most makers do not necessarily want children to fail on their tests, at school, in their careers, etc. and this was probably not the original intention of makers who “celebrate failure.” Clarification about what is meant by “celebrating failure” in the Maker movement is therefore needed, particularly as educational spaces take on the notion that children—and, more specifically, low-income youth in under-resourced schools—must be taught to have “grit.” This idea arose out of Angela Duckworth’s [5] study of how perseverance (which she and her colleagues call “grit”) related to achievement among successful populations (e.g., West Point cadets, Ivy League undergraduates, etc.) with the conclusion that grit reflected both resilience in the face of failure as well as sustained interest in a practice over time.

Of course, persistence and passion are characteristics we wish to see in all of our students. However, as Mike Rose [23] warns, “grit” can be dangerous when taken up as the newest “fad” or “magic bullet” to improve schooling through character education that could “sacrifice policies aimed at reducing poverty for interventions to change the way poor people see the world” (par.

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2). Rose [23] explains that this can be problematic when "a focus on individual characteristics of low-income children…take our attention away from the structural inequalities they face" (par. 14). He continues: "[i]t is hard to finish what you begin when food and housing are unstable, or when you have three or four teachers in a given year…[i]t is equally hard to pursue a career with consistency when the jobs available to you are low-wage, short-term and vulnerable, and have few if any benefits or protections" (par. 21). Furthermore, "grit" alone does not make a successful person who positively engages with school, community, and family. A combination of personality traits are necessary to develop that "well-functioning and ethical person": "[t]he items in the grit instruments could describe the brilliant surgeon who is a distant and absent parent, or, for that fact, the smart, ambitious, amoral people who triggered the Great Recession" [23] (par. 13).

This brings us to an important point that Kohn [14] makes: "What matters isn't just how long one persists, but why one does so" (par. 7). Narrowly focusing on persistence alone by celebrating buzzwords such as "grit" can take attention away from the reasons driving youth onward, as well as the quality of their efforts.

Furthermore, the idea that "failure" should be celebrated may not make sense or appeal to our youth. Nor does it reflect the more nuanced ways that making education can support creativity, passion, persistence through unexpected challenges, and a focus on process over product.

So how should we understand "failure" in the making/tinkering community? This paper explores ways to reframe our conversations about failure through a focus on "iterations and drafts" in the context of an afterschool tinkering program geared toward broadening participation in science, technology, and engineering for young women.

2. REVIEW OF LITERATURE ABOUT "ITERATION" IN MAKING/TINKERING

This paper highlights the efforts of a research-practice partnership called the California Tinkering Afterschool Network (CTAN) involving the Exploratorium (San Francisco), Techbridge (Oakland), Discovery Cube (Orange County), and Community Science Workshop (Fresno and Watsonville). In our collaboration, we appreciate the notion that valuable learning can occur when students push themselves through challenging moments, moving past project failures toward their personal goals. Yet putting these ideas into practice requires sensitivity toward our students' experiences and perspectives within our various afterschool tinkering programs. We understand that most youth are uncomfortable with the notion of "failure." Verbally acknowledging that we learn from failed projects does little to engage students in moving past unexpected setbacks. This is especially true when we have all been taught that the point of learning is ultimately to "succeed."

In order to support youth in our afterschool programs to work through and learn from the inevitable missteps and frustrations that arise in their tinkering/making projects, our Network focuses on the *iterative design process* as a means of celebrating process over products rather than focusing on failure. We draw on the idea that "[t]he process of becoming stuck and then 'unstuck' is the heart of tinkering" [21] (p. 55). The value of this aspect of tinkering has been illustrated in the Exploratorium's "Tinkering Learning Dimensions Framework" [2, 13] which outlines what learning looks like in tinkering activities. One of the Dimensions of Learning is defined as "Initiative and Intentionality" which includes "persist to optimize strategies or solutions" [2] (p. 104) and "persistence in the face of setbacks…[when] learners continue to work with a creation that fails to function or causes them frustration and disappointment" [13] (p. 158). This also involves "intellectual courage…[when learners] continue to work and play despite a lack of confidence or others' skepticism in their approach" [13] (p. 158). Tinkering activities focused on the iterative design process make room for such initiative and intentionality.

In CTAN, we have been trying to understand how a focus on the iterative design process can engage youth in meaningful STEM learning, regardless of gender, age, socioeconomic status, home language, race/ethnicity, interest in science, etc. And as Martinez and Stager [16] would argue, learning through iteration in tinkering/making is *not* the same as failure: "any iterative design cycle is about continuous improvement, keeping what works, and dealing with what doesn't. This is learning, not failure" (p. 70).

