# The Makerspace Movement: Sites of Possibilities for Equitable Opportunities to Engage Underrepresented Youth in STEM

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## Abstract

**Background/Context** Large gaps in achievement and interest in science and engineering [STEM] persist for youth growing up in poverty, and in particular for African American and Latino youth. Within the informal community, the recently evolving "maker movement" has evoked interest for its potential role in breaking down longstanding barriers to learning and attainment in STEM, with advocates arguing for its "democratizing effects." What remains unclear is how minoritized newcomers to a makerspace can access and engage in makerspaces in robust and equitably consequential ways.

**Purpose** This paper describes how and why youth engage in making in an after-school, youth-focused, community-based makerspace program "Making 4 Change." Four in-depth stories of engagement are shared. Using a mobilities of learning framework, we discuss how youth appropriated and repurposed the process of making, and unpack how the program attempted to value and negotiate youths' ways of making from an equity-oriented perspective.

**Research Design** Utilizing a two-year critical ethnography, involving 36 youth over two years in 2 making settings, we assumed roles of both program teachers and researchers. Data collected included field notes, session videos, weekly youth conversation groups, youth created artifacts and interviews. Analysis was iterative, involving movement between a grounded approach to making sense of our data, and a mobilities of learning framework.

**Findings** Three forms of engagement – critical, connected and collective – supported youths' sustained and mutual engagement in the makerspace. Across the three, it was essential to balance purposeful playfulness with just-in-time STEM modules, invite a broadening range of identities youth could draw on and perform, and to more critically address the affordances and constraints inherent in a community makerspace.

**Conclusions** From the insights gained, we suggest that framing youths' experiences through the lens of equitably-consequential learning and becoming challenges the field to consider how making – as a practice – is never separate from individual and social histories that unfold across space and time. Who can make and who cannot, whose knowledge matters and whose does not, are all a part of making itself. But such understandings are not without tensions, for the work that youth do, which can invoke nontraditional tools and practices towards nontraditional ends, can be fraught with complexities that youth and adults alike are unprepared to handle.

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*"There are a lot of people who get frostbite in the winter when people are outside. Ours is way cheaper than a regular sweatshirt and way warmer. It will keep you warm and snug. It will have a heater in it, and lights for glamour and fashion." Emily*

*"Our idea could help change things. People make fun of you. Why are you wearing that? You are ugly. There are stains on your clothes. . . I was like I am going to give you something beautiful but with casual in it so that you don't expose yourself. Like a jacket that goes all of the way down." Jennifer*

Jennifer and Emily's idea to make a heat-up, light-up sweatshirt grew out of their concerns that people in their community should have more fashionable ways to stay warm in the dark and cold, something they had experienced living in Michigan. Not only would the shirt be warm and bright, it would also be lightweight and beautiful. The aesthetics of the shirt carry deeper meaning than just beauty, however. These are safety related issues for the girls as well, as they were concerned about inappropriate exposure and also being bullied for clothing choices.

The girls' design work, completed over an 8-month span in an afterschool makerspace program, was a response to complex layers of concern. From October to May the girls iteratively revised their design specifications to account for their growing understanding of what was possible in their design (e.g., what kind of heating elements could be powered by small, flexible solar panels), as well as what they determined their users might enjoy (e.g., casual with fashion). They sketched up different design ideas, tested out various heating elements, solar panels, and approaches to storing the solar energy. They also interacted with a range of community and technical experts as they hit sticking points. Peers provided on-going fashion advice, engineers and mentors provided help with technical tools, calculations and design

decisions (e.g., multi-meters, circuitry, determining power requirements), and a mom taught the girls how to use a sewing machine.

On several occasions, the girls almost gave up. About 5 months into the project, Emily threw her arms up in despair after realizing the heating element they desired for their jacket demanded too much power. To make the frustration greater, she determined this after spending nearly two hours working out the calculation with Jennifer and a mentor at a corner table in their makerspace. She stated, "I like this heating source but we can't use 110 batteries! We don't even have that many batteries. And the sweatshirt would just be too heavy. I don't know what to do!"

These types of critical junctures, however, became generative. On this occasion, one of the makerspace mentors reminded the girls of a video blog and hand sketch they made 2 months prior, which included ideas about insulation. Jennifer had been especially proud of this idea as she had gotten it from her family's fireplace design at home. The moment became pivotal as they returned to the need for insulation in order to enable smaller heating elements with lower power demands to work more efficiently in their design. At another critical moment, Jennifer accidently "cut too deep" into the prototype, which led to a neighborhood mom who worked at the community center joining us in the makerspace and teaching all of us how to use a sewing machine. On the day that she cut too deep into the jacket's fabric, Jennifer left the makerspace crying as they did not have another jacket, and neither she nor Emily knew how to sew. As Jennifer stated in reference to a picture of her cutting the shirt, "This is me making a horrible mistake by cutting it, and so I had to learn how to sew. Next time, if something breaks, I know how to sew it back together."

In the end, the girls used three small heating elements and insulation to keep the design lightweight. They switched from a sweatshirt to a faux fur-lined "bomber" jacket to enhance the

prototype's fashion appeal, and they made plans to add lights and beads for decoration. They decided on a flexible lightweight solar panel to keep two small rechargeable batteries charged, in order to ensure that the jacket was versatile, light, "green," and fun.

This vignette raises important questions for us as we consider how the maker movement might more seriously engage equity-related concerns, including:

- How do makerspaces support *sustained* engagement in engineering design among youth from minoritized communities?
- What forms of engagement matter, for whom and why? How do these forms of engagement embrace and respond to the complexity of ways in which youth frame problems worth solving in makerspaces?
- What are the equity oriented and consequential implications that relate to designing makerspaces for youth from minoritized communities?

These questions speak to equity-related concerns that young people from minoritized communities face as they seek to engage in makerspaces. To make sense of these questions, we present a set of cases from our multi-year, multi-sited critical ethnographies of youth-centered makerspaces in Michigan and North Carolina. We use our analysis to argue for an expanded view of engagement that might frame the design of makerspaces with equity as a primary goal.

## Equity and the Maker Movement

**Inequality & STEM.** Large gaps in achievement and interest in science and engineering [STEM] persist for youth growing up in poverty, and in particular for African American and Latino youth from lower-income communities. These gaps persist across all levels of educational attainment. In the U.S., the percent of engineering bachelor degrees awarded to African Americans in the U.S. has hovered around 4% (Yoder, 2014). African Americans, Latinos, and

Native Americans account for only 6% of the total STEM labor force, even though they represent over one-fourth of the US population (National Science Foundation, 2014). These interest, achievement, and career gaps have changed little in the past two decades despite science and math reform efforts in school settings.

The research literature documents many reasons for these persistent gaps, including inequitable access to resources, quality instruction, and role models, along with cultural barriers and stereotypes (Margolis, Estrella, Goode, Jellison Holme, & Nao, 2008; Oakes, 2005). As these gaps indicate, the impacts of these inequalities are great, on both individual youth and communities. Success in STEM is one viable route towards personal and community economic advancement for youth growing up in poverty. Success in STEM also factors into opportunities for empowered democratic participation. That lower-income communities of color experience the greatest levels of environmental injustice and often have the least voice in STEM-related decisions affecting their communities are further evidence of the impact of these persistent inequities (National Academy of Engineering, 2010).

High quality out-of-school time STEM experiences can positively impact participation and learning in STEM, particularly among youth from lower-income communities (Falk, Storksdieck & Dierking, 2007; Harvard Family Research Project, 2012). A meta-analysis of the impacts of out-of-school time programs suggest that such programs increase attitudes towards schooling and educational aspirations, improve grades and test scores, and decrease disciplinary action and drop out rates (Lauer, Akiba, Wilkerson, Apthorp, Snow, & Martin-Glenn, 2006).

The "maker movement" has evoked interest for its potential role in breaking down barriers to learning and attainment in STEM. The maker movement is a relatively new phenomenon – grassroots-oriented and driven by makers themselves (Peppler & Bender, 2013).

While people have *always* been making, the maker movement is an attempt to organize resources, attention and people around maker *communities* and maker *practices*, such as hybrid material/digital fabrications and collaborative designs for do-it-yourself projects (Honey & Kanter, 2013). Advocates of the maker movement argue for its "democratizing effects" – with access to a makerspace, "anyone can make… anyone can change the world" (Hatch, 2014, p. 10). Makerspaces potentially offer opportunities for young people to engage in STEM knowledge and practices in creative and playful ways, where "learning is and for the making" (Sheridan, Halverson, Brahms, Jacobs-Priebe & Owens, 2014, p. 528).

**Attending to Equity**. There is little evidence that the maker movement has been *broadly successful* at involving a diverse audience, especially over a sustained period of time[1]. The movement remains an adult, white, middle-class pursuit, led by those with the leisure time, technical knowledge, experience, and resources to make. Even with the growth of community-based makerspaces, users of these spaces tend to be white adult men (TASCHA, 2012). Little research has been conducted on how the maker movement might address equity concerns broadly. However, the research that does exist, even though scant, offers important insights into the pressing concerns essential to opening up the maker movement more broadly.

One set of studies examines the affordances of making activity. Making, as a set of activities, is built on practices and mindsets that underscore the importance of collaborative and iterative construction of objects through the creative use of material and digital fabrication tools (Halverson & Sheridan, 2014). The argument is that making affords *new forms of learning* because "what" individuals make become the "evolving representation of the learner's thinking"

[1] There are pockets of success around the nation where makerspaces have successfully reached a more diverse population, than the trending white and male nature of these spaces (e.g., such as the Mt. Elliott Makerspace in Detroit). However, these spaces are the exception and not the norm. *And*, little research has been done on these spaces to document what is working, how or why.

and "promotes understanding through interpretation," further developing knowledge (Halverson & Sheridan, 2014, p. 507). Moreover, making activities potentially teach content, practices and mindsets that are not strongly encouraged or covered in school settings, such as engineering design, multi-modal practices, creativity, and the importance of failure and iteration (Hetland, Winner, Veenema, & Sheridan, 2013; Martin, 2015). From an equity standpoint, these findings are important. That makerspaces legitimize non-school based practices essential in problem solving and design may make the spaces more appealing to youth for whom schooling has felt marginalizing (Buchholz, Shively, Peppler & Wohlwend, 2014).

