MOBILITIES OF CRITICALITY: SPACE-MAKING, IDENTITY AND AGENCY IN YOUTH-CENTERED MAKERSPACES

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Abstract: In this manuscript, we examine the stories of youth makers from non-dominant communities, and argue that through their making practice they are involved not only in "artifact making" (the prototypically viewed outcome of makerspace work), but also in space-making within and across the worlds of STEM, makerspaces, and community. Such space-making fosters new forms of interaction among scales of activity, and supports the movement of ideas, resources, relationships and people in support of youths' emerging practices and how they might be recognized for them. As the youth engage in their making practice, they inscribe new meanings for what it means to make within the worlds they inhabit, refiguring participation in these worlds and the possibilities for becoming within them.
Keywords: Science, STEM, youth, making, identity, mobilities of learning

Interviewer: Samuel, why did you decide to make a light-up football?
Samuel: Well, when little kids are playing outside football and it's getting too dark, and they still keep playing and somebody might get hit in the head or something cause they can't see the ball really, so I 'm going to light up the football so you can see where it's going. (artifact interview, May 2014)

Samuel designed a prototype of a "light-up football" while working in an afterschool community-based makerspace over five months. His light-up football had LED tube lights that wrapped around the ball to provide maximum lighting with minimal added weight, friction, or power expenditures. Because the lighting was efficient, it kept hands from getting burnt. The lights were powered with batteries that could be recharged at a solar docking station, limiting environmental impact and saving money. The football, itself, was constructed from nerf material to minimize added weight and to reduce the possibility for injury if one were to be hit in the head. The batteries were stored in a pocket at the center of the ball, accessible by a small door, to keep it weighted properly and to minimize their potential contact with water or sweat.

The idea for a light-up football grew out of Samuel's desire to make something that would be helpful to people in his community. Samuel knew that lighting was a concern at night due to limited working streetlights in his neighborhood. He also felt that the game of football was a positive peer activity that helped young people his age make friends and stay out of trouble. He knew that most families could not afford an expensive toy, and that inefficient designs were costly to the environment as well.

Samuel worked on his design for five months seeking help from family, friends, and engineering and football experts alike. He was proud of his efforts. As he stated, "I was really

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proud 'cause it just made me feel good about myself so I could, like, kinda, acknowledge people what I could do. . . Like make what I did, a light-up football. I wanna make more stuff like that."

Samuel's making practice is not unique. Over the past several years we have been learning alongside youth makers in non-dominant communities who engage in making practices in community settings. Many of the youth have taken up complex and time-consuming projects to address concerns that they believe are important to their community. From designing light-up birthday cards for family members when store bought cards are too expensive and impersonal to prototyping rape alarm jackets for teenage girls, the youths' making practices reflect a desire to engage the multiple and intersecting spaces of community while also challenging what it means to become in STEM.

Returning for a moment to Samuel's light-up football, we see his work drawing upon, but also challenging, the discourses and practices of STEM, makerspaces, and community. Samuel draws upon and deepens his understanding of energy transformations and circuitry while also offering a vision for how STEM expertise can be rooted in, and contribute, to place. His light-up football subverts the power structures that shape life in his makerspace and his community, while also creating new possibilities and meanings for being and becoming, across and within the boundaries of these spaces. Samuel's identity as a maker grew as his practices took shape within the intersecting spaces of his engagement.

In this manuscript we examine the stories of youth makers from non-dominant communities, and argue that through their making practice they are involved not only in "artifact making" (the prototypically viewed outcome of makerspace work), but also in space-making within and across the worlds of STEM, makerspaces, and community. Such space-making fosters new forms of interaction among scales of activity, and supports the movement of ideas, resources, relationships and people in support of youths' emerging practices and how they might be recognized for them. As the youth engage in their making practice, they inscribe new meanings for what it means to make within the worlds they inhabit, refiguring participation in these worlds and their possibilities for becoming within them.

Our research questions are thus:

- What making practice do youth from non-dominant communities, ages 11-14, take up in afterschool community-based makerspaces?
- In what ways does their practice inscribe their spaces of making with possibilities for doing and becoming in STEM?

To answer these questions, we present two in-depth narratives of youth, ages 11 and 12, engaged in making practices within community-based makerspaces in non-dominant communities. These cases are meant to be illustrative examples of a broader set of 24 cases of sustained youth engagement on a making project that we have generated between 2013-2015. The first case involves Samuel's efforts to build the light-up football discussed earlier during the 6th grade. The second case involves Jennifer and Emily's efforts to prototype a heated, light-up sweatshirt in the 7th grade. While these narratives revolve directly around the youths' making of artifacts, we hope to show how their practices for doing so alter the landscapes in which they work, and their opportunities to do and become, within and across these spaces.

Conceptual Framework: Mobilities of Learning and Social Practice Theory

We are interested in questions of youth engagement and identity work in making as it relates to how the spaces and places of making get re-organized, disrupted, and/or expanded through youths' making practice. In particular, we are concerned with how youths' making practice takes shape across multiple scales of activity simultaneously, but also over time (e.g., locally among peers in small group work as well as in the real and imagined spaces of STEM) (Jurow & Shea, 2015). Thus, we draw from mobilities of learning studies and social practice theory to frame our concerns. We are particularly interested in those studies that take a critical orientation, weaving in issues of power.

Mobilities of Learning. A mobilities of learning framework is concerned with movement – of people, ideas, tools, resources, bodies and relationships – and how such movement shapes and reshapes the spaces and places of learning, and the social practices enacted and made possible therein (Leander, Phillips & Taylor, 2010). As individuals move through space and time, the sociohistorical narratives around them shift, shaping and reshaping how they inhabit or reinhabit space. For example, Kwan (2008) describes how Muslim American women's movements within public spaces have become restricted in the United States since 9/11 in response to rising political narratives, even when the actual physical access to these spaces remain unchanged. At the same time, she illustrates how such limitations in *physical* movement sit in juxtaposition with increasing access to new *digital* spaces. These arising digital spaces have become new homes for exposing oppressive narratives experienced by the women, as well as for opening up new opportunities for relationship building practices across cultural difference.