In a reflection on tinkering, learning, and equity in afterschool programs published by FabLearn in 2013, Vossoughi, Escudé, Kong, and Hooper [27] highlight the value of focusing on iteration through "drafts" as an equity-oriented pedagogical move in tinkering. By reframing "mistakes" and "failed attempts" as "drafts," children are given space to express all ideas such that different "lines of becoming" can be appreciated (p. 3). Importantly, rather than emphasizing learning as an individual pursuit, their work describes the need to create the social "contexts" or learning environments necessary for youth to pursue their creativity within learning communities.

Of course, the idea that iterations and drafts are valuable for learning is not new. Blikstein [3] has described the importance of creating safe spaces for youth to iterate on designs in a "digital fabrication lab"—a practice that "the one-size-fits all 50-minute [traditional school] format" doesn't necessarily allow (p. 7). Blikstein [3] describes how a roller coaster project created by John, Tyler, and Bob doesn't work. However, with the collective support of others in the lab, peoples' suggestions about how to move the track rather than the car, and time/space to create multiple iterations, the boys were able to create a working prototype (p. 12). Blikstein [3] emphasizes that engagement in learning despite design challenges and setbacks was possible through explicit organization of activities and environments that support youth to iteratively work through their projects.

Turkle and Papert [25] have also illustrated how working through iterations and drafts in computer programming can deepen student learning, especially for learners who do not necessarily identify as programmers or follow traditional pathways to computing. They share Lévi-Strauss's description of non-Western scientists as "bricoleurs" who construct theories by "arranging and rearranging" during which mistakes become opportunities for "mid-course corrections" (p. 135). In this way, bricoleurs value hindsight, drawing important conclusions through iteration upon what others might consider "mistakes." Turkle and Papert use this framing to describe how talented and creative computer programming students are often bricoleurs whose approaches unfortunately go unappreciated or unrecognized. This is described through examples of a first-year female college student and a young girl who coded like writing "poetry" or "sculpting" in ways that challenged traditional methods of hiding code in a "black box." These young women were not valued by their computer science learning communities which leads one to wonder: how would embracing learners' open iterative design approaches impact entry into computer science for individuals historically underrepresented in the field? Were these young women eventually thwarted from pursuing computing courses or careers because others did not value their approaches and transparent iteration drafting processes? These examples illustrate how supporting iterative approaches to learning can (1) allow us to "see" students' thought-processes and problem-solving approaches, and (2) invite diverse learners into intellectual activities that they find meaningful.

3. CONTEXT OF STUDY

There has been growing excitement about the possibilities of making/tinkering for teaching Science, Technology, Engineering, and Mathematics (STEM)—particularly for youth underrepresented in STEM fields. This is because making/tinkering provide low barrier of entry for people to engage in STEM phenomena and practices while creating objects with aesthetic and self-expressive dimensions [20, 21, 27]. Our collaboration called the California Tinkering Afterschool Network (CTAN) brings together four organizations at five afterschool sites in the state to better understand how STEM-rich tinkering can support meaningful STEM learning and equity-oriented pedagogy toward engaging culturally and linguistically diverse youth in the low-income communities we serve.

In our work, we focus on "tinkering" which is a genre of "making" that involves a "playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities" [22] (p. 164). Our network focuses on the ways that tinkering activities with associated pedagogical strategies can make STEM more accessible to youth from low-income, historically marginalized communities by allowing students to use an array of ideas and materials rooted in their experiences and interests, therefore valuing learners' diverse ways of knowing [26].

More specifically, in CTAN we are trying to answer two questions:

1) What does effective facilitation of equity-oriented, STEM-rich tinkering involve?
2) How can we support educators to develop facilitation skills that sustain tinkering in afterschool programs?

In this paper, we explore the first research question by building on Vossoughi et al.'s [27] description of how a focus on iterations/drafts can support equity-oriented teaching in afterschool tinkering. Their work illustrates that when iteration or drafts are valued as the expression and pursuit of ideas, then: (1) tinkering activities allow for learners to pursue multiple pathways (characteristics of tinkering activities as defined by Petrich et al. [21]), (2) diverse ways of thinking and approaches are celebrated and (3) practices/concepts are made transparent so that thinking can be made visible and skills shared [9].