What counts as making is another area of work taken up by a handful of researchers. Making is often described as a practice of bricolage, or creating things from a diverse range of tools and practices that happen to be available in-the-moment. However, bricolage in unfamiliar territory can be daunting, especially if one is not accustomed to either the tools or the culture of making to which they have access. However, makerspaces that take on broader views of learning and development may be more likely to value the resources and capacities of young people who have been historically marginalized in making and in STEM, thereby shifting the culture of making to one that is more inclusive. Of particular concern are newcomers – new to STEM and new to makerspaces – individuals who may benefit most from becoming a legitimate member of a making culture. Vossoughi and her colleagues (2013) point out that making pedagogies promote social interaction through shared activity and play, and can be helpful in supporting newcomers in gaining the confidence to shift how tools, experiences and ideas might be used in these spaces towards more consequential ends.

Other studies have examined how the making community supports an expanded set of outcomes in learning (Bevan, Gutwill, Petrich & Wilkinson, 2015; Authors, 2014, 2015;

Sheridan et al., 2014). The field has doubled down on narrow outcomes of STEM learning in both formal and informal settings with increasing focus on accountability, making these studies particularly salient from an equity standpoint.

For example, Sheridan et al. (2014) suggest that making values *multi*disciplinary engagement, which manifests itself in both the tools and practices (e.g., sewing and circuitry) and in the questions asked and artifacts made (e.g., e-textiles). Such outcomes can be thought about in terms of developing STEM expertise grounded in new forms of practice that value "historically feminized" practices, such as crafting alongside more traditionally "masculinized" practices, such as electronics (Buchholz et al, 2014, p. 283). Such diversity in ways of learning, doing and becoming potentially open up making to individuals who have not historically seen themselves as a part of STEM. We see these same ideals echoed in Kafai, Fields, and Searle's (2014) work, which shows how makerspaces bring together both "hard" and "soft" skills towards challenging what counts as legitimate learning and making.

One recent study conducted over 18 months at the Exploratorium offers further insight (Bevan et al., 2015). Researchers examined the forms of learning in their on-site making and tinkering environments. They argue that "engagement, initiative and intentionality, social scaffolding, and developing understanding" are all "indicators" of learning and offer evidence of what these forms look like in making practice (p. 105). For example, with respect to the first indicator, engagement, the authors suggest that in addition "to simply being present and active" engagement also involves "points of transition or choice" such as "moments where young people's levels of investment and persistence can be documented as they commit to new or continued courses of action" (p. 115). A second indicator pertinent to equity is that of initiative and intentionality, or a "moving beyond the general expectations or activities modeled in the

Tinkering Studio to do or create something different" (p. 109). While the examples offered in this study relate to makers persisting through design problems (e.g., how to work the switch), this indicator might also speak more broadly to young people moving beyond traditional making practices to more hybrid forms that encompass their situated needs and experiences. These, and other forms of engagement identified in this study, speak to equity concerns related to when, or why, youth may choose to not persist in a making project.

In our own work focused on equity in makerspaces (Authors 2015; Authors, in press), we have examined the role of pivotal reflection points in how, and why, youth from minoritized backgrounds "make for the public good." Attending to the situated vulnerabilities of communities, ethical dimensions of engineering design, and action-taking all point to how the youth seek to iteratively revise their designs in a community-based makerspace. These studies call attention to the potential youth-oriented makerspaces can have in supporting youth in framing, unpacking, and interrogating salient concerns and needs with the tools of science, engineering and communities so as to innovate unique solutions to address particular inequities in their lives.

While such findings are important, they urge us to interrogate whose histories still remain silent in these making worlds. We wonder if individuals who do not see their cultural repertoires of practice reflected in makerspaces – in the people, practices, tools and artifacts produced – will be attracted to makerspaces. This is an especially pertinent equity concern given that makers have been defined as "people who design and make things on their own time because they find it intrinsically rewarding" (Kalil, 2013), and "enthusiasts who play with technology to learn more about it" (Martin, 2015). In addition, crafting practices, while historically feminized, are not necessarily shared across points of intersectionality, such as race or class. As we describe later,

crafting practices such as threading needles, sewing, tying knots and so on were as foreign to the girls as to the boys in our own experiences. Furthermore, while we believe these practices (and the associated cultural tools) need to be opened to all people, we are cognizant that simply providing access to these tools may not, by themselves, shift the culture of makerspace practice. Gaining deeper insight into what might be other forms of "collaborative contested practices" (Buchholz et al, 2014, p. 283) as well as empowering equity-oriented pedagogies (Vossoughi et al, 2013) which provide expansive learning moments for youth, are important.

## Conceptual Approach: Mobilities of Learning

Our questions around equity and the makerspace movement relate to learning opportunities and how they are configured in makerspaces. Our questions are also tied to the real and imagined geographies of learning/making experienced by youth as they work on and within the boundaries of STEM design in makerspaces. Thus, we draw from mobilities of learning studies to frame these concerns. We are particularly interested in those studies that take a critical orientation, weaving in issues of power and positioning.

A mobilities of learning framework, grounded in sociocultural learning theories, takes an expansive view of learning, where learning involves both vertical and horizontal movement, and takes form as ideas, tools and practices are re-authored and re-mixed towards new possibilities for becoming in-practice across setting and over time (Engeström & Sannino, 2010; Gutiérrez, 2012). Studies, for example, have documented how individuals navigate and bridge the worlds of home, school, and community, including how they move people, practices, tools, and ideas across these settings (Ehret & Hollet, 2013; Taylor & Hall, 2013). These studies take serious the notion that there is continuity between youths' worlds and that of STEM, and that we best understand these worlds as "generative resources in learning new ideas and traditions of inquiry"

(Warren, Ogonowski, & Pothier, 2005, p. 121). They have also led to the recognition that youths' mobilities, among a vast range of learning arrangements, make learning and identity work always "tangled up" among practices in complex ways (Rahm, 2012).

Mobilities of learning also call attention to the ways in which learning is always taking place *somewhere,* both in "relation to history (time) and context (place/space)" (Bright, Manchester, Allendyke, 2013, p. 749). One area of research that informs the space-time of learning is that of connected learning. Studies within this domain focus on the increasingly complex and networked modes of knowledge production and sharing that youth experience as they move across the spaces of their lives individually, and with others. These studies suggest that as individuals pursue shared interests through peer relationships, more expansive and meaningful outcomes result that are "value additive," "elevating individuals and collectives in an integrated way" (Ito et al., 2013, p 48). Connected learning studies have also yielded insights on the role of people in opportunities to learn. Barron, Martin, Takeuchi & Fithian (2009) examine how parents serve as brokers in children's technology learning. Others have reported on social network building as crucial to learning (Ching, Santo, Hoadly & Peppler, 2014).

However, how such connections form, and the learning opportunities they provide, ought to be thought about as much more than interest-driven (Garcia & Morell, 2013). Connections and interests are shaped by one's own historical geographies, suggesting that issues of power and privilege are deeply entrenched in how one experiences learning (Haan, Leander, Unlusoy & Prinsen, 2014). As individuals move through space-time, their activity is enabled and constrained by the social structures-in-motion, shaping what it means, for example, to make or to be a maker.

From an equity standpoint, a mobilities of learning framework offers important lessons. First, a mobilities of learning perspective challenges normative views of what it means to

participate in practice within community by making visible the boundaries of formal/informal, novice/expert, and past/present/future, and how these boundaries change over time and across space (Rahm, 2014). We are interested in how new routines, ideas, and ways of being become legitimized in practice. We consider that youths' "interests" are a reflection of their lived experiences in the world, and how they have learned to navigate those experiences through "localized and contested power geometries" (Bright, et al., 2013). Youth's experiences can expose and challenge *normative views of making* while also building a makerspace community that legitimizes their lives.

Second, these theories help us to see how learning and doing are situated within local practice. How actors are positioned (and by whom) across time and space, the individual and collective funds of knowledge actors bring to the process and whether those funds of knowledge are recognized and valued (Bang & Medin, 2010), all shape opportunities to learn and become. Unequal distribution of power impacts whether one sees oneself as capable and welcomed in STEM (Nasir, 2011), often resulting in youth from minoritized communities losing interest in STEM before high school. As individuals join new communities of practice, such as a makerspaces, they call upon salient practices and ways of being that are learned in that community, as well as from other places. These actions can position one as either central or marginal to their new community depending upon how they are received by others. How youth leverage their knowledge of community concerns and values could be positioned by the teacher/adult facilitator or peers as either important or not, for making. Broader sociohistorical narratives around who can be a maker or a STEM expert influence how youth come to a makerspace seeing themselves as capable in making.

In what follows, we share "sticky points" (critical junctures) and insights related to equity that have risen for us in our work with engaging youth in community-based makerspaces at their local community centers using these conceptual perspectives as interpretive guides. We share these insights *not* to suggest our project as an exemplar of a uniquely equitable makerspace, but to trouble the notion of makerspaces as an implicit panacea to equity and access issues in STEM.

## Context: Making 4 Change

Our study is grounded in middle school youths' experiences in two different makerspace contexts, Michigan and North Carolina [MI and NC], over the course of two and one years respectively. The makerspaces in both locations are housed in Boys and Girls Clubs [BGCs] (community-based clubs focused on youth development, homework help, and sports) in mid-sized cities, both facing some degree of economic depression. We have worked together with staff at the BGCs to establish these makerspaces, with the primary goals of supporting youth in developing productive identities in STEM, while also learning about making/engineering design in culturally sustaining ways. In both locations, we sought to engage youth iteratively and generatively in maker space activities and in community ethnography as one approach to embedding local knowledge and practice into making and engineering design.

During 2013-2105, 36 youth participated, of whom 11 participated for 2 years (2013-2015), and the remaining 25 participated for 1 year (2014-2015). The youth were primarily from grades 5-8 (ages 10-14), and from lower-income families. Most are African American, although a few are white or biracial (See Table 1).