Examining the critical literacy practices of migrant youth in Southern California, Gutiérrez (2008) describes how youth use their "complete linguistic toolkits" – toolkits made up of linguistic practices of home and community, such as testimonio, in addition to the practices that are sanctioned in school settings – to navigate "the paradoxes of migration, immigration, and schooling" in the US. (p. 150). These hybrid practices helped students to link their past and present to an imagined future, and to re-organize everyday concepts acquired through social interaction in the joint activities of school-based literacies. She suggests that these "rich interactional matrices of practice" lead to a new dialectic between the "the world as it is and the world as it could be", opening up new spaces for learning and transformation (p. 160).

In both of these studies, who individuals are and who they can be across the temporal, physical, and virtual spaces of their lives, and the practices they take up within and across these spaces, emerge from and transform the meanings of space as constructed through social activity.

Mobilities of learning studies remind us that learning always takes place *somewhere,* both in "relation to history (time) and context (place/space)" (Bright, Manchester, Allendyke, 2013, p. 749). One thread of work that is particularly salient to our own work is that which examines space-making as a part of more expansive views of learning. We use the term space-making in ways similar to that of place-making (e.g., Cresswell, 1996; Massey, 2005; Lombard, 2014). An individual's opportunities to be and to become are shaped by place. At the same time, who one is also gives meaning to place: "Places do no have intrinsic meanings and essences . . . the meanings of place are created through practice" (Creswell, 1996, p. 17).

By drawing attention to space over place, we acknowledge the itinerant over fixed nature of learning, where space reflects "a territory defined by practice-based learning, inhabited by a network of people, ideas, and objects in movement" rather than a fixed geographical area (Fendler, 2014, p. 787). We also use space to suggest that the possible platforms for being and becoming are not only solely contingent on the structural landscape of geographical places but also tied to norms and power structures. "Space" connotes the plurality of spaces (platforms for being/becoming) that may be connected to a singular geographical place (e.g., home, school).

In our own work (Authors, 2009) we have shown how a 6^{th} grade teacher and his students re-authored the multiple spaces of their classroom over the course of months in ways that pushed back against the oppressive structures experienced there. Located in a low performing school in the heart of one of the nation's poorest congressional districts, the school had a history of low test scores. Most science instruction occurred in what youth referred to as "drill and kill" format as their teacher sought his best to cover the tested materials. The school offered free breakfast and lunch to all students. However, many students stated they would rather "starve" then eat the school food, as eating school food held a social stigma despite its commonplace structure. Through youth and teacher co-designed lessons, the students engaged in learning activities that brought them out to local bodegas and into their homes, bringing in cultural repertoires of practice that positioned them as "local science experts" who not only taught each other science, but also shared "real" food to eat in science class and oral histories of their families' food and science experiences. The intersecting spaces of school science, neighborhood corner stories, local stories of food and the home, and the physical space of the classroom literally and figuratively transformed as youth re-created it in political, pedagogical and physical ways.

Gutiérrez's (2012) work on expansive learning helps to further unpack the importance of movement across both vertical and horizontal dimensions of learning. Here, movement refers to the ways in which 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). As learning takes place, new activity structures are produced as vertical and horizontal dimensions interact, leading to new forms of activity. Gutiérrez describes these new forms of activity as dynamic forms of hybridity that emerge as tensions and contradictions arise within and between activity systems, transforming how and why these systems overlap (Gutiérrez, Baquedano López, & Tajeda, 1999). In these studies, *hybridity* refers to the novel combinations of different repertoires of knowledge and practice (e.g., science and peer/family/community) as individuals horizontally move ideas and practices. However, it also refers to the hybridity that exists at multiple levels of the learning environment, where many activity systems come together (e.g., science, student, teacher, schooling, etc.). This dynamic and three-dimensional perspective allows us to better understand youths' horizontal movement and hybridization toward making/engineering designs that are both meaningful from a disciplinary perspective and compelling to youth committed to their families and communities.

Other studies 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). Such 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). This view sits in contrast to the view that the worlds of home and school are disparate, and must be bridged. They have also led to the recognition that youths' mobilities, amongst a vast range of learning arrangements, make learning and identity work always tangled up among practices in complex ways (Rahm, 2012).

Mobilities of Learing and Making. Mobilities of learning perspectives have shed important light on recent makerspace research. Two threads of work emerge. First, making has been studied 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. Advocates of the maker movement argue for its "democratiz-ing 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).

Second, making activity is viewed as a dynamic multi-practice. To make, individuals are involved in the process of re-authoring and re-mixing practices from a wide range of experiences, both in and out of school. Sheridan et al. (2014) suggest that making values multidisciplinary 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 multi-practice values "historically feminized" practices, such as crafting alongside more traditionally "masculinized" practices, such as electronics (Buchholz, Shively, Peppler & Wohlwend, 2014, p. 283). These ideals are echoed in Kafai, Fields, and Searle's (2014) work, which shows how makerspaces bring together "hard" and "soft" skills towards challenging what counts as legitimate making.

Makerspaces also legitimize non-school based practices essential in problem solving and design, potentially opening the spaces to youth for whom schooling has felt marginalizing (Buchhol et al., 2014). 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). Making affords new forms of learning over time because "what" individuals make become the "evolving representation of the learner's thinking" and "promotes understanding through interpretation," further developing knowledge (Halverson & Sheridan, 2014, p. 507). 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).

What is taken up less frequently, and central to our own concerns, are how unequal distribution of power impacts how mobilities of learning and doing in making take shape across the powered boundaries of gender, race and class, and its impact on youth positionings in the making spaces they inhabit (Vossoughi, Escudé, Kong & Hooper 2013). Despite the democratizing effects of making, how youth leverage their knowledge of community concerns and values could be positioned hierarchically by the teacher/adult facilitator or peers, even if such practices have a role in making (e.g., Vossoughi et al., 2013; Authors, 2015). Broader sociohistorical narratives around who can be a maker influence how youth come to a makerspace seeing themselves as capable in making. As we consider our work with youth from non-dominant communities in makerspaces, we want to pay attention to how the shifting nature of STEM, making, and community spaces are always under negotiation, resulting in potential in-between spaces as different individuals reproduce and resist the narratives at play there.