Our work adds to the conversation by sharing what the iterative design process looks like and means to youth and educators creating Maker Faire projects in a Techbridge afterschool program. Our research questions include:

1) How do Techbridge girls make sense of their tinkering experiences while persisting through challenges in the iterative design process?
    a. What does learning through iteration look like?
2) What pedagogical moves do Techbridge students and educators value for supporting iteration as a means for overcoming unexpected challenges?

Techbridge offers afterschool programming to young women, with a focus on youth from communities underrepresented in science, technology, and engineering fields. This program seeks to inspire girls to discover a passion for STEM through hands-on learning and real-world exposure to STEM projects and fields. Techbridge also offers support for girls' families, role models visiting the afterschool programs, school districts, and program partners to provide guidance to young women so they can pursue their personal interests or career pathways. Participation is voluntary and free. Techbridge "program coordinators" team up with teachers from local elementary, middle, and high schools to recruit students into the program and co-lead afterschool engineering and making/tinkering activities at the school sites. Girls are recruited by teachers and program coordinators who present at events and set up information tables on campuses during school hours. Girls and their parents are asked to commit to staying with the once-a-week program for the full school year. Most sites follow a general inquiry-based, hands-on curriculum of activities throughout the school year according to age group. However, the particular Techbridge site participating in this study involved public high school girls beginning the school year with open-ended problem solving activities, followed by designing/creating their own projects using Arduino microcontrollers that were shared at Maker Faire in San Mateo in May 2015.

4. METHODS

This research drew on qualitative methods—interpretive participant observation privileging the "*immediate and local meanings of actions*" [8] (p. 119)—to provide "thick descriptions" [10] of learning and pedagogy in tinkering activities. Design-Based Implementation Research (DBIR [19]) also informed the formulation of research questions, approach to data collection (e.g., co-design of interview protocol, shared decision-making on data sources for analysis), as well as data analysis with Techbridge program directors and facilitators collaborating closely with Exploratorium researchers in a mutual research-practice partnership.

Data sources were collected at a high school Techbridge program serving 25 girls of whom 40% were White, 20% Asian/Pacific Islander, 20% Latina, 8% African American, and 12% multi-ethnic (African American and White, Latina and White, and Asian and White). Researchers visited the Techbridge afterschool program every week during the last half of the 2013-14 school year and the entire 2014-15 school year. Data sources included fieldnotes, audio recordings of interviews with students and facilitators, video recordings, photographs, researcher memos, and student work. Data sources were analyzed using a grounded theory approach [11] that involved reading through the data corpus to identify common codes that emerged across the data sources. This data corpus was then reviewed again to mark themes in which groups of codes aligned. These themes were then grouped into shared categories and then data sources were reviewed again to find lines of contrast that might highlight important outlying events, ideas, and practices informing shared categories.

5. FINDINGS

5.1 Youth Perspectives on Tinkering

Observations of the Techbridge afterschool program revealed that students were regularly encouraged to use iterations/drafts as a means of developing their projects. Techbridge educators called this the "Engineering Design Process," which included a continuous cycle of brainstorming, designing, testing, and redesigning. Every project—whether a single day's activity with a problem to solve or the program's culminating Maker Faire project—required that the girls sketch out or write about their plan, share that plan with facilitators before moving forward, reflect on what was working or not working with first prototypes, then redesign and rebuild to fix problems and improve on first prototypes. An example is shown below in which a student named Ali[1] sketched out her idea for how to repurpose an object purchased for under $5 at a local second-hand store (this was part of a "hacking" assignment; see Figure 1 below):

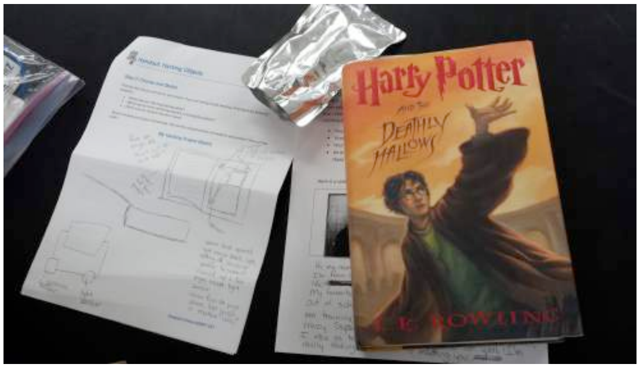

Figure 1: Ali's design sketch of the first iteration of her hacking project.