[Insert Table 1 about here]

Our makerspace programs in the two cities, which we refer to as "Making 4 Change" or M4C, was designed to support youth in sustained engagement in engineering for sustainable

communities, a design goal that incorporates multiple perspectives and the collective good. In maker teams composed of old timers and new comers, middle school youth collaboratively generate initial ideas about potential problem spaces and associated questions. Using the cultural tools of ethnography, they move together into community spaces to glean insights into how these problems matter, technologically and socially. As community ethnographers, they identify vulnerabilities of relevance in their communities (e.g., safety, water, transportation). We conjecture that ethnography supports youth in generating and analyzing data from multiple perspectives, while also expanding their social network of "experts" related to their problem (including nontraditional forms of expertise). As youth return to their makerspace, they leverage these data towards defining more complex, but constrained, problem spaces, and begin to explore and try out new possibilities and approaches. As they work on design solutions in makerspaces, they, along with their makerspace teachers, invite community members of ranging expertise to provide help, insight, and feedback on their efforts.

The goals for the makerspace members during the school years of this study were: (1) to design, construct, test, and refine prototypes that would use "green," renewable energy to help peers and/or community members, and (2) to produce, edit, and present short videos to educate others about their prototypes. While these are our goals as adult facilitators committed to an equity-agenda for minoritzed youths' makerspace experience, we are mindful of our "outsider" status to youths' communities. Thus, we constantly engage youth in dialogue to unpack what these goals mean for them and their communities, and the plausible routes to get there.

## Methods

### Critical Ethnography

Our study was carried out as a critical ethnography over a two-year period. Critical ethnography was selected as our methodology because of its explicit focus on participatory critique, transformation, empowerment, and social justice. Critical ethnography is grounded in the idea that researchers can use the tools of ethnography to conduct empirical research in an unjust world in ways that examine and transform inequalities from multiple perspectives (Trueba, 1999). Critical ethnography provided an approach in which to "politicize" the interaction between actors and the social structures through which they act, grounded in the belief that these relationships are never neutral. This approach was important as we attempted to make sense of how youth, who are positioned in particular ways due to race, gender and class, engage in makerspace activities.

**Our roles.** We employed this methodology due to the desire to conduct research "with" participants, rather than "on" or "for" them. We assumed multiple roles throughout the project acting as teachers, mentors and researchers. This positioned us as members of the group who had various degrees of influence on the direction of inquiry as the investigation progressed. For example, at the beginning of each school year, as mentors, we co-designed initial whole group activities around defining a problem space as a way to support youth in naming issues that they care about – one initial way to legitimize these concerns in their makerspace. We also worked on developing a series of "just in time" activities around a) community ethnography, and b) making practices (e.g., how to solder), and c) energy systems and transformations. Our goal was to provide helpful experiences and small bits of information that youth and mentors could collaboratively grab hold of as design work indicated.

**Youth roles**. Youth also assumed multiple roles throughout this project being actors in investigations while also having input on the direction of this study. In weekly conversation

groups, youth identified topics they wanted to learn more about (e.g., for just in times), and also provided critical feedback on what tools and resources they wanted more of in their makerspace. They identified the core need to collaboratively get smarter on what a "youth-centered" maker space might be, which became central to our analysis, when they complained vehemently at one point that "all" of the makerspaces they ever visited were "not kid friendly." At the same time, while the youth were adamant about the kid unfriendly vibes given off by these makerspaces, they were unable to pinpoint immediately why that is so. Therefore, the youth also spent time during M4C unpacking and discussing what some pertinent elements need to be in place, and why, for a youth makerspace to be authentically kid-friendly.

**Specific methods**

Data were generated, 2013-2015, from artifacts, weekly youth conversation groups, and video analysis capturing youth interaction with STEM and community experts at various stages in their design process (See Table 2). In addition we used mid- and end- of year course artifact interviews, researcher field notes (per session), and youth created multimedia (e.g., video blogs) showing progress on their design to community members and STEM experts.

[Insert Table 2 about here]

Data analysis involved multiple stages and levels of coding based on procedures for open coding and method of constant comparison (Strauss & Corbin, 1998). Our first pass involved reading through artifact interviews transcripts (conducted yearly at mid year and end of year) as well as our fieldnotes and the students' sketch-up notebooks kept during the course of their participation. The goal of this initial read through was to surface points and open codes of a) tensions and connections among the various youths' forms of engagement in making, b) critical design moments (e.g., sticking points, changes in direction, etc.), and c) generally how youth

talked about and framed what it meant to participate. For example, in trying to open code for critical design moments, we noted times when youth made shifts in design, became deeply frustrated or disengaged, or otherwise more explicitly noted for us (e.g., artifact interviews) when they felt they were stuck or had important turning points. Weekly conversations were held between the authors on these insights as a way to work towards a more "expansive consensus"; that is to say that any differences in view were debated until new meaning was generated as a result of our differences. A detailed list of emergent open codes were kept with analytic memos attached to them, which we then brought to bear on other data sources, such as group conversation transcripts and various student artifacts not included in their sketch up notebook.

Our second pass involved identifying important resources and practices used by youth in their making, in relationship to the previously identified critical events, tensions and connections. With the help of our theoretical framework (mobilities of learning), we worked to make sense of what it meant for the youth to move, repurpose or remix the ideas, practices and resources they leveraged within these events. This axial phase of coding was used to uncover relationships and connections between the youths' making and the tensions that emerged from the data. In developing these coding schemes, we paid attention to how, and where, youth engagement appears greatest and the forms such engagement took, how they move ideas and resources across spaces, the different forms of learning, and the identity work that take place within and across these spaces. We took these data points as significant markers of equity – opportunities to access and activate traditional and nontraditional resources and to be recognized for doing so, as important to the making process and outcomes.

The relationships and connections identified in this second stage of coding, in turn, guided our selective coding, and became categories and themes, from which our example cases

were selected for a final round of analysis and presentation. This final phase involved writing the narratives related to students' participation in the two makerspaces under study, including what youth learned, the resources they leveraged, the actions they took, the roles/positions they assume and how these were recognized by others.

## Stories of engagement and the sticking points they produced

Below we offer four example vignettes of youth making that raise questions and challenges regarding equity and access issues in makerspaces. Across the vignettes we examine what forms of engagement matter, for whom and why, and identify the contributing factors that appear to propel or stall youth engagement. We look closely at how youth navigate who they are and what they care about in the context of their makerspace work.

**The Anti-rape jacket: Kairee and Mirabel risking new narratives for making**. Kairee joined the M4C makerspace in MI in Fall of 2014 because her friend, Mirabel, recruited her. Mirabel had previously been involved in M4C, the result of another friend recruiting her into the club in 2013, to build a solar powered heated birdhouse, due to their shared interest in caring for non-migrating birds during the often harsh winter their city faces (Authors, 2015).

Neither girl expressed interest in in-school science learning, but both enjoyed social interaction, and opportunities to get on-line during the afterschool club. Kairee, in particular, was clear that she "absolutely hates science, math and basically anything about school." She said she is surprised that her work in the makerspace is STEM because "it can be fun sometimes" and it is not as "boring" as school. Mirabel, the more serious of the two, often re-directed Kairee from singing and dancing to working on their project. Both girls expressed a desired future in STEM, however, stating that they both wanted to become surgeons. Mirabel's favorite subject was math, and Kairee claimed an "obsession" for all maker-themed programs that she could find on

television at home (e.g., home improvement, interior design, and cooking shows). Both mentioned their desire to "make stuff and invent stuff and take stuff apart" as reasons for joining the club—as an example of "how crazy" she was with the determined curiosity to learn about how things work by taking them apart, Kairee even shared an anecdote in which she once got in trouble for throwing her mother's microwave down the basement staircase "to see what was inside it." Additionally, they shared that the club's activities offered a welcome escape from the everyday boredom they felt in having "nothing else to do after school."

During the initial sessions in their makerspace program in Fall 2014, mentors led the youth in conversations and activities meant to support youth in identifying safety issues they were concerned about in their community. The girls did not settle on a problem space right away. They, along with many of the youth at the maker club, felt stuck on what problems they might address. As Kairee said, "I don't have any science ideas!" As part of a structured activity intended to engage the youth in community ethnography, the girls designed a 7-item survey to find out what safety concerns mattered to the members of their community. They asked questions such as "What are your most important safety concerns?" and "Where do you think safety is most important?" The survey was easy for the girls to conduct. M4C is housed in the clubroom at the BGC, and so they simply walked around the club interviewing their peers and staff. They also stood by the Club's front door to catch parents as they picked up their children.

The girls and their peers in the club collected 62 survey responses on mobile tablet computers. From graphs they made of their data, they noticed that "commuting" was the main safety concern, identified by 74% of the respondents. When they looked closely at the comments written by the respondents, they broke down commuting into transportation, walking, and child safety in the dark. They noticed that kids were more concerned about safety as it relates to being

*personally harmed by people*, while grown ups more often identified *getting hurt in cars*. They were concerned with the responses on walking in the dark, such as the following ones they highlighted: "Walking home from the club at night," "walking in the dark where there are no street lights," and "guns, rape, and violence." Later in an artifact interview with Kairee and Mirabel, they connected this last survey response to a local news story they had seen earlier that year about a young Black girl who had been sexually assaulted in their area. As African American girls themselves, both recalled conversations they had with each other about their concern for their own safety and the safety of their friends and siblings.

The two girls brainstormed different ideas in response to these safety concerns including, "personal lights for walking in the dark," "jacket that yells for help if you are in trouble," and "a panic phone to call for help." Their favorite idea was the "jacket that yells for help." We asked the girls to create a sketch up of their idea, the goal of which was to support them in thinking concretely about their design and to solicit input from others before they began design work.

They used paper and pencil to sketch their jacket, pointing out both technical and social specifications (see Figure 1). The sketch up was simple: The jacket would yell "help" when the user "stomped her foot." It would be "powered by solar energy," so that the owner would not have to worry about changing batteries. It would have buttons down the front and a colorful cotton material so that it would be "affordable and attractive." They also generated a list of next steps for getting started: "1) Find out if there is a jacket that yells for help by searching the internet, 2) get a jacket that has the colors, materials, buttons we want, 3) Find a way to make an alarm that yells help, 4) get solar panels, and 5) figure out how to put it together."

The girls shared their sketch up with their peer makers in the club, during a whole group conversation orchestrated by the mentors to serve as a formative feedback cycle on initial design

ideas. One of their peers, Jennifer (opening vignette) said in response, “It's a rape-alarm jacket!” While this peer call out was met with laughter from Kairee and Mirabel initially and comments to the effect of “I can’t believe she just said that!”, the two girls took the idea seriously, for it tied closely to a personal sticking point for the girls in their everyday lives. They had expressed concern during the previous weeks about personal safety in their walking commutes. Mini dance and song sessions often turned into stories from school about girl-boy relationships, and the emotional, psychological and physical challenges they can present.