Method

Context: Making 4 Change [M4C]. Our study is grounded in middle school youths' experiences in two makerspace programs in Michigan and North Carolina, over the course of two years. In both locations, the makerspace programs are housed in Boys and Girls Clubs, which are community-based clubs focused on youth development, homework help, and sports for youth from low-income backgrounds. Both are also located in mid-sized cities facing some degree of economic depression.

In our research and development roles, we have worked collaboratively with Boys and Girls Club staff to establish makerspace clubs, with the goals of supporting youth in learning about making and engineering design in culturally sustaining ways. In both locations, we sought to engage youth iteratively and generatively in maker space activities by incorporating youth authored community ethnography as one approach to more explicitly embedding local knowledge and practice into making and engineering design. As youth sought to name design problems they hoped to address in their makerspace, we co-designed activities with them that would support them in engaging their community in providing insight or input on the problems they named. For example, when youth decided they were interested in safety concerns, we worked with them to design an open ended survey they could give to community members to solicit their experiences and ideas about safety. We also worked with them to figure out the primary safety locations (e.g., on the playground), and designed and supported them in systemically observing what happened in these locations.

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 6-8 (ages 11-14), and all were from lower-income families. Most are African American, although a few are white or biracial (See Table 1).

[Insert Table 1 here]

The Boys and Girls Clubs we work with refer to these makerspace programs as "Making 4 Change" or M4C. We designed these programs 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 that matter to them. Using the cultural tools of ethnography, they move together into community spaces in order to glean insights into how these problems matter, technologically and socially. As community ethnographers, they identify vulnerabilities of relevance in their communities (e.g., 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.

Critical Ethnography. Our study was carried out as a critical ethnography over a two-year period. We selected critical ethnography 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.

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 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 interview transcripts as well as our fieldnotes and the youths' sketch-up notebooks kept during the course of their participation. The goal of this initial read was to open code for 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) 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." 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 youth 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 appeared greatest and the forms such engagement took, how they moved 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 (the case = the project, which typically involved more than 1 individual). This final phase involved writing the narratives related to students' participation in the two makerspace programs under study.

Narratives of Identity Work

Samuel & the Light-Up Football

Samuel joined M4C in October of 2012, during the autumn of his 6th grade year. He had been "wanting to join for a while" but needed to wait until he was in 6th grade. While he did not have friends already in M4C, he said he wanted to join because he "kept seeing" what other kids were doing, and he, too, wanted to do "something like that." He wanted to be able to "do stuff with my hands, be active and stuff."

Samuel got off to a rocky start in M4C. He began working with two boys who wanted to design a miniature racecar. A racecar did not interest Samuel. He offered many alternative ideas to his group mates, but they shot down his ideas in favor of their car. He became so frustrated that one day he exclaimed loudly to one of the M4C mentors, "No one wants to work with me!"

But, Samuel quickly teamed up with another peer, who overheard his concern and asked him if he wanted to work with her saying, "We can even put your invention first and put my invention second." After two sessions together, the new partners were seen giggling together in front of their shared laptop and practicing a “secret handshake.” But, this group dissolved too, as Samuel felt that his new partner was a little “too bossy.” However, Samuel stayed tight with his new friend, having on-going dialog as their projects developed side-by-side.

Samuel continued to attend M4C, working mainly on his own until late in the fall semester, when family issues prevented him from having transportation home from the club. He had moved from living with his mother to his grandmother, and missed nearly 2 months of M4C.

This missed time was a big setback for Samuel. His first day back occurred on the first major “feedback cycle” day, where the youth shared their work-to-date with local engineers and community members who provided insights and ideas. His peers had already created 3 dimensional printouts of their project ideas, had notebooks full of sketches and research, and prepared short videos explaining their ideas. All Samuel had to share was his idea – a light-up football – an idea he had been “thinking and thinking and thinking” about at home. Nonetheless, as he met with different visitors, he developed a robust description of his idea. One visiting science teacher pushed Samuel to put his ideas on paper. Together, they drew a model of what his light-up football might look like. In the process, Samuel and the visiting science teacher discussed the position of the lights: Where on the football should the lights be so that the entire ball can be seen in the dark? How could he ensure that the lights were not protruding on the football so that the shape and smoothness of the football was not compromised?

Between January and April, Samuel continued to work on his idea 2-3 days a week after school, both during M4C time, and on his own time on days that M4C did not meet. In the end, he successfully created a working light-up football using rechargeable batteries. He also had plans to make a solar docking station to recharge the batteries, but the docking station was not completed that year.

Why a light-up football? Samuel was keen on making this football because he wanted to help keep his peers and the younger children in his community safe. He stated that his motivation for this project was his care for the people in his community:

> [My football] say about me that I really care about people. And I could do stuff in the community, do stuff together, like peers can do stuff together, like neighbors or school neighbors could go outside and do stuff together. . . Cause, like, some kids don't really play football, don't have no friends and stuff, so I go find people to help out a little bit.

Samuel’s idea of care is nested in an understanding of the special needs of the young people in his community. He lives in a neighborhood where there are limited streetlights (not uncommon in lower-income neighborhoods in the US, where city infrastructure breaks down), and where there is gang activity. He also lives in the far northern US, where daylight hours are short for the majority of the school year, when play is limited to the after school hours. The lack of working streetlights makes it difficult to see the football and to see others, potentially making it unsafe to play.

Samuel was equally worried about his peers who do not have friends, perhaps reminiscent of his own experiences. He had recently moved to his grandmother’s care, as his immediately family was in social and legal distress. He viewed football as a way to bring young people together in safe ways, rather than through dangerous activity. From Samuel’s perspective, a light-up football would have wide appeal. He believes a light-up football could bring kids together who may find the lights cool, even if they do not like football. As Samuel stated, “I think other people will like my invention. Because, like, some kids like stuff that glows in the dark, so kids, like, some kids like my cousins, they play football, they're on the football team, so they'd probably like the football that glows outside and throw around and stuff to get better at the - for next year - for the next season they play football."