Ali planned to insert a photo-sensor and a speaker inside the book. Her goal was to have the photo-sensor trigger a speaker to make a screaming sound whenever the book was opened to the first appearance of its evil character (Voldemort). She wrote, "when book opened light sensor detects light, setting off, causing speaker to scream." As the weeks progressed, Ali's project underwent various phases of redesign as she worked through challenges, learning how to code the photo-sensor and use a power drill.

5.1.1 Girls Define Tinkering as an Iterative Process

The year was full of tinkering activities similar to the hacking project described above, and culminated in the ultimate tinkering project of girls' own designs that was shared at San Mateo's Maker Faire. Yet how did girls make sense of their experiences tinkering at Techbridge?

We had the opportunity to talk with approximately half of the Techbridge girls specifically about their tinkering processes when creating projects[2]. The *Harry Potter* book hacker explained: "**trial and error. Mostly error**" [Ali; 5/16/15]. Ali's partner for the Maker Faire project expanded on this point by noting that "trial and error" wasn't as simple as doing something until it worked, but that "trials" involved careful "experiment[ation] and **seeing what happens when I test this or this**" [Erin; 5/16/15]. Similarly, Paloma stated that tinkering meant "figuring out how something works…**test[ing] it in different areas. Chang[ing] something and then test[ing] it and then chang[ing] something again. It's like a constant process**" [Paloma; 5/16/15]. This process included the purposeful testing out of ideas and designs to reveal new knowledge. Tinkering required girls "to **respond to different problems** we're having and try new approaches if something's not working out perfectly. So our project could be different from something we started with and that's fine, we **just work through it and come to our end result**" [Helena; 5/16/15]. However, echoing Ali's earlier comment about facing "mostly error" in tinkering, Luisa noted how the tinkering process included "**frustration**" since projects were "**never completely done**" but were **"worth continuously working on"** [5/18/15]. As Jenna explained, projects could be challenging but "you can figure it out and you can **learn from your mistakes…even if you've never seen it before** or never seen anything like it before" [5/16/15]. The majority of girls seemed to embrace the idea that tinkering involved a continuous process of experiencing challenges and working through them toward learning something new.

5.1.2 Autonomy and Creative Authorship

When asked what inspired them to work past these challenges and continue developing their projects through each iteration, many of the girls emphasized the importance of **having autonomy and creative authorship of their projects**. For example, Erin explained that she was able to enjoy the process of trial and error and continuous "experimenting" because "it was something **I wanted to do because they let me choose** what I wanted to do and work on—if you want people to learn stuff you should let them choose what to do" [5/16/15]. Ali similarly noted that it was more exciting to push through those "trial and error" moments with iterative design when she had come up with the project idea herself because "there weren't really instructions so that **you just *had* to figure it out by yourself**" [5/16/15]. Paloma also explained that she would find herself "committing to that project and really wanting to do [it]…**because you chose this thing to do and solve**" which felt different from what usually happened in school where "we don't have that much of a process and we certainly don't have that much freedom to choose what we want to do" [5/16/15]. Relatedly, Rebecca explained "if I like what I'm trying to do and, okay, I'm going to figure out and troubleshoot and try to fix it. But if it's something where I just…don't really care about it that much then whatever, I'm frustrated**…[I] liked [my] project so I wanted to finish**" [5/16/15]. Techbridge girls emphasized that they were committed to working through challenging moments through the iterative design process of tinkering because they felt ownership of their projects and processes.

5.1.3 Ownership Over Challenges

In their interview, Angie and Lulu offered an example from their experiences between creating projects to present at Maker Faire in 2014 vs. 2015. In 2014, the girls followed a step-by-step dancing robot project to recreate for the Faire. In 2015, the girls worked with two other Techbridge girls to create an interactive soundbox that created sound and flashed lights when copper plates on the outside were touched. Angie noted that during the robot project "**we didn't have to think because it was just copy the book. But this year [2015] we have to think and have disagreements**" [3/16/15]. Lulu added that this meant "**the problems are more exciting** [with the interactive soundbox] than the problem we had last year" [3/16/15]. When asked to elaborate about these "disagreements" and "problems" being exciting, the girls

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[1] All names of youth and educators have been changed.