An anti-rape jacket positioned the girls with agency and voice over an act meant to silence and dominate. This focus provided direction to the girls in how they might move from a sketched out idea to a workable prototype. The new idea drove the girls to conduct research that neither they, nor their mentors, had thought of before. Instead of searching for a jacket that yells for help on the internet as their first step, they began by searching rape statistics of African American girls. They wanted to know who was most at risk for rape. They felt that this data was necessary because it might impact the color, size, and style of the jacket. When they presented their prototype for feedback to members of their community during a more formal feedback cycle day involving community members, local engineers and scientists, and educators, they framed the problem space personally: That girls *their* age “made up 44% of the rapes” in their community. This data was upsetting to them. As they reiterated after completing their project, “Rape is a big issue. It is bigger than most people think because only one-third is reported. And it’s really unfair for girls.” Later in an interview, they explained that as they learned about the risks of sexual assault for girls under the age of 18, they were additionally concerned about the effects of their race. According to the online sources they found, young girls of color, girls who looked like them, were at an even higher risk of sexual assault, compared to girls who are white.

In preparation for this formal feedback cycle, the girls listed their design's technical specifications in ways that captured these concerns: 1) The alarm would be loud enough "to hear it from at least 1 block away." 2) It would make a sound that would "Get people's attention" not scare them from helping. 3) The alarm would be set off by pressing "a secret button" because stomping might get too much attention from the potential attacker. 4) The coat would have "a solar panel that you can sew into the shoulder using conducting thread" so that it "looks nice," and "wires that will hide in the jacket that won't overheat or get you shocked". However, because the girls worried most rapes happened in the dark, they needed a way to store the solar energy. As the girls wrote in a blog post, "The jacket is powered by solar energy. We have a flexible solar panel . . .We picked the back so that the sunshine can directly hit it. We also have rechargeable batteries to store the energy we get from the sun through the solar panel."

The subsequent design process was not easy for the girls, but the focus on the jacket provided an enduring in-road that kept them engaged. We highlight one additional episode, however, that captures some of the challenges and possibilities for how nontraditional forms of engagement supported the girls in persisting when they ran into design trouble.

For several sessions in late January (after about 4 months of work on their project), Mirabel and Kairee had been working with different alarms, wires, switches, and batteries in order to figure out how to design the circuitry for their jacket. This play was brought on by the mentors having brought in specific activities intended to support the youth makers in figuring out how circuits work so that they could apply these ideas to their designs. The girls had been particularly disengaged with this activity, and were far behind their peers in figuring out both the power requirements of their possible alarm system choices and how to put the various alarms into a workable circuit. One mentor described them in her teacher field notes as having "an

intense amount of passion… but also an intense amount of distraction potential in terms of everyday realities and practicalities. When they feel that it's too 'school-ish,' they will check out. They are freely willing and able to check out whenever they feel that it is necessary… or deserved. Today… they were very upset... They are pushing boundaries." Kairee and Mirabel seemed particularly frustrated because the alarm systems were not easily configured into a circuit the way they had envisioned, into their jacket.

One of the mentors asked them to sketch out how they might attach their alarm to their design, but the girls resisted the task. Instead they talked and joked loudly with two other girls (their best friends) who were sitting at the same work table. One of these friends snatched up a collection of different types of alarms, and began playing with them, causing all four girls to get even more rowdy. The two mentors closest to the girls kept asking the four to quiet down, and to stop setting off the alarms. They resisted and continued to play – *loudly*. But, then we noticed, right in the midst of our own frustrations, that the blaring alarm had the two girls, plus their two friends, momentarily, dancing in synchrony to the alarm. All of their eyes and hands were on the alarms, and there were expressions of joy. When we later asked them about this moment, one of the girls described it as a moment of success. They found the alarm they liked. It was loud and shrill and perfect. It got *everyone's* attention quickly. Their satisfaction – emotional and technical – was very real and important to their project. As mentors, we realized our mistake in trying to shush them; we needed to learn in that moment from the girls how they needed to proceed on this design. In the end, they used this alarm, and they figured a way to disassemble it so that the alarm and its trigger button where located in different parts of the jacket.

The youth reported having many of their peers say that they planned to buy one of their anti-rape jackets, once the design was complete. That their project was the *loudest* due to the

alarm testing gave them an ownership over the space that they did not have before, as relative outsiders to making. After 5 months of design work, the girls achieved a working prototype, with a solar powered alarm that could be heard from at least one block away (see Figure 2).

**Why bother with paper circuits? Nadia & Shauna's different approaches to making with paper circuits**. Similarly to the MI youth, the M4C youth in NC also engaged in community ethnography to ascertain what safety concerns resonated most with their community. The youth first brainstormed their own safety concerns and came up with ideas on what to innovate. The youth then canvassed peers and adult mentors at the BGC with a short interview protocol to see which of the innovations would be most compelling and relevant to the community's needs. They narrowed down their projects to include an alarm-protected school locker, an automated baby-gate for handicapped caregivers of toddlers, and safety-glasses with a remote sensor that a parent can use to track their child who wears the glasses while playing outside. All of the innovations required understanding electronics and circuits.

Since all the youth participating in the NC M4C had no prior experience with the process of making and did not appear to have a robust level of content understanding of circuits, we decided to engage the youth with creating paper circuits, a "low barrier, high ceiling" maker activity that requires one to actively engage in making, and figure out some principles of electronics. While as mentors we found many sources on how one should approach paper circuits, we are cognizant of the fact that these "instructables" themselves promote a particular way of approaching making, that is likely rooted in the dominant culture. We reminded ourselves to deviate from the script, not to require youth to follow specific guidelines, and to embrace any tangential offshoots to which youth may direct themselves during the paper circuits activity.

As an introduction to the activity, we engaged the youth in a short science talk regarding the components of an electrical circuit, using a diagram we drew, in response to youth feedback that all of them are not entirely certain about what makes a circuit. The purpose of the science talk was to have youth discuss what they did know about circuits, tell stories of their experiences with electricity and circuits if they had any and ask questions on what a circuit is, including the parts that make up a circuit (battery, conductive material, switch, output--e.g. LED light). The youth accessed the conversation, and the claimed space, in different ways. Consider the actions of Shauna, a 6th grader, and Nadia, a 5th grader, as described below:

> Author: We've talked about what a circuit is, and what it can do in powering certain outputs. Do we agree how a circuit works? What questions do you have?
>
> Shauna: Wait! I don't understand how the battery releases electrons. What happens inside the battery?
>
> Author explains how the electrochemical reaction works in a battery.
>
> Shauna: But what happens to make the battery rechargeable? How does that work? How do you get the electrons to go back into the battery?

Shauna sat on the carpet in front of the diagram propped against a desk and puzzled over the processes of energy conversion in a primary cell battery and a secondary cell (rechargeable) battery. She did not want to begin exploring paper circuits until she came to a level of understanding of the science content that she could be satisfied with.

Nadia, on the other hand, could not wait to make her paper circuit. We had brought examples of paper circuits that we had made before the session to show the youth. Nadia had spied our examples and was visibly excited. She immediately clung to Author's arm and asked in an animated fashion, "Are we gonna do THAT today?" Throughout the science talk, Nadia sat as near to Author as she could and whispered furiously during every pause between people

speaking, “Can we do it now? Can we do it now? I want to do it now!” During an extended pause, she whispered excitedly, “I want to do it now cuz my mom’s birthday is coming and I want to make her a card with lights!” Nadia could not wait to get her hands on the materials (flat round lithium batteries, different colored LED lights, copper tape, stockcard) to create a circuit.

The access points for Shauna and Nadia were very different. Shauna took a school-based approach, seeking to make sense of the science content before working on the paper circuit. She referred constantly to the adult examples and was meticulous in making sure the connections, as the circuits turned in right angles, were “clean”. Shauna was excited about how “cool” the LED lights were when they lit up as part of a picture with the circuit hidden in the back, and she gave equal attention to making sure the negative and positive “legs” of the LED light connected to the correct portions of the copper tape. Shauna was the first in the group to create a circuit that lit up an LED. She then went on to help some of her peers create “clean circuit corners.” Nadia’s first priority, however, was to make the LED lights light up, whichever way she could. She was driven by her desire to create a birthday card for her mother, and started not by drafting her circuit on the back of the paper (as adult mentors suggested), but by drawing a rainbow with clouds on each end where she wanted the LED lights to be (see Figure 3).

Nadia spent a significant amount of time decorating her rainbow, and less time on constructing the paper circuit. When she had difficulty laying a neat copper tape circuit and her LED lights failed to light up, she decided to forego the copper tape and ensure success by simply connecting the metal wire “legs” of the LED light directly onto the lithium battery. She ended up with 2 lithium batteries, each with its accompanying LED light illuminating each end of the rainbow. Nadia solved her design problem with her truncated version of a paper circuit.

One could conclude that Nadia "missed the point" of paper circuits completely because she failed to "lay a closed path" via the copper tape. One could also conclude that Shauna's engagement was much more "rigorous" because her ordered steps of focusing on content knowledge before engaging in practice more closely resemble traditional academic protocol. But if we are focusing on creating an equitable makerspace in terms of access and process, Nadia's approach and priorities should be equally as acceptable as Shauna's. Nadia's success with her first rainbow card circuit, which she tweaked by limiting the circuit path, gave her satisfaction and met her goal in the moment –creating a birthday card for Mom that lights up. She returned the next session with a more complicated card design that required the laying of a copper tape path, which she was then willing to take time to explore and figure out. Nadia's making process differed from Shauna's. She prioritized the end product –a rainbow birthday card for Mom with two colored lights—before following the examples shown in laying a copper tape circuit. The satisfaction Nadia gained from her success was integral to her subsequent persistence with paper circuits. Honoring Nadia's approach was important to us because how she chose to take up paper circuits was contrary to what is sanctioned in school science protocols.

We also want to point out the intensive mentoring and adult attention given to both youth throughout their paper circuits making process. We are convinced that an intense level of adult attention is necessary in order to productively engage with individual youth in ways that honor how they bring their particular interests and experiences to bear on the making enterprise.