Confronting challenges. A light-up football presented Samuel with many design problems of both technical and social consequence. First, lighting a football demands power. But, as Samuel noted, powering the lights costs money. His initial solution was to use rechargeable batteries because "mine's rechargeable batteries so we can see all the time but so you won't have to keep going back to the store and buying, like, batteries to reuse." Saving both money and time by not having to return to the store to buy new batteries were both important in order for Samuel to keep the lights powered.

Rechargeable batteries also addressed another design concern: care for the environment. Samuel was worried in particular about the problems created when non-rechargeable batteries are thrown into the trash:

> [Rechargeable batteries] make the world greener, so when you throw batteries away, and those critters can get inside your trash, like the raccoons can take your batteries, take your trash and batteries out. So to leave it, like the batteries everywhere, so they can eat it and stuff. I didn't want that to happen so I made it so it could be rechargeable batteries so it could, the batteries can just be used on and on again.

Powering the lights was, in fact, the "biggest design challenge" Samuel stated he faced. He noted in his sketch up notebook that he needed to balance the number of batteries required and the brightness of the lit football. Two batteries did not light the ball well enough, but more than two batteries, he felt, made the football too heavy, and too expensive. This insight seemed to spur Samuel to expand his design concerns to also include the weight of the football, and the location of the weight. Having his football like a "regular football" in terms of size, shape and weight, were all important, but all impacted by his desire to have a light-up football.

Samuel sought input on these concerns from local football experts, which included a local football star, who starred at the local university, and who is active at his community center, and his friends who play for local community teams. When recounting how these different experts helped him in his design, Samuel noted that the football star helped him to think about how to make the ball balanced, so that it would not be too heavy on one side or the other. To solve this problem, Samuel had to cut deeply into his prototype to place the batteries in the far center:

> I changed a lot, like make sure it's not so heavy, so like, if you throw it, it's not going to go far as a regular football. So when I met with "TD", we was outside throwing the football around and he said that, my football is, that, it's like a regular NFL quarterback player throws it, it'll go just like a regular football. . .So I used that, and so when I went back and tried to do it, I made sure that when I cut it, I made sure that it could be deep enough so it won't, like, make it so heavy. So it could be, not be so light, it could be just right. So *like a real NFL football*.

Samuel asked the football star to comment further on the feel of the football. He wanted to know if the football felt "comfortable when you throw it" and "how far can you throw it, if it's heavy or light?" Video footage shows Samuel passing the football to the star so that he could throw it. TD, the football star, then said, "How far can you throw it? Well, this is probably about as heavy as a real football, so you could probably, depending on who the quarterback is or whoever is throwing it, you could probably throw it the same distance as a real football."

However, Samuel also sought out further input from his friends, who felt that Samuel could do more to make the ball lighter and to better balance the weight. He said that he listened to his two friends whose ideas "helped" his "invention." He said that they were concerned that the ball was still not light enough (weight); they wanted the ball to be lighter so that it could go farther. They suggested that he remove some of the lights so that they would not "make it heavier" and "pull it to the ground." Samuel sought out "different LED lights" as not all LED are "the same." He opted with a LED tube lighting "because it's a tube and you can, like, stretch it around the whole football. So, what I did was, I had it made so when you throw it, it could get more spin and then you could see the light very well." This seemed to solve several of his problems.

Samuel took his peers' comments to heart. This kind of positioning within and across these worlds suggests that Samuel was concerned with more than simply making it in the minds of experts. He wanted to be sure his product worked for his friends; the very youth who would use it when it was complete. That his friends offered more critical feedback than the adults – who perhaps were more willing to believe that Samuel had the expertise to accomplish something better – is also interesting. Both groups recognized Samuel for his expertise, but the youth wanted and expected more from him.

Another design dimension important to Samuel related to his continued concern about safety. In choosing his lighting, he opted to use LED lighting, even though it was a bit more expensive in production. He felt that LED lights would ultimately be more energy efficient, reducing energy costs and environmental impact but equally as important because very little energy was converted to heat, they would not burn the players' hands. Given that his target audience involved "6 year olds and up", keeping hands safe was important. As he states, "Yeah I learned about the LED lights, they, uh, they're not hot - hot - hot, like, like the regular batteries, I mean not the light. They don't get so hot, so cause they're real bright but it's like they save energy so it won't be like, if you throw it or touch the light it won't, like burn your hand."

He also opted to use a soft foam, nerf style ball. In talking with his mom, whom he did not see often, he became convinced this would help kids be more safe if they got hit in the head: "Yeah I asked my mom and she said that, if you mean, like, [...] this football, like, so if somebody tries to catch it and they get hit in the head it won't be so hard. So I used, like, a foam one, so it could be, like, when you catch it or get hid, your head, will be, like, soft. So it won't, like really hurt that much." This seems particularly salient because much of the "off-season" practices happen informally without access to helmets or pads.

Lastly, we note that in response to a peer's feedback, Samuel included tests of his prototype to see what happened when it got wet (see Figure 1). As he explains, "We wanna see if this football is waterproof. [puts football under a stream of water in a kitchen sink]. Well, it's wet but, I think it still will work let's see. [turns on football, and it lights up]. Awww Cool!"

[Insert Figure 1 here]

Multiple Perspectives. Many different kinds of experts were helpful to Samuel as he sought ideas for his design, and positioned himself as an interested learner and designer, caregiver, football expert, and friend. His mom provided insight on safety related to head injuries, and this prompted Samuel to use a softer foam material. His peers provided feedback on weight, size, lighting, and use in the rain. The football star tested the ball for comfort, distance, and feel. Energy experts helped Samuel to consider issues of energy transformations involved in lighting, helping him to select energy efficient lights that would not burn hands. They also provided insight into how he might cut the football so that he could get the batteries inside the ball rather than hanging on the outside, as he had originally built:

> So I had made light-up football, and I didn't know, I had put the lights in it and I hadn't cut it and put the lights in it. And I didn't know where I wanted to put the on and off button, so I had let it hanging out. Then when I met with the experts and they said I

> should cut little squares off the, put the box, put the box on the, on and off button, inside the light-up football.