[2] Quotes shared in this article come from conversations with girls who chose to focus on their tinkering processes in interviews. Since some girls talked more about other topics (e.g., what tinkering looks like in their families, afterschool vs. in-school, etc.) not all participants are represented in this article focusing on learning and iteration.

explained that with the robot project, they knew the problems they were having were related to access to wifi and the trial program they were using for free. They couldn't find consistent wifi and they couldn't afford to pay for more than the trial program. Thus, they felt uninspired to be able to do anything to improve their project. However, with the soundbox project, it was more "exciting" when the problems had unknown solutions but also when "we know it's our fault. I feel like it's better than having it not be your fault…**the fact that we didn't quite know what the problem was…you had to think about it and you're actually doing something, so I think that's better**" [Lulu; 3/16/15]. In other words, Lulu was explaining that the problems arising with the soundbox were original issues stemming from their actions and so the girls knew they could figure out solutions if they kept trying to solve these problems. However, with their previous robot project, they knew that problems were rooted in the wifi and program, neither of which the girls could change or control. Angie embellished on this idea of the importance of ownership over tinkering projects to foster the desire to solve challenges and debate solutions with one another: "[with the robotics project] I feel like there was less to argue over because we had instructions and all we had to do was follow the instructions and probably whine about why it don't work, but this year **we came up with the ideas**…**you can change it because it's our idea, we don't have to follow instructions**" [3/16/15]. The girls felt more committed to working through challenging moments in the iterative process of design and redesign while creating their Maker Faire projects when they had a sense of ownership of the ideas and, therefore, ownership of the challenges and frustrations.

5.1.4 Process vs. Product

Yet why would the girls at Techbridge persist through the frustrations arising during their tinkering projects? Multiple girls mentioned the idea that "having to go through so many failures to have a success is challenging, but it's also really rewarding when you succeed because you know you were trying hard" [Elena; 5/16/15]. What was particularly fascinating about this idea was that the rewards of persisting through challenges were more valuable the harder the effort; this went hand-in-hand with the notion that the process of trying to figure out solutions was more rewarding than the final success: "We want to do everything we can do, and if we stop in the middle when we could have kept going, that's really disappointing and defeats me even more than just failing. Like, **doing everything you can is almost more rewarding than succeeding**" [Elena; 5/16/15]. This suggests that girls respected the intellectual complexity of their tinkering processes.

Interestingly, Elena and her partners (2 of 3 who were new to Techbridge) never completed their Maker Faire project. However they proudly displayed the four non-functioning prototypes they created at Maker Faire in San Mateo. When asked about their presentation, Elena's partner explained it "was still rewarding" because even though "it doesn't work, I'm cool with that" because "we worked really hard on it" [Mila; 5/16/15]. Mila was particularly proud of how her group's soldering progressed with each prototype and how they were still able to come up with code for their arduino even if they couldn't test its effectiveness. This focus on process over product seemed to help the girls reframe any feelings of disappointment or frustration that one might naturally feel when multiple prototypes failed to work.

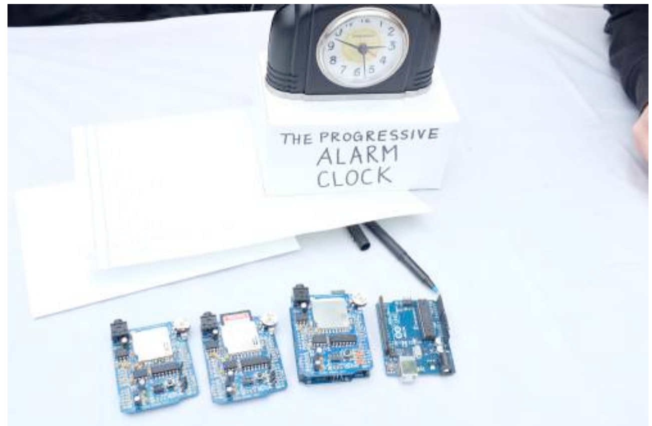

Figure 2: Elena and partners' non-functioning wave shield prototypes on display at Maker Faire 2015.

Importantly, the girls seemed to recognize that their teachers' emphasis on the idea that the iterative design process never quite ends and projects do not need to be "perfect" was central to their abilities to value process over end-product while committing to problem-solving in iterative design. As Elena explained**:** "if somebody is telling you that it has to be perfect and then you fail, that's super disappointing, but if you see what could be improved and you're seeing…I think that actually lets us look at our projects and not say that they're perfect but see the things that we could improve even if we think that we have succeeded, we can still say, 'it's not perfect, I could do this and this to make it better, and next time…' I think it's a good outlook" [5/16/15]. The ways girls internalized this notion became visible in how Paloma described projects as never having an "end" because you could always continue "perfecting it" [5/16/15]. As Paloma explained, "I was familiar with prototyping but I think Techbridge really cemented that idea, that you make different prototypes and test things out" [5/16/15]. Techbridge educators supported girls in embracing the idea that projects didn't need to be "perfect" or match their original designs exactly—"prototypes" were embraced as part of the iterative design process in Techbridge tinkering activities.