**Fall and Malcolm: Changing notions of expertise**. Fall and Malcolm have been long time (4+ years) participants in various STEM programs we have hosted at the BGC in MI. Both still hang out at the BGC– Fall as a high schooler and wanting a safe place to socialize with friends, and Malcolm, a recent high school graduate, and community club staff. While they have

not been official participants in the new makerspace program, we found it interesting that these two teens periodically join in M4C activities, offering up their expertise as it fits in-the-moment.

Fall joined in M4C activities one day a week during the 2014-2015 school year. As youth worked on their projects, she would borrow one of the mentor's smart phones to take pictures so that she could "live blog" what groups were working on. She posted her favorite pictures on-line with some written text. It is noteworthy that Fall struggles in school, with an IEP, and self reported D's on her report card. Writing does not come easily to her, but she loves "reporting to the "world" about her peers' makerspace activities. As she wrote in a blog post recently:

> At the end of the year event, I saw everyone's final work on their experiments that they have been working on for the past couple of months. These inventions look amazing and I loved seeing everyone is having fun and wanting to learn more about science and green energy. Also it was nice getting to help out and getting to come back to help this year. This is a picture of me and Author at the end of the event. We really had fun seeing everyone show off their cool inventions. I think that I'm gonna come back next year and help again. ~Fall, blogger extraordinaire

She often provides her own commentary on why the projects are important or of interest to her community, as this blog from mid-spring entry suggests:

> J and her partners are working on a house alarm that also has dance lights if you want them. The house alarm system takes pictures of intruders and also plays music when they walk into the house. I think this is a good idea to invent because people who have an alarm system probably haven't thought of that idea. Music might trick them or scare them and also you can get their picture, too. It depends what kind of music you pick. ~Fall, blogger extraordinaire

In "reporting to the world," Fall calls attention to the long-term investment youth made in their projects, alongside their importance for the community. She is proud to be a helper, and with an emerging ethnographer's skill, carefully describes the youth's works to those willing to read.

Fall has also taken on other leadership roles as needs have arisen. For example, on the day that the various M4C youth groups were presenting their initial design prototypes and plans for feedback from a range of outside experts (a science teacher, an engineer, a physicist and a community member), Fall asked if she could sit with the expert panel so that she could also provide feedback from the perspective of a "teen." She wrote down her ideas, nodded and applauded when she loved ideas, and spoke to both social and technical aspects of the designs. She has also taken it upon herself to work with another teen to design and build a "little free library" for their makerspace so that kids – both inside and outside the club – can get inspired by STEM books. She has also leveraged her making blogging experience to apply for a scholarship to study engineering at a residential university program seven hours from home. Fall, who has historically struggled in traditional learning spaces and with traditional learning tasks, has re-created herself in this making space as a reader, writer, and engineer.

Malcolm's participation is different than Fall's. Due to his staff responsibilities, he only stops by every once and again. However, his visits are always punctuated by a playfulness with the other youth, who look up to Malcolm as a trusted friend and leader. He quickly sizes up the situation and tries to help whoever is struggling, even if he does not have what one might expect to be the technical expertise needed to help in some instances. For example, one group of girls were working with a mentor to program an arduino board that could allow them to take pictures from their computer remotely, but none of us could figure it out. Their project involved a new home alarm system that would capture identifications of the home invaders. The girls started to bicker with each other. It was at that moment that Malcolm had entered the room to say hi and had noticed the girls struggling to get along. He said "what's up" and asked whether they wanted another pair of "hands" on the problem. He sat down between the girls, and began taking silly

pictures with them using the computer keyboard. After re-focusing the girls with the picture taking, he turned his attention to the arduino project. While Malcolm was new to arduino coding, he had expertise on the computer from his work over several years in the after-school club. He worked side by side with them attempting to co-learn arduino programming with them. As one of the girls said, Malcolm made it okay to be frustrated and we "didn't have to be mad."

In each of these instances, Malcolm and Fall authored new ways of being in the makerspace that sit far outside the prototypical maker. Fall is the blogger, critic, and helper. Malcolm is the drop-in problem solver, who smooths over friendship tiffs and adds insights and flare to projects. While makerspaces are meant to democratize, for some youth who enter these spaces as outsiders to STEM and to making, they may perceive both real and imagined hierarchies because of who they are, what they can do, and what they care about. Fall and Malcolms' roles disassemble the hierarchy in ways that open up new spaces of becoming and participating by others.

**Kalvin & Locks: Investigating electronics with littleBits**. As a "just in time" STEM content building activity to further explore electronics, the M4C youth at NC played with littleBits – magnetic electronic components with various controls and outputs now popular in makerspaces (littleBits.cc). The attraction of littleBits is the ability to quickly snap together color-coded pieces (e.g. blue for power, pink for input options, etc.) to test different circuit outputs (e.g. servos, buzzer, motor) and how to control the circuits with various inputs (e.g. dimmer, timer). Forgoing the guidebook that came with the littleBits kit on how to create a particular circuit to do a particular task (e.g. make your shoes light up) we asked the youth to grab some bits and "figure out" what individual bits do. We did not tell the youth which bits they could pick. Upon collecting some bits, they started to compete with one another to see who could

string the longest circuit that got as many outputs working at the same time. This seemingly random and "unrigorous" way of playing satisfied the youths' curiosity, playfulness and let them figure out, at once, the different outputs. We did not anticipate such a move from the youth.

We then posed a design challenge to the youth at the next M4C session. Using littleBits and a "junk pile" of potentially useful objects, the youth were challenged to either: 1) Build something that you can use on a camping trip, or 2) Build something that will help you move 2 small items across the table.

We wanted the youth to pair up as partners. After most youth paired up, Kalvin and Locks were left and they refused to work together. A 7th grader, Kalvin started attending the BGC 2 years ago. He self-reported, and the club staff confirmed, that he was an angry, defiant young man who "had problems with authority" when he first arrived. Since joining M4C in the preceding Fall, Kalvin demonstrated commitment to M4C with his steady attendance. Even though he still tended to clown around, he was able to focus on the task at hand, even when he was working solo. Locks, a 5th grader who comes across as more reticent and shy than the other youth at M4C, was also a less regular participant in the program due to family-related transportation issues. As such, Locks did not have firm friends to immediately partner with at M4C sessions. After refusing to work "officially" as a team, Kalvin and Locks agreed to work physically next to each other so they can help one another, if necessary. Locks decided to tackle the first challenge building a camping tool; Kalvin chose the second challenge.

As the rest of the youth crowded around the junk pile and hot glue guns to select materials to use for their designs, Kalvin quickly picked two golf balls and a length of twine from the junk pile before returning to his seat. He then constructed a littleBit circuit with a button switch connected to three different outputs –an LED light panel, motor and servo. He

wanted to wind a length of wire from the junk pile onto the motor so that when the circuit is closed, the motor would wind the wire upwards from the floor, pulling a golf ball.

Kalvin decided that the LED panel, although interesting, did not do anything towards moving the golf balls and so he removed that output. He decided to use the servo to push the golf ball along the window sill so that it would roll instead. After rummaging through the junk pile, he found an old floppy disc on which to rest the golf ball and somehow attach the servo to the disc platform. He had to fiddle for a while to get everything balanced, and even then it was precarious. The golfball would not stay on the floppy disc.

Kalvin broke apart the floppy disc to reveal a small aperture that he could slide the servo blades through, both stabilizing the platform and increasing the amount of control he had to set the servo into motion pushing the golf ball. The servo also gave the floppy disc an incline that he could use to control the direction of movement of the ball. Kalvin was then able to move the two golf balls across the table with a minimal amount of junk material –just a floppy disc that he took apart, to control the movement of the ball. It was minimalistic and effective (see Figure 4).

While Kalvin was focused on his own work, he also responded to Locks when she had questions about her creation. She wanted to build a hiking headband that had a "rear view mirror" that stuck out from one side so hikers could see what was behind them, "in case someone was following you, or there were bears or other animals that could be dangerous". She wanted her mirror to have lights that could be lit up to "scare away any attackers." Locks was not present during the last M4C session in which the youth initially explored littleBits. She keenly observed, from her own seated position, without leaning over at all towards Kalvin, how Kalvin initially strung a long circuit with an LED light output, a motor output and a servo. She wondered aloud, seemingly to no one in particular, which output would be the best to control her rear-view mirror,

and Kalvin responded that the servo could move the mirror's position so that she could "see more" of the background. As they conversed, they each sat at their side of the table and kept their conversation low-key and quiet. Unless one was sitting close to them, it would be difficult to tell that they were indeed, conversing. Locks carefully watched what Kalvin was doing, and visibly showed silent delight, when he got his design to work.

While we wanted to encourage collaboration, we also did not want the youth to feel as if they were forced to work with others when they would rather not. While the rest of the youth paired up quickly along existing social ties, Kalvin and Locks, for reasons particular to them, did not want to be openly seen to partner together. Yet they found a way to unobtrusively support each other, with their own way of collaboration. Locks was able to observe and borrow from Kalvin's ideas (using servo and LED lights) and Kalvin acted as the expert with more littleBits knowledge who could give Locks useful suggestions, in ways that did not compel the youth to enact a kind of social performance (as "partners working together") that would make them uncomfortable. In addition to sharing his expertise with a peer, Kalvin was successful during the session with what he created to meet the design challenge doing solo work, which he preferred.

**Sustaining youth engagement in makerspaces**.

The youth with whom we work *all* attend schools where STEM education is limited (e.g., limited hours of instruction in the $6^{th}$-$8^{th}$ grades compared to mathematics and literacy, or significantly fewer course options at the 9-12 level, compared to area schools). We posit that sustained, mutual engagement in makerspaces opens up more equitable opportunities to learn and become in STEM for them. By referring to both "sustained" and "mutual," we mean to convey a sense of 'working togetherness' that goes beyond collaborative in that the agendas and agency brought to the table by different youth can be simultaneously addressed, without one

ceding power to the other in the usual sense of consensus building "give and take." We also mean to convey a sense of shared sustainability in youths' engagement. When youth engage mutually over time, they could be working together to innovate one product (e.g. Kairee and Mirabel) or working alongside on their own products with significant peer support (e.g. Locks and Kalvin). Short-term trial and error design is tied to what one already knows as they enter the makerspace. Sustained, mutual engagement with others (and which contributes to others) could yield new and different opportunities to learn and become in STEM. Opportunities to learn and re-mix STEM knowledge and practices with what one brings into the makerspace can make possible more robust designs and more expansive possibilities for becoming in making. Sustained, mutual engagement also promotes greater opportunities to build social networks in support of STEM learning, increasing youths' mobilities among a range of learning arrangements, opening up new forms of learning and becoming (Rahm, 2014).