The Internet provided information on different styles of LED lights, and whether similar products existed in the marketplace. All of these people and resources mattered in helping him bring his design to fruition. When competing views arose, Samuel turned to the data to look for patterns and to decide when additional data were needed. As he stated:

> I went to go ask other people who haven't had the same answer and then, so I used their evidence against mine and their evidence was good, my evidence was good. So I kept asking more people and then I had, and then other people had the same evidence.

In commenting on the different forms of data, he distinguishes between quality of data from both substantive (how many used this evidence) and source (who said what) points of view.

Samuel successfully completed his football and a picture of him with his ball and the football star hangs proudly on the main wall of the Boys and Girls Club cafeteria (see figure 2).

[insert figure 2]

Jennifer & Emily's Heated Jacket

Jennifer and Emily joined M4C in autumn of 6th grade, at the same time as Samuel. Jennifer joined because she wanted to use the computers. She thought that "science is boring," and often complained that she was not allowed to "build" things or "use technology" in school science. However, she felt that she was good at using the computer and the Internet. She was proud of her efforts to get behind the firewall set up at the club or to jailbrake her mom's phone. As she stated: "I am good at jailbreaking stuff. I am actually good at jailbreaking. Like going on an iPad or iPod or whatever, it's like an unlock. You can jailbreak it and get inside of it." However, Jennifer told us that no one recognized her interest or ability with technology. For example, when teachers asked questions about computer skills and the Internet during class, Jennifer said she was the first one to raise her hand, even though she was rarely called on to help.

Emily, however, joined M4C because Jennifer did. The two had been best friends from an early age. They both came to the local community club together after school because both of their mothers worked during the after school hours, and their school did not provide after school programs. Emily felt that M4C gave her something to do with her friend that was interesting.

In this vignette we describe their design work in the 7th grade, where they eagerly returned to participate in M4C for a second year.

Why a heated jacket? The two girls spent the first month, with their peers in M4C, surveying peers and community members about the safety issues they cared about. The youth collected 62 survey responses from peers, parents, community members, and staff at their after school club. From graphs made of the data, the two girls and their peers noticed that "commuting" was the main safety concern, identified by 74% of the respondents (n=46). When they looked at the comments written by the respondents, they broke down commuting into walking at night, weapons, wearing helmets, and cars. When they brainstormed ideas, they noticed that even though the topics were different, there was a cross cutting focus on getting to places safely. When they looked again at the comments written by the respondents, they noticed that walking in the dark was important because it was related to their abilities to walk home after M4C.

While Emily wanted to work on a walking stick/blind cane as one way to address safe transportation, Jennifer was adamant that they should do something else that would help them and their peers. In her view, the walking stick/blind cane was a good idea, but it would not help the people *she* wanted to help. This caused some friction between the two youth, as Emily spent time sketching out a detailed blind cane, while Jennifer spent her time, combatting every argument Emily made about why it was important. However, Jennifer argued strongly for her idea – a heated, light-up sweatshirt. She recalled a time when her mom took her horseback riding. This was a very special trip, but the day was cold. Jennifer had gotten "so cold" she could "not feel her hands," and they had to end their afternoon early, and she missed her opportunity to fully do something she had always dreamed of doing. Emily dropped her idea of the blind cane, and decided to work with Jennifer on her idea. As she said, "It's hard to persuade Jennifer . . . when she argues like that. I'm going to go with her ideas. . . she is my *best* friend!"

After agreeing on the idea of a heated, light-up sweatshirt, they worked on an initial rationale for the shirt, which they shared with outside visiting experts – teachers, engineers, community members. They described their project as a sweatshirt that would be "warm and bright," and that would also be "lightweight and beautiful." Emily described the shirt this way: "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."

The aesthetics of the shirt carry deeper meaning than just beauty, however. Both girls were concerned about inappropriate exposure and also being bullied for appearances. As someone who has been bullied herself for appearance, this was an important concern for Jennifer, "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." "My idea could help change things. People make fun of you. . . Why are you wearing that? You are ugly. There are stains on your clothes." Being bullied was important as both girls described being bullied for their appearances, e.g., being told "You are ugly" or "Hey, nappy-head".

Multiple inroads. During the initial phase of the project, Emily and Jennifer initially delved into the project by spending several hours on Pinterest and Google, looking for ideas on hoodie designs and approaches to lighting and heating. This on-line exploration led to many different ideas for the hoodie, including clearer ideas on what they did *not* want to do. "All of the heated jackets are for hunting and construction, not for casual." "Look, they all have those big heating parts, and that would be heavy!"

While these efforts served them in their design decisions, they also prolonged their engagement with the larger technical challenges they faced, which related to figuring out how to heat the jacket in ways that were not bulky, heavy or expensive. In fact, they spent months playing around with the fashion side of the jacket, such as taking extensive time on Pinterest exploring how to design the lighting. They also interviewed their peers to see what they wanted out of hoodie fashion. At their peers' insistence, they also spent time designing a logo for their jacket in Google Sketch Up, so that it could be 3-d printed and placed on their jacket.

In moving from their collective set of on-line and experiential ideas to an actual design and prototype, the girls nearly gave up on many occasions. However, the girls noted time and again that they could not let their friends down. Jennifer initially found inspiration in some of her out-of-school and out-of-club experiences (television, the internet, a power outage, her family's fireplace) to delve more deeply into the science of her design, as she discussed in her video diary. As she later elaborated in her interview:

> Bob [a visiting scientist] said that heat was very expensive. . . I remember watching a video in 3rd grade, and they went to the north pole. There was freezing cold water. Some animals that live there have blubber, and that protects you from the coldness. . . So, I went on line and researched this. Kind of like when we had that big snow storm here and everyone's power went out. I remember after that when the power came back on you

brought in the light thing and it had a silver lining and so the heat would stay in, and not go out. It wouldn't leave it. The silver lining got hot, not raging hot, but warm. It got warm because the heat source was right there. In my design, the thing is going to be far away from the silver lining so it wont get too hot and burn you. I thought of this myself just thinking about it. You don't get everything from teachers. The silver lining, as a kid I seen a lot of it because we had to put it in our fire place. We had to put silver lining around it so the heat would stay in it, but it wouldn't burn anything outside of it.

Jennifer and Emily incorporated these ideas into her hand drawn sketches of the jacket, which garnered positive attention from her peers and adults.