5.2 Pedagogy that Supports Learning through Iteration

When students were asked to describe the pedagogical supports they found most helpful while tinkering, the majority noted the importance of having educators by their side but never telling them the answers. As Elena explained: "I find it really helpful when they work *with* us instead of *for* us. They work with us so that we can learn and we're not just doing what they told us to do. So next time when we get stuck again we can figure it out on our own" [5/16/15]. Jenna also said she liked that her Techbridge teacher "asks a lot of questions before he jumps in to answer you…he'll ask me questions and he makes you realize what you've done and what you could easily fix once you've realized it" [5/16/15]. Helena agreed with this, explaining how the ways educators stood by their side to work through challenges without simply explaining how to solve them was valuable: "It's not us asking and the teacher coming up with an answer and showing us exactly what to do" [5/16/15]. The girls felt that they could work through frustrating moments with their projects because teachers were willing to "stick with you" [Erin; 5/16/15] and be "side-by-side trying to figure it out" [Paloma; 5/16/15] without simply giving an answer and moving on.

Interestingly, students' descriptions of effective pedagogy reflected educators' philosophies about how they try to support Techbridge girls through frustration and challenges. One educator explained that his role was not really to give "information" or "how to do things, it's not the knowledge in that sense but knowledge in the sense of **it's okay to try things**" [Mr. A; 3/23/15]. In order to encourage girls to try things, Mr. A focused on asking "rhetorical questions for the girls to think about…You need to ask a lot of rhetorical questions where they're digging for the answers. They're thinking about it" [3/23/15]. Similarly, Mr. E explained that he often did not know how to solve challenges girls faced in their projects, but he would be honest about this with the girls which went a long way in helping them embrace challenging moments and seek answers to frustrating problems. Mr. E noted, "I think that humility and just being okay with not knowing everything… **I think students really appreciate when you don't know the answer, I think they feel more comfortable coming to you when they know you're just not going to pretend** or if you acknowledge that you don't know everything I think they feel more comfortable reaching out for help" [3/23/15]. As Ms. C explained, "students getting frustrated is a weekly occurrence" but "we try to encourage them to take a step back and reflect what the issue is" while also explaining that it's okay not to know a solution immediately [3/22/15]. As Mr. E added, he felt it was important to teach "students to be okay with what they know and what they don't know and sort of **not see that as a reflection of themselves**" [3/23/15]. This pedagogical approach to supporting girls through iterative design processes in tinkering required reframing challenges as frustrations with the projects, rather than indications of intelligence.

The ways that Techbridge educators enacted these sentiments were visible not only in Mr. A's "rhetorical questions" or Mr. E's honesty about not knowing answers, but also by creating an environment where educators and students shared their "glorious goofs" and where educators shared the challenges they faced in projects alongside the girls. "Glorious goofs" involved regularly writing down a mistake or challenge faced during the program day onto a poster that all the girls could see. A volunteer would then read all the "goofs" experienced by students and teachers alike. Ms. C noted that girls took pride in being able to say "Oh, I made this mistake but I learned from it!" [3/22/15]. Mr. E also felt it was important to show educators' unfinished or unsolved prototypes. He explained: "making examples doing the project yourself, coming up with a list of things that were hard or a list of things that you would adapt [are valuable because]…it shows the girls that you can adapt it doesn't have to be rigid" [3/23/15]. These kinds of pedagogical strategies were just a few that Techbridge educators adopted as a way to support girls in the iteration design process and in working through unexpected challenges.