We suggest that by deliberately designing for mutual, sustained forms of engagement, youth will have access to a more expansive space to learn and become in making. We propose three ways in which sustained mutual engagement is supported, as evidenced by our study.

*Learning within the tension: Purposeful playfulness and just-in-time content/practice learning.* Jennifer and Emily's heat up jacket became increasing more sophisticated (e.g., large heating element → insulation → smaller heating elements→ fewer batteries → solar panels) as they slowly revised different parts of their design. Their efforts were punctuated by opportunities to play around with new tools and ideas and how they can merge together (e.g., taking apart an iron, debating fashion sense, etc.), to solicit community insider information (e.g., what designs are attractive to young people, how much the weight of the jacket matters), and to dig deeper into technically challenging calculations and design concerns (e.g., incorporating small solar panels

into the jacket, figuring out how to store the energy in batteries). They also integrated important funds of knowledge (e.g., the fireplace Jennifer's father built providing insulation design ideas, knowledge of why kids get bullied, where to find fashion ideas on pinterest). They needed the time, space, and support, to flexibly move between and merge the technical challenges with everything else they brought to the table.

If makerspaces are to help ameliorate inequality in STEM, then opportunities need to exist for youth to develop robust knowledge and practice within the domain. At the same time, we recognize that one of the very assets of a makerspace is in how it supports young people in making in ways that are creative, playful, and personally relevant (e.g., Vossoughi et al, 2013). Sustained and mutual engagement allows for both playfulness and deepening understanding to co-exist, and for the emergent tensions to be *productive spaces of learning* – for example, playing with the rape alarm opened up new ideas for tackling the challenge of how to design the rape alarm jacket.

We have found that designing and making available "just-in-time learning resources" to support deepening understandings of STEM knowledge and practices is central to this equity concern. Such a making/learning space supports a non-linear making approach, as youth organically move between the processes of making to content learning (anchored in short, authentic, just-in-time inquiry-based activities) that support the progress of the making process, very much an "on the job training" kind of approach, where the "job" is making and the "training" is relevant STEM content that complements and deepens making expertise. We have seen how some of such "just-in-time" learning modules unfolded with the littleBits sessions as described in the Kalvin and Locks story, where youth playfully explored with littleBits at a time

when they needed to develop more understanding in circuits, and just enough for them to be more informed about the technical dimensions of their desired innovation.

We have also found that sustained engagement provides more and varied opportunities to play around with the tools, resources, and ideas available in the makerspace, in ways that open up mastery of these tools in both traditional and nontraditional ways – and for traditional and nontraditional purposes. For example, we witnessed how youth coopted making tools for the co-production of counter-narratives as can be seen in the rape alarm jacket. Other examples, while more mundane, are equally as important in helping to secure more equitable modes of participation for youth. Making art with glue guns in the makerspace before applying them to on-going projects is one of many examples we have of youth using what they know and are comfortable doing (art), towards expanding their tool-related repertoires of practice for doing less familiar and less comfortable work (e.g. making a heated jacket). We see as complementary to this playful way of learning, the explicit leveraging of nontraditional tools and the juxtapositioning of nontraditional tools and ideas (e.g. Nadia's approach to paper circuits, youth wanting to make an automated baby gate for adult, handicapped caregivers of toddlers). This is important because such playing around helps to shift authority structures, de-territorializing ownership and forms of legitimate participation, such as how tools get used and for what purposes. Youth, thus, need the time to figure out how to use these tools in new and different ways. Learning is always taking place in relation to one's sociopolitical history and context (Bright, Manchester, Allendyke, 2013).

Our experience with youth working hard to learn and improve their expertise with particular tools sits in contrast to what others have espoused about the benefits in the "free choice" nature of makerspace engagement: that "there is little talk of weakness, or even areas of

improvement: there is no sense that everyone need to code, or knit, or use a 3D printer" (Martin, 2015, p. 35). We argue that engaging the youth in productive struggles is a core component of an equity-oriented youth makerspace. Without sustained opportunities to toggle between playful exploration and just-in-time learning to build these connections, youth may leave a makerspace feeling further marginalized. It takes time to *see* and *feel* the generative possibilities in learning how to use making tools in traditional ways; it takes even more time to build the confidence to coopt tools for new purposes, and to author a history of practice which supports it.

The tension pertaining to this approach, we have found, resides chiefly in negotiating a balance between supporting playfulness before intervening with a "just in time" learning module that could be content-focused (e.g. investigating electricity and circuitry), or maker-tool focused (e.g. learning how to use a sewing machine). Such a balance point differs among youth, some of whom prefer to persist a little longer before requiring help, while others may be more prone to rapid exasperation. As program planners and facilitators, we have to continually remind ourselves to guard against a "one time fits all" balance point for the youth, which admittedly, makes for challenging planning. We are cognizant that such negotiations also directly affect how we support the youth in developing persistence and grit, qualities that are crucial learning outcomes for engaging in the Making enterprise.

*Broadening the range of maker identities for minoritized youth.* As people populate makerspaces, and leave imprints through the enactment of novel practices and the production of artifacts made public there, a narrative around what it means to make (identity), what one can make (the making process), and who is allowed to make (maker community) all take form. If one has never used a power tool before, how do they learn to become an expert in nontraditional uses of the tool? Who models these new practices, when and for whom? That the vast majority of

maker magazines and how-to guide books are written by white men or at least reflect a white middle class way of approaching things further solidifies this problem space. We suggest that youth be given a wide berth to author maker identities that encourage mobilities of salient identities, resources and practices.

The youth benefit from an expansive view of what it means to become a "youth maker". Some of our youth at M4C come to the makerspace with no explicit interests in making, at least in its traditional forms. However, many end up staying because the enterprise of making is woven into other salient areas of their young lives – afterschool hangout space, spending time with friends, access to the internet and computers, and snacks. While it is important to us that the youth eventually engage in making, we hold no explicit making expectations of them when they first enter the space. We also do not frame the "youth maker" identity as one that is grounded in hobbyist "interests" (Martin, 2015). In co-opting the processes of making from ones that are benignly recreational to purposeful actions informed by marginalization, violence prevention and courageous agency, the youth makers inscribe a different kind of maker identities; identities that are girded with gumption, risk and survival.

Youth also author different, equally legitimate youth maker identities. Fall's identity as a blogger extraordinaire required her to unpack and understand the youths' creations and their process so that she could blog about their progress to the non-making world. Malcolm inserted himself as a "just in time" problem-solver to aid his peers in figuring out arduino programming, even as he had not been to the makerspace recently due to grave health issues. These newly authored roles push against the usual hierarchy in any community of practice that would also exist in a makerspace, where recognized experts are the makers who have most visibly wielded tools skillfully and created admirable artifacts.

Additionally, as the physical makerspaces (i.e. the four walls in the makerspace rooms) take on a "BGC Youth Makerspace" identity, we want to consider how the space will be historicized. How actors (i.e. youth makers) are positioned (and by whom) across time and place, the funds of knowledge actors bring to the process all shape the meanings inscribed in these spaces over time. What artifacts of practice endure and become reified in these spaces? What kinds of artifacts, along a spectrum of "completion" should be recognized and held up as exemplars? For example, Fall's blogging historicizes youth making practices, and extends them into the virtual world. Her blogs incorporate rich ethnographic descriptions of works-in-progress, often showcasing the particular challenges that youth face in the moment.

*Unpacking "community" in a community-based makerspace for youth from minoritized communities.* In seeking community-based partnerships with BGCs, we recognize the significance in housing makerspaces in physical and figurative spaces where the youth "rule." We have learned from our long-term partnerships that there are specific affordances that support productive hybrid STEM identity work for under-represented youth, when such programs are housed in these community spaces (Authors, 2010). These spaces are shaped by youth culture – their ideas, ways of relating, interests and desires (Ito, et. al., 2013). How youth move in these spaces significantly shapes how they engage in makerspace activities.

The affordances of being at a BGC invites participation in a variety of novel ways – stepping out of the club room into the lobby allowed Mirabel and Kairee to get immediate feedback on their rape-alarm jacket. Likewise, conducting sound tests in the parking lot outside the club solicited voluntary input from community members in the immediate area. We see this movement as "a process of (continual) deterritorialization" of the making space – who can make and who cannot, whose knowledge matters and whose does not (Fendler, 2013), and what things

can be talked about (e.g., rape). This movement helps break down settled notions of what it means to participate by making visible the boundaries of formal/informal and novice/expert and how these boundaries change over time and across scale (Leander et al., 2010). At the same time, it raises questions about how makerspace designers, teachers and youth give life to boundaries allowing them to shift in location, duration, and integrity. Understanding how binaries break down and how such breaking down leads to deterritorialization is of deep importance.

It is not our intention to paint a utopic picture of a community-based youth makerspace as an unproblematic answer to equity concerns. There are tensions that arise from youths' membership in these spaces that have jeopardized their participation. While the makerspace itself may be more inviting of young people's whole worlds, crossing the layered boundary from club lobby (snack space, social space, gaming space, etc.) into the makerspace is not always so straightforward. For example, youth who became "teens" in one of our settings were suddenly governed by a different set of "club rules" that curtailed their makerspace involvement, due to requirements of where "teens" could be at the club at any given time, and privileges (such as makerspace participation) were stripped from teens who were deemed to be misbehaving at the club. However, in general, we assert that *the affordances of a youth community space,* such as the BGC, outweigh the constraints imposed on the goals of creating and sustaining an equity-oriented youth makerspace program.