Expansive Challenges. Moving from her ideas/sketches to actual hands-on design work still seemed to present a big expanse that the girls needed to figure out how to cross. They knew they wanted to build a heating system, but did not know exactly what that meant. Their experiences, in their everyday life involved “heating pads” that “plugged into the wall” and their Internet searches pulled up heating pads with AC/DC adapters but these were too expensive.

The girls asked the M4C staff to bring in a “few different” heating pads – like the “kind you use when you get hurt” for them to test out. They specified in their sketch up notebook that they wanted “big” and “small” heating pads, that had “different settings” for the heat.

One of the mentors brought in two heating pads for the girls to test out. As part of this process, she provided the girls an activity that would help them to test the power requirements of the system with the different heating pads in place. The activity involved measuring the amps and volts the heater needed and calculating the total power requirements for their design for a specified usage period. Then, they had to measure and calculate the amps and volts each rechargeable AA battery could send. By comparing the two figures they could then determine how many batteries their design might need.

However, the girls were not at all interested in conducting these experiments. They put the power requirements activity to the side to do their “own” tests. They were more immediately concerned with how soft the heating pad was, whether it fit well inside the jacket they planned to modify, and how warm it got. These tests led the girls to select the largest heating pad, for it scored the highest on each of these concerns. One of the mentors stepped in at this point, and asked the girls how many rechargeable batteries it would take to power their system. When they did not know, she worked with them on the power requirements calculation they shunned earlier. Together, they spent nearly 90 minutes on this task. They figured out that if they wanted to power the heating pad they would need 101 AA batteries to do so. Emily threw her arms up in despair and said they couldn't do it; they didn't even have enough batteries even if they wanted to.

However, their mentor reminded the girls of a video diary they made earlier on insulation, and she suggested that they go back and watch it to get some ideas. The girls watched and laughed at their video, seemingly breaking down the tensions that surfaced at the frustrations of their calculations. They asked us if we could get them some “silver lining” material to help them to “keep the heat in” and if we had any ideas for smaller heating elements that would “only take 2 batteries.” Together, the two girls and the mentors searched on line for small heating elements. Jennifer immediately found several that were “good for power” but “ugly” that she pinned on her Pinterest page. One of the heating elements, however, stood out because it was 5V and DC powered, small, flexible, light, and inexpensive. As Jennifer speculated, they could probably “afford a few of them” for the jacket, both in terms of costs and battery power, so long as their “silver lining worked.”

Two weeks later, when the mentors brought in smaller 5V heating elements, the girls began to test how warm they could make the jacket, both with and without insulation. For the silver lining, they used a cut-up mylar balloon, because as Jennifer read on line it was "space insulation" and that was "cool" and as one of the mentors noted, it is the "same material" that they use for "runners in marathons." The girls took temperature measurements at 1-minute intervals with the 5V heating element, and noted the differences with and without mylar insulation (see figure 3).

[insert Figure 3 here]

The use of the smaller heating elements led to another stumbling block. Jennifer had cut too far into the jacket when they had planned to use the bigger heating element. Now, with the smaller heating elements, she felt she had ruined it. They did not have another jacket to work on, and was ready to give up. In the next session, one of the mentors brought a sewing machine to the M4C. When Jennifer saw the sewing machine, she ran to the mentor. Jennifer really wanted to use the sewing machine to fix her jacket, and asked the mentor if she could use the machine. Unfortunately, the mentor was not able to use the sewing machine, and, so, Jennifer asked the mentor if she could bring one of community center's staff members to the M4C room. She said, "I know Ms. Y. can use the sewing machine. She told me before. I remember it!" With the mentor's permission, Jennifer asked Ms. Y. to come to the M4C room. Ms. Y. showed Jennifer how to use the sewing machine and helped her to sew with it. Jennifer kept her eyes on Ms. Y. and tried to learn everything that Ms. Y. showed her. Several young people in the M4C took an interest in what Jennifer was doing with the sewing machine.

After Ms. Y. left the M4C room, Jennifer taught her new sewing skills to the others in the room. Jennifer loved the sewing machine, and in time became one of the resident experts, sewing both for pleasure and for other people's projects. Perhaps more importantly, learning to use this tool helped her to identify with the importance of learning from failure and iterative design. As she says, "This is me making a horrible mistake by cutting it, and so I had to learn how to sew. But next time if something breaks, I know how to sew it back together." (see Figure 4)

[insert figure 4]

Discussion

The youth in our study have engaged in making practices that led to the creation of new artifacts that mattered to people in their communities. Further, youths' making practices were undergirded in what we view as "mobilities of criticality," as they re-mixed and re-purposed tools, practices and relationships from various communities towards space-making. In what follows, we first describe how the youths' making practices are rooted in community, and are reflections of their deep and critical knowledge of the needs their communities face within and across the spaces of making. Then we discuss how the youth's in-the-moment actions – a reflection of their making practices – served as critical "pivot points" in their design work. The pivot points connected scales of activity, including STEM inquiry, making, community and action taking, in how they provided analytical foci for driving technically-oriented design work, and opportunities for social negotiation towards new possibilities of doing and becoming in STEM, makerspaces and community. We end with a discussion of the importance of mobilities of criticality in space-making.

Rooted in Community

Practices as rooted in community. The youth in our study, in on-going ways, position themselves as a part of, or inside, the urban ecology, rather than outside of it. Relph (1976) first proposed the insideness-outsideness dialectic to illustrate how one's sense of place exists as "a full range of possible awareness, from simple recognition for orientation, through the capacity to respond empathetically to the identities of different places, to a profound association with places as cornerstones of human existence and individual identity" (p. 63). In schools, teachers and students are rarely asked to identify with place. The very notion that one can position oneself as inside or outside of place stands in stark contrast to the driving norm in science education, where the focus is on generalized, "across the board" scientific knowledge and practice. However, in taking on local problems, in community spaces, youth use their insider knowledge and status to frame the problem space, and to work towards community sustaining solutions.