5.3 Seeing the Value of Iterations Emerge: The Case of Luisa

Luisa's experience at Techbridge offers a particularly interesting illustration of how youth learned through iterative design. Luisa had explained that tinkering required a disposition of working through "frustration" with "trial and error" while embracing the reality that "**things don't work**" so one needs to "**try again**" [5/18/15]. This attitude was visible in Luisa's presentation of a Rube Goldberg machine at Maker Faire in 2014. Luisa and her partner created a machine that was supposed to end with a trophy hitting the "play" button of an iHome stereo. Their machine did not perform perfectly and Luisa had to reset it several times for Maker Faire attendees. While some might interpret the imperfections of this Rube Goldberg machine as a "problem" or "failure," this was not how Luisa interpreted the experience. When interviewed about her project, she recognized these imperfections in the machine as simply "**part of the routine**." She noted that she did not feel stressed in any way because they had "**dealt with it [trial/error] a lot here [at Techbridge]**" [5/18/15].

During her senior year in the fall of 2014, Luisa returned to Techbridge. The ways she embraced this attitude of embracing iterative design and working through challenges was visible during an introductory activity at the start of the school year. Students were given the challenge to design a tool that could pull a golf ball out of a paper bag without one's hands ever touching the inside or outside of the bag. Students were given limited materials (chopsticks, a specific amount of tape, rubber bands, index cards). At the end of the activity, all the girls came up and shared their projects with one another. When Luisa and Trisha went in front of the class to describe their invention, they showed a scooper created out of two sticks with post-its at the ends attached with thumbtacks. While Trisha was setting up their project, Luisa mentioned to the class that their project was still in "prototype phase" and 'it doesn't work, but that's okay.' The girls laughed about this and seemed completely comfortable that their project was the only one that didn't successfully grab the golf ball out of the bag. Seeing this moment as valuable for illuminating the iterative design process, Mr. E asked everyone: 'Did any of [your] inventions end up looking like the first sketches?' Only one group raised their hands. [Fieldnote; 9/15/2014] In this moment, the educator encouraged Techbridge girls to consider how it was expected that designs should shift and grow over time with multiple iterations while facing unexpected challenges. One can begin to see how Luisa's approach to tinkering and ability to work through challenges was made possible through an embracing of the iterative design process as well as with the social and pedagogical supports made available in the learning environment.

6. DISCUSSION AND CONCLUSION

Moving beyond focusing on "failure," Vossoughi et al. [27] have emphasized the importance of iteration/drafts as an equity-oriented approach to engaging youth in working through challenging moments while tinkering. They note the crucial role of pedagogy—through teacher talk and gesture—in providing space for youth to learn through iteration and drafts. These iterative practices in turn, relate to a set of equity-oriented design principles for tinkering such as "building generous learning environments" and "widening definitions of learning, intelligence, and science" [27] (p. 4).

This paper illustrates how youth and educators made sense of and valued tinkering's iterative design process, building dispositions that embraced challenges to work through frustration. In interviews, girls described how tinkering's iterative design process was made meaningful by the creative authorship they were given to not only take ownership over their ideas, but also over the challenges involved in pursuing their designs. Yet this was made possible because of the pedagogical supports and learning environment educators provided for girls to feel safe tinkering. Developing a space where girls could try out ideas, figure out problems alongside both peers and adults, and ask any questions without feeling like the end-results of their efforts would define either their ability or intelligence was important to supporting the iterative design process. This resulted in a program culture that valued process over product.

Girls then celebrated their “processes over products” at Maker Faire 2015 as Elena and her partners proudly displayed four wave shields that they had soldered but couldn’t make function, or as Ali and Erin demonstrated an unfinished light-up outfit to Maker Faire visitors. Unlike most Maker Faire presenters, the Techbridge girls willingly shared their non-functioning iterations of projects and felt comfortable recognizing that tinkering involved a continuous process of design and redesign. They demonstrated a widened definition of what it meant to learn and be smart through the support of their afterschool educators. The Techbridge girls were not focused on “failing fast” or “failing forward,” but rather on learning through process and continuously perfecting their iterations/drafts.

Instead of using “failure” as a framework for learning, the Techbridge girls and educators emphasized an alternative set of values regarding the power of the iterative design process in tinkering. This allowed for a more generative approach to engaging with STEM practices such as asking questions, designing and testing models, making observations, and redesigning through their tinkering projects. Girls were willing to take on unexpected challenges not because they wanted to “fail,” but because they wanted to work through multiple iterations of their own designs.

Techbridge creates a learning space for girls to take risks in pursuing their ideas, to have agency in choosing their projects, to exercise their own approaches in creating, and to accept iterations as a part of the scientific process. This type of learning space is not often available to low-income or historically marginalized communities yet is essential for learners to see the array of problem-solving approaches they can take to work through STEM concepts and skills. To that end, we are interested in the ways this approach to tinkering and learning makes STEM concepts and skills more meaningful for all youth.