Differentiating between the types, and affordances of different community spaces is an important equity-related consideration. We conjecture that both the quality and opportunity for consequential interactions between youth and community members might look very different in a makerspace that is housed in a public library, versus a youth-centered community space like the BGC. With a library makerspace, it is often more difficult for youth to walk out of the

makerspace to interview public members on difficult topics, due to potential the lack of relationship with the other library visitors or the norms of a library space. At the community center, the youth have established relationships with the staff and a robust sense of their identities as "club kids" who *belong* in this space and who understand the cultural norms of this space. Across the complex web of spaces that makes up a community center, there are more likely to be *concrete traces of youth's lives and work there*, upon which youth may move into and out of the makerspace (Rahm, 2014). For example, many of the youth regularly go down to the BGC art room to find items to incorporate into their designs. They bring their computers and cameras into club offices, lobby and game room to incorporate staff and peers into their digital productions. They bring friends into the makerspace on occasion to play particular roles in their work, from dance choreography to help with sewing. These movements of ideas, materials, relationships, and histories all shape what has been possible for youth in the makerspace, from what they make to who they are as makers.

We have intentionally worked to connect youth into a broader, social network of experts who are largely grounded in the community (e.g. STEM experts, parents, community makers active in other local makerspaces, local business persons, undergraduate engineering students, science educators, etc.). Part of our task is seeking out local experts who can speak to various aspects of the youths' innovations and inviting them to serve as mentors/adult making partners of the youth and to commit to a somewhat long-term relationship with the youth as they progress in their making. One difficulty we face is seeking out experts with diverse backgrounds (e.g. African American, mixed race, female engineers, etc.) to whom youth may more readily relate (i.e., "someone from my community, who looks like me"). Given the under-representation of the

African American and Latino populations and minority women in STEM professional fields, this remains a challenge.

A tension that can arise relates to the expectations of experts trained in formal STEM fields. We are intentional in creating an inclusive and expansive youth maker culture. As youths' making processes are not linear, youth may not have a traditional storyline to formally "present" their innovations when in conversation with experts. Further, we are concerned about the tensions that may arise with the very positioning of community experts to whom youth could pose their questions about their making. How do we, and the youth, strike a balance between how much of experts' suggestions to take, and how much to encourage youth to push back and "go their own way," a hallmark of the maker and hacker culture? Encouraging youth to press on with their own ideas also honors our desire to have youth themselves determine and inscribe what can be made, what constitutes the process of making, and whose ideas count. With expanding the youth making community to include experts, we increase both the degree and kind of expertise youth can have access to, but we also increase the number of stakeholders in youths' maker enterprise, which may have both positive and potential negative outcomes towards equity related goals in fostering youth from minoritized communities makerspaces.

**Expanding views of engagement: Critical, connected & collective.**

We just discussed how sustained engagement in makerspaces might be supported. We now turn to the forms of engagement that matter for the youth in our study, and how these forms embraced and responded to the complexity of ways in which youth framed the problems worth solving in maker spaces. Across the vignettes and in our broader data set, we saw how and when engagement was critical, connected and collective, and we saw how this specific type of engagement supported youth in learning and becoming in makerspaces in meaningful and

equitably-consequential ways. Recently Jurow and Shea (2015) have written about "consequential learning" – or learning that changes the community of practice in which is takes place. The term consequential surfaces the critically important role that disrupting normative practices play in learning. Similarly, we also draw upon the term consequential to foreground the importance of such disruptions. 'Equitably-consequential' underscores the importance of the ways in which learning and becoming are forward directed and transformative for both the self and the community, such that acts of learning and becoming contribute productively to, and help to legitimize, an ever expanding range of ideas, tools, resources and ways of being in the makerspace. Like Jurow and Shea we are interested in how the youths' practices interrupt flows of peoples, tools and resources and how these interruptions matter to both individuals (youth) and communities (makerspace community, STEM community).

However, building further on this ideal, we use the term equitably-consequential to call greater attention to the ways in which the *movement* of young people's makerspace practices over space and time transforms the boundaries of participation in making in-the-moment and over time. Such movement brings along with it a critical orientation to the complex, dynamic interaction between vertical and horizontal dimensions of learning. We suggest that such transformations support youth in persisting in a STEM trajectory beyond the initial communities in which they participate, (e.g., vertical movement), and that the artifacts innovated by youth within these makerspaces hold potential for ameliorating particular, personally felt and experienced inequities in their lives in-the-moment (e.g., horizontal movement).

*Critical engagement: Histories and geographies of youth's lives*. For many of the youth, engagement in the makerspace was about critically engaging the issues that framed their young lives, whether it was concern about sexual violence and bullies, or access to "cool," light up

cards that one's own family could not afford. These histories and geographies of learners shaped the ways in which the youth bounded the problems they sought to solve and the solutions they developed.

In stressing criticality, we push on the notion of "interest-powered," one of the hallmarks of connected learning. Interest powered learning are always connected to politics, and place a high value on activity that is tied to both civic and political outcomes (Ito, 2013, p. 60). This is certainly true of the youth's interests, with whom we work. However, when considering equitably-consequential making for youth, the kinds of experiences, relationships, and identities that youth are allowed to connect with their making, have often been trenchant, imbued with the perilous nature of their peripheral positioning in society. The risk-taking here for youth is quite high, and puts a different spin on what it means to work towards political outcomes. The youth are driven by critical interests grounded in unequal power-dynamics in their everyday lives and that fundamentally impact their survival. The anti-rape alarm jacket exposes the limits of interest-driven framing for young women. The need to outfit a jacket with a rape-alarm reflects the girls' experiences in the world, and how they have learned to navigate and respond to those experiences through the power dynamics that play out there, both in-the-moment, and historically. The youth's focus on the jacket was not as much interest-driven as it was an attempt to make in ways that positioned them with agency over the dangers in their lives. Similarly, Nadia's light up card was politically oriented (she desired a card for her mother that she could not buy, and she was willing to make to get that card) and impactful at different scales (attending to socioeconomic injustice and a desire to please her mother) (Bright et al, 2013). These critically-oriented forms of engagement in space-time open up new possible trajectories for making.

*Connected Engagement: With and for community members*: Each of the vignettes sheds light on the complex ways in which space-time, and the sociocultural histories therein, shape how youth connect their making with others, and to broader social issues. The current discourse on making has not accounted for these dimensions of how and why youth make in robust ways.

The youth drew upon their complex networks of support to develop and legitimize their making. In their design efforts, they gave prominent roles to older, respected members of their communities as well as to peers – seeking help from one of the mothers on how to use the sewing machine, surveying parents and club mentors, and getting advice from peers. While expert advice was critical too, it was not the only kind of advice that mattered. The learning opportunities afforded by interactions with their community were critical in how youth saw themselves as makers. In Jennifer's description of learning to sew from a mother and her subsequent reflection on her new learned skill: "Next time if something breaks, I know how to sew it back together." Similarly, when peers boldly renamed Kairee and Mirabel's "help jacket" as a "rape alarm jacket," the young women responded by doing more extensive research on rape.

Each of the youth in our study had different reasons for joining the makerspace and leveraged different points of entry to legitimize their actions there. We see this strongly in Fall and Malcolm's engagement, where they authored new roles for themselves to continue to engage in the makerspace in ways that make sense to their seniority in the program, connected to who they were outside of the makerspace (basketball coach, high-schooler). In Fall's case, these new roles opened up new possibilities for becoming beyond her makerspace that her school experiences had previously shut down. Nadia's primary impetus for engaging with paper circuits was connected to her identity as a daughter who wanted to make a light-up birthday card for her mother. Kairee and Mirabel joined at the urging of friends, and they enjoyed the social

interactions they participated in there as much as the making itself.

*Collective Engagement: Together for the public good:* To an extent, the youth's work deviates from the prototypical maker who is the "independent," "individualistic" "do-it-yourself" learner. Instead of being primarily motivated by their individual interests, the youth in our study, similar to the Turkish-Dutch youth in Haan et al.'s study (2014), define their engagement through collectively formed interests, and often interests that carried deep meanings on issues of race, power, oppression and danger. By collective forms of engagement we do not simply mean that youth work in groups, but rather they work on problems that are defined through interactions with others and leverage others' experiences and struggles – which they see themselves as a part of – towards making. The anti-rape alarm jacket and the heat-up jacket were inspired by collective community experiences and needs. Similarly, what the NC youth were making (e.g., motorized baby gate activated by sound for wheelchair-bound elderly caregivers), were informed by community contexts. These maker "projects" are distinctly different from the regular maker projects undertaken in prototypical makerspaces (e.g., projects discussed in *Make* magazine). This collective form of engagement also speaks to the knowledge communities in which youth parrticipate, and which cross into the makerspace: peer, family, on-line, STEM, and local communities.

The vignettes illustrate how youth expanded the boundaries of participation in making, reshaping how making might be refigured towards the public good. Community-based and participatory forms of research/activity were central to the youth's practice, as they iteratively moved and repurposed ideas, tools and practices across and within their community and makerspace. The youths' movement across communities allowed for new forms of making that foregrounded collective responsibility and the public good as essential to both the learning and

doing of makers.

The three forms of engagement described above are all undergirded by mobility – mobilities of identities, practices and resources that youth intentionally deployed in their makerspace engagement. Looking at Fall and Malcolm's authoring acts, we see that they leveraged other salient identities outside of the M4C context, including "older club youth," "tech-savvy youth," and "blogger," in combination with their "senior M4C youth maker" identities to engage in particular ways. With their newly inscribed maker identities, Fall and Malcolm exemplified how the movement of their resources resulted in individual and collective outcomes that traversed the physical, affective and virtual realms. Because of the mobilities of their resources, Malcolm and Fall need not "prove" legitimacy before engaging as "senior makers." To us, such legitimacy is equitably-consequential, as it insures continued participation and access to resources for Malcolm and Fall, who, due to personal circumstances, are not able to be consistent, weekly participants.

## Conclusions

> "To us, a makerspace is a place where you can invent, have fun, and make stuff to save the world… If you don't feel welcome then you won't want to go help people build stuff. If we help people learn about what this stuff is, they'll know. A makerspace is a community because it's all of us there." Ayana (11 years old) & Desiree (12 years old)

We have argued that makerspaces can support youth from minoritized communities in learning and becoming in STEM in meaningful and equitably-consequential ways when opportunities to make are sustained and mutual, and when forms of engagement supported are expansive towards critical, connected and collective ends. Framing youths' experiences through the lens of equitably-consequential learning and becoming challenges the field to consider how making – as a practice – is never separate from individual and social histories that unfold across space and time. Who can make and who cannot, whose knowledge matters and whose does not,

are all a part of making itself. Every day decisions in maker spaces inscribe not only what counts as authentic "making," but also youth identities as makers, participants, collaborators, community-members, young people *who legitimately belong in this makerspace*, signifiers that endure as historicizing elements shaping the emerging culture of the youth makerspace.