The youth's making practice, as rooted in a wide range of community spaces, draw upon (and incorporate) expert knowledge on issues inside to these spaces, such as the funds of knowledge one has because of where they have grown up, and with whom (Moll, Neff & Gonzalez, 1992). These practices also incorporate insider positioning status, such as that which grants access to the social networks and contexts necessary for gaining deeper insights and access to resources when needed.

For example, the youth brought to their investigations a wide range of funds of knowledge and relationships that played a role in how they defined the problems they wanted to work on, and their various dimensions. These funds are tied to particular community spaces where youth have insider status. Some of these funds included: Family, geocultural, community, peer, and pop culture funds (see Table 3). For example, knowledge of where streetlights have historically not worked, why kids at their school get bullied, fashion, how to work with one's hands to build, or the reasons and impacts of major economic concerns of the home, all reflect their insideness – their membership and experiences in the community spaces that they inhabit. How the youth drew from these funds across spaces reflect their attempts to author interconnecting corridors for traversing between these community spaces, and their STEM-infused youth makerspaces. These different points of intersection, as we describe later, became meaningful sites of negotiation.

The youth were not initially expert in all of the community insider knowledge they needed or ultimately leveraged. Sometimes, specific technical insights or challenges opened needs for new funds, such as when Jennifer and Emily needed to learn how to sew, or when Samuel needed to learn more about what made for a "real" football. Having insider status enabled the youth to tap into informal social networks for the right kind of help in acquiring such funds, or how to do so. Jennifer and Emily eventually learned how to sew from a mom who worked at the community center that housed the makerspace program. Samuel sought out help from his cousins (family) and peers (school and club communities) who play on the local community football team. Through these interactions, youth further established corridors of connections between the different spaces where they are insiders, both broadening and thickening the networks that can serve STEM mobilities.

Practices as enactments of their deep and critical knowledge and care for the needs their communities face. There are nodes of criticality in many of the funds deployed by the youth, and in how they sought to leverage these funds towards engaging more deeply in the technical dimensions of their work. We believe this is in response to the injustices these young people face growing up in lower-income communities. All communities face risks that result from geographical, socioeconomic, and political challenges. However, the risks are greater for young people growing up in lower-income communities of color, where environmental and social injustices loom large. All three youth, like many of their peers, live in multi-generational poverty. Unemployment in their communities are some of the highest in the nation, and government spending on such things as infrastructure (e.g., streetlights) have been severely cut.

At the same time, these young people value their communities and the positive experiences they have there, from participating in programs at their club, to a strong sense of community within their churches and neighborhoods, and rich culture in faith, music, fashion, and community action. The youth, in many ways are protective of their community, and that they leverage these more critical funds towards solving local problems is important. As one of their peers stated in defense of their city:

> Great Lakes City isn't boring as long as you get out. People say Great Lakes City is boring, but I have been around the whole Great Lakes City area. I have been to the east, west, north and south side of Great Lakes City. I was even born on the Southside of Great Lakes City. I am just going to tell people don't just down Great Lakes City because you haven't been out enough. Don't try to ruin someone else's fun of coming to Great Lakes City, because you thought it was lame or you thought it wasn't fun or you thought it was a depression to you.

We see such criticality enacted by these youth in their making work as tied to four domains in particular: *Economic* (e.g. making their designs affordable), *environmental* (e.g., designs that reduce their communities carbon footprint and support local ecologies), *social* (e.g., fostering positive peer relationships, healthy well-being, community ownership, and preventing bullying and gang activity), and *urban infrastructure* (e.g., providing lighting and warmth on cold, dark days).

For example, Samuel worried about dangerous peer friendships, such as gangs, and believed some of these peer-related challenges might be remedied with positive play, such as with a football. Samuel persisted in refining his football so that it met the needs of a wide range of peers. He first sought peer input on lighting – weight and design. He then pushed for input on weighting and feel. He tested his football with peers his age and peers younger than him. He pressed them for feedback on what functionality they needed, which is why he ultimately sought to make sure his ball was waterproof. Each interaction required Samuel to consider many new technical factors in his design that he had not previously considered (e.g., safety of material, not burning hands, waterproof), but he was deeply motivated by how and why his football would serve his local peer community.

Likewise, Jennifer worried about (the lack of) fashionable or new clothing and its relationship to bullying. Jennifer and Emily noted the twin challenges of keeping warm in the winter and of getting bullied for one's clothing choices, especially when clothing options are limited due to family finances. The girls wanted the jacket to be lightweight so that they were not relegated to a lumpy, thick jacket –very unfashionable – to keep warm. Costly winter jackets typically tout slimness as a key, attractive feature. Jennifer's design would, as she stated, be "beautiful but with casual in it so that you don't expose yourself." People would not be able to make fun of you for clothes that had "stains" or were "ugly." Both the girls and Samuel worried about the economic challenges their families faced, such as whether the jacket or the football would be affordable as well as how to keep down the energy costs down.

The youth's insideness provided access to important funds of knowledge and social networks, but at the same time, their status as a member of M4C elevated the importance of these funds as important in scientific and technical investigation. This was accomplished through new forms of practice that re-made the spaces of their work. While youths' making practices were shaped by the structures of the places where they worked – normative practices around engineering design, the tools and resources made available in their maker space, the technical knowledge brought in by their mentors – their enactments of their deep and critical knowledge of and care for community, also influenced activity within these spaces. Such performances re-shaped these spaces in the moment, but also provided new pathways for future makers to traverse. The youth were creating and claiming new territories in space-making. As Jennifer and Emily spent time on Pinterest, showing others their ideas, and creating pages of pinned designs, they also created new spaces for Jennifer's technology interests to flourish in her work, to position themselves as fashion experts amongst their peers, and to share ideas with others on what to do when you are stuck (e.g., Pinterest). This is similar to Creswell's (2004) analogy of place-making in a public park, where people ignore the bisecting pathways in favor of a diagonal short cut through the grass. Such performances give way to new mud paths through the park for current and future park goers.