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Iterative design is a design methodology based on a cyclic process of prototyping, testing, analyzing, and refining a product or process. Based on the results of testing the most recent iteration of a design, changes and refinements are made. This process is intended to ultimately improve the quality and functionality of a design. In iterative design, interaction with the designed system is used as a form of research for informing and evolving a project, as successive versions, or iterations of a Tinkering with "failure": Equity, learning, and the iterative design process. In FabLearn 2015 Conference at Stanford University, September 2015.Google Scholar. Stenerson, M. E., Salmon, A., Berland, M., & Squire, K. (2014, October).Â Designing visible engineering: supporting tinkering performances in museums. In Proceedings of the 14th International Conference on Interaction Design and Children (pp. 49--58). ACM. Google Scholar Digital Library. Petrich, M., Wilkinson, K., & Bevan, B. (2013). It looks like fun, but are they learning. Design, make, play: Growing the next generation of STEM innovators, 50--70.Google Scholar. Resnick, M., & Rosenbaum, E. (2013). Designing for tinkerability. The Iterative Design is a design methodology based on a cyclic process of prototyping, testing, analyzing, and refining a product or process. Based on the results of testing the most recent iteration of a design, changes and refinements are made. This process is intended to ultimately improve the quality and functionality of a design. In iterative design, interaction with the designed system is used as a form of research for informing and evolving a project, as successive versions, or iterations of a design are implemented. It seems both methods are about creating a part of the system , refini Tinkering, Learning & Equity in the After-School Setting. Dr. Shirin Vossoughi. Stanford University SF Exploratorium Pier 15 SF, CA, 94111 (424) 298-7573.Â We build this argument by sharing some of the design principles, interactions and practices that constitute the Afterschool Tinkering Program â€“ a partnership between the SF Exploratorium and San Francisco Boys and Girls Clubs.Â Tinkering is primary insofar as the environment emphasizes the iterative process of learning, and works to cultivate playful experimentation with a range of possibilities and ideas. To this end, we are interested in the ways improvisation and experimentation can enrich the process of making, and the ways planning may be a productive tool within tinkering activities. Design is an iterative process. Several analysis steps using candidate designs are necessary before a design is finalized. This is a laborious process. The designerâ€™s intuition, prior experience, and knowledge about the entity being designed guide this process. Often it is a trial-and-error process even for an experienced designer who encounters a new design task. Synthesis, on the other hand, is a systematic step of arriving at a design in less time than in trial-and-error design. If optimization is used, the systematic synthesis can also give the optimum design.Â Problems with the original intent will cause a change in design. More problems cause more iteration until a workable design is in place.

failing-forward;[30] and 4) Expanding the outcomes of making to include agency, identity, and the after-life of maker projects.[26] Cutting across these areas are specific attention to gender and computer science,[25] indigenous epistemologies and maker activities,[28] and how makerspaces may ground STEM-rich making in the lived experiences and wisdom of youth of color and their families and. communities.[31]. One emerging area of studies examines the production of an equitable culture in making, including in-depth longitudinal cases of youth makers in community settings, how youth and community co-design for equitable learning opportunities and outcomes.[27]. Difficulties.Â "Tinkering with "failure": Equity, learning, and the iterative design process". Fablearn. Tinkering with â€œFailureâ€: Equity, learning, and the iterative design process. In FabLearn 2015 Conference at Stanford University, September 2015.Google Scholar. Ryoo, J. J., & Kekelis, L. (2016).Â Tinkering, learning & equity in the after-school setting. In Annual FabLearn conference. Palo Alto, CA: Stanford University.Google Scholar. Vossoughi, S., Hooper, P. K., & EscudÃ©, M. (2016). Making through the lens of culture and power: Toward transformative visions for educational equity. Harvard Educational Review, 86(2), 206â€"232.Google Scholar. Wardrip, P. S., & Brahms, L. (2015, June). Learning practices of making: Developing a framework for design. In Proceedings of the 14th international conference on interaction design and children (pp. 375â€"378). Iterative and incremental development is any combination of both iterative design or iterative method and incremental build model for development. Usage of the term began in software development, with a long-standing combination of the two terms iterative and incremental having been widely suggested for large development efforts. For example, the 1985 DOD-STD-2167 mentions (in section 4.1.2): "During software development, more than one iteration of the software development cycle may be in progress at...