But such understandings are not without tensions for the work that youth do. Invoking nontraditional use of tools towards nontraditional ends can be fraught with complexities that youth and adults alike are ill-equipped to handle. How work-in-the-moment is legitimized requires those with power to see beyond their own worlds and into youth worlds. Clear tension arose between Kairee and Mirabel and the mentors as the girls played loudly with the alarms, only for the mentors to later see the power of those actions. Nadia and Shauna approached their paper circuits differently, and when juxtaposed could be positioned with Nadia as the inferior scientist or Shauna as the traditional scientist. Yet, both needed their own starting points, side by side, to author an agentic space in their maker community. How actors (i.e. youth makers) are positioned (and by whom) across time and place, and the funds of knowledge actors bring to the process, all shape the meanings inscribed in these spaces over time. How artifacts of practice endure and become reified in these spaces, intentionally and unintentionally, all open and foreclose opportunities for sustained engagement. A more focused agenda on equity-oriented maker spaces is needed – one that takes into account those whose histories still remain silent in making worlds and in STEM.

As makerspaces continue to appear across the nation, and with the continued gaps in opportunities to learn/participate in STEM among youth of color and in poverty, understanding and shaping this movement with an equity-oriented lens is important. If makerspaces are made accessible or attractive only to those who already have the social and cultural capital for success

in STEM, then gaps in access and opportunity may *increase* as a result of the maker movement. With increasing interest in introducing makerspaces in public settings, as well as in adopting them for formal school settings (e.g., Next Generation Science Standards), a lack of dialog on how to do so in equitable and consequential ways may disadvantage schools and communities for whom the risk, and potential reward, remain high.

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**Table 1: Participants**

| Year | Location | Total Participants | Demographics |
|---|---|---|---|
| 2013-2014 | Michigan | 14 youth | 2 White<br>10 African American<br>2 Biracial |
| 2014-2015 | Michigan | 21 youth | 2 White (both returning)<br>17 African American (8 returning)<br>2 Biracial (returning) |
| | North Carolina | 15 youth | 14 African American<br>1 Biracial |

**Table 2***: Data Forms and Generation Strategies*

| **Data Form** | **Specific Data Generation Strategy** | MI (2yr) | NC (1yr) |
|---|---|---|---|
| **Participant Observation** | • Makerspace sessions/activities: Video recordings of twice weekly sessions and field notes in two sites<br>• Makerspace Community Events | 72hrs/yr<br>8hrs | 70hrs<br>n/a |
| **Conversation Group** | • As a way to debrief what was happening in the club as well as to plan for future activities | 30 hrs/yr | 30hrs |
| **Artifact Think Aloud** | • Allowing youth opportunities to talk about their engineering design work in detail (mid and end of year) | 4 hrs/gp/yr | 3hrs |
| **Artifact Collection** | • Youth's sketch up notebook, 3D Google SketchUp model of design, worksheets, prototype, movie, etc | ongoing | |

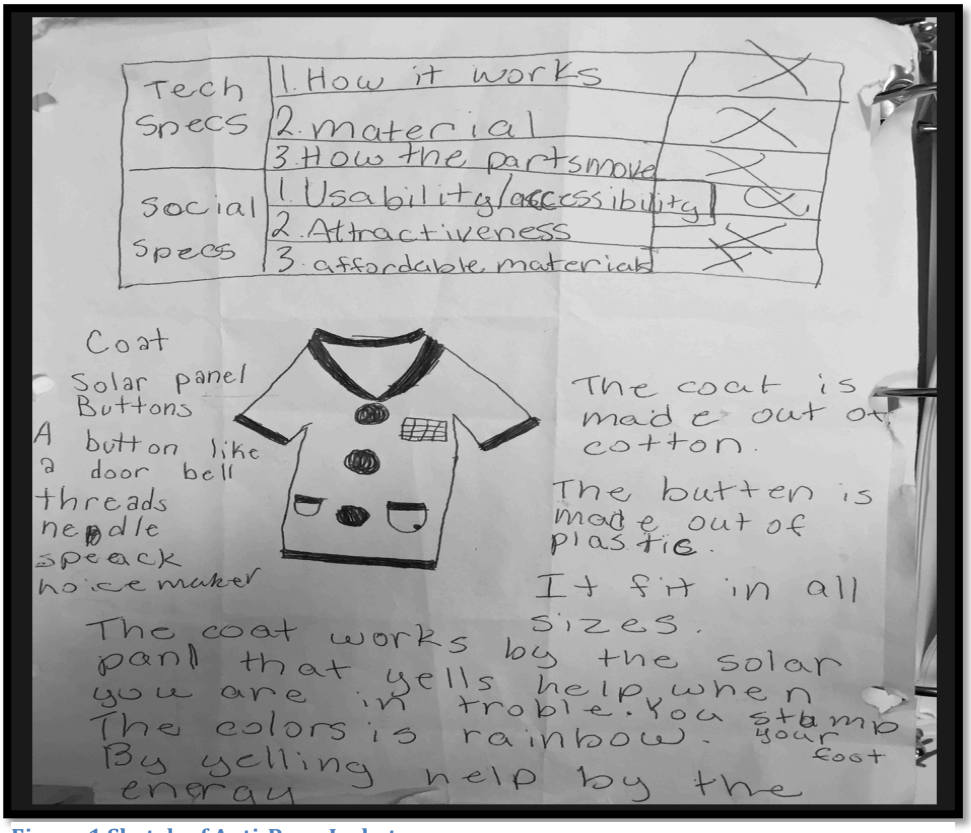


**Figure 1 Sketch of Anti-Rape Jacket**

**Figure 2 Girls testing voltage on anti-rape jacket**

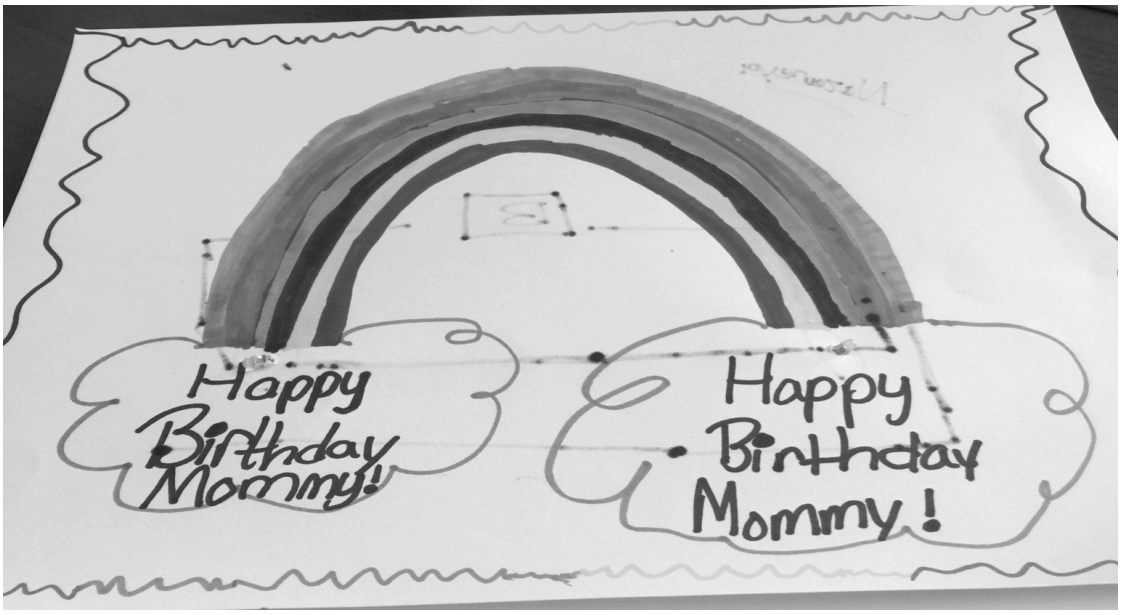


**Figure 3 Nadia's birthday card**

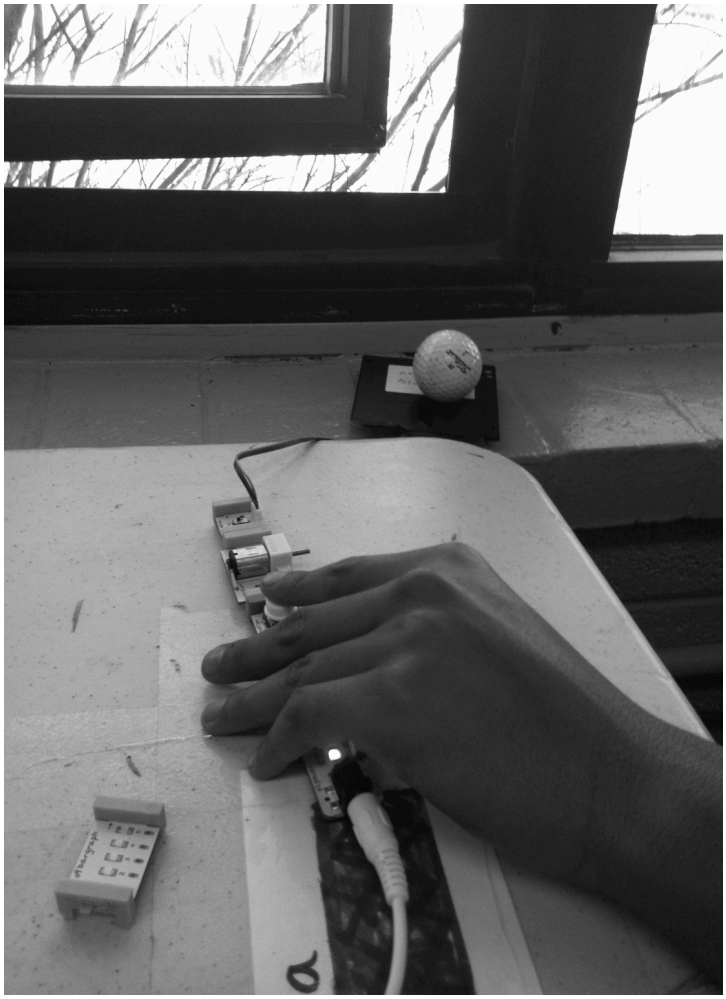

**Figure 4 Kalvin's challenge design**