Pivot points & their functions

As youth engage in community-rooted making practices over time, their in-the-moment actions served as critical "pivot points" in their design work. These pivot points connected scales of activity, including STEM inquiry, making, community and action taking, in how they provided analytical foci for driving technically-oriented design work, and opportunities for social negotiation towards new possibilities of doing and becoming in STEM, makerspaces and community. Here we refer to Holland et al.'s (1998) use of the term pivot to refer to "mediating or symbolic devices" not just to "organize responses but also to pivot or shift into the frame of a different world" (Holland et al., 1998, p. 50). When youth leveraged their funds of knowledge, for example, towards work on their projects, they etched their insideness onto their engineering design, in ways that impacted the design process and how/where it unfolds, as well as their role in it. As pivots, these funds were not simply complementary to the youths' engineering design, but *essential* to *both who they are and their design work*. Pivot points included *tools* (e.g. sewing machine, Google Sketch Up), *relationships* (e.g. Samuel's ties to his cousins and peers) and the *innovations* themselves (e.g. Samuel's light-up football), all of which were able to shift the nature of STEM engagement for the youth, and potentially transform their possibilities for becoming and being within particular spaces (e.g. Samuel's peers and cousins engaging in safe play at night in their neighborhood).

The three key functions of pivot points are 1) Using funds as navigational indicators to secure a productive launching space to begin their making project; 2) driving technically-oriented design work in dialog with community interests, and 3) facilitating social negotiations towards novel space-making endeavors to broaden possibilities for becoming in STEM.

1) Using funds as navigational indicators to secure a productive project launching space. We have been concerned with how youth locate productive starting places for projects. Such initial location work can be challenging, for it involves social negotiations of who to work with, along with considerations of what challenges might be worth spending time on. In both cases presented in this manuscript, as well as in many of the cases from the larger study, the youth leveraged their funds as navigational indicators to author a productive project launching space.

In their club, the youth were charged with a fairly wide-open making task: design something that "uses portable energy" and solves a problem or fills a need. In response to this challenge, Samuel drew from a wide range of funds – M4C youth makerspace, family, peer, and residential community funds – in order to locate a starting point. As Samuel noted in his interview, his light-up football was an idea he "thought, and thought and thought about" while home at his grandmother's house unable to find transportation to the club nor able play outside after the dark. These considerations – limited streetlights, personal safety, and friendships – made that much more salient by his move to his grandmother's care, became points of negotiation for how and with whom he would work. Samuel's initial ideas were legitimized by his cousins and peers who knew that he had experience playing football, and would understand their needs.

Jennifer and Emily also drew on a wide range of funds as their launching space. Their leverage points came from both the community survey (of 62 community members) where they noted "traveling in the dark" was a "huge," but complicated, concern, as well as from personal experiences being bullied for clothing choices and being cold outside in the winter. Both girls enjoyed fashion, and were inspired by their time spent on Pinterest. Jennifer and Emily eventually constrained their task by honing in on designing something fashionable that would prevent bullying based on looks, but that would also keep people warm and well seen on dark and cold winter days. Like Samuel, the girls also located their starting point by considering, both the kind and degree, of the various funds they possess as insiders to different communities.

2) Driving technically-oriented design solutions in dialog with community interests. We also see imprints of youth's rootedness in community in how they worked across scales of activity in their systematic efforts to refine their design constraints and evaluate possible solutions towards optimization.

New design cycles were initiated on both technical and community terms. For example, youth-set end-point assessments required them to seek multiple perspectives, both community-oriented and technical. As community funds initiated more complex design conditions, Samuel needed to deepen his knowledge of energy systems and environmental and economic impact. Working with a mentor, Samuel figured out how to calculate power requirements of different lighting systems. This technical task was one that became salient once his peers pointed out his chosen lighting system required too many batteries. He also read information on the Internet on the affordances of LED lights, when his friends told him that bulky lights would not work on the football. He spent time figuring out how to assemble the components in a circuit with a switch so that the batteries would not be wasted in daylight.

Their initial design ideas were attentive to *specific* community concerns, but initially framed through fairly *vague* technical and scientific terms. This kind of pivot point was particularly important in helping the youth to grapple with technical and scientific considerations that were challenging to them. The specific community concerns helped the two groups functionally break down the work they needed to accomplish from a technical standpoint – e.g., having a need to experiment with power requirements and conducting challenging calculations. This is important given the new focus in the science education standards in the US on supporting students in systematically refining design constraints and in evaluating possible solutions towards optimization, through multiple cycles of prototyping solutions, designing/conducting tests towards optimizing solutions, gathering/ analyzing data from multiple perspectives, and engaging in dialog on complicated conflicts in perspective and design trade-offs (NGSS Lead States, 2013). Their funds also gave them starting points for where, within their social network, they might look for feedback.

For example, if we trace Samuel's work on his football, he began with the initial technical challenge of how to light the football. He systemically tested different lights for lighting quality (systematically gathering data & developing technical expertise), but then confronted the problem of how inefficient lights could burn hands (setting new design criteria based on both technical and family concerns). After settling on energy efficient LED lights, he confronted the challenge of how too many lights added too much weight to the ball, making it not a very effective piece of sports equipment (setting new design constrains based on peer/sports funds, requiring new scientific expertise to do so). The weighting presented a complex problem because a certain level of lighting was needed to be safe after dark if football play extended about 100 yards (using community and sports funds to further optimize design), and even if he found light-weight lights, the batteries needed to power the lights added substantial weight (developing deeper technical expertise in response to need to optimize). He resolved part of the concern by testing different lighting configurations and opted for LED ropes or tubing that could wrap around the ball, such that when it was thrown with a spiral it was very easy to see (optimizing design further). The wrapping also solved the problem of how to append the lights in a way that did not distort the shape of the ball. Still, affixing the batteries to the football continued to distort the shape and displace the center of mass (need for further optimization based on sports & peer funds). At the same time, the heavier ball (added lights and weights) made the football more dangerous from an injury standpoint (e.g., getting hit in the head, according to his mother), especially salient for Samuel's design since the intended users of his football –youth in his neighborhood –are unlikely to have protective football gear such as helmets. Both weight and safety pushed Samuel to use a softer "nerf" style material. Late in the design process, Samuel felt responsible to incorporate waterproofing concerns into his design specifications, when younger community testers asked about being able to use the light up ball in the rain. This presented an additional technical challenge, but at the same time Samuel readily incorporated the design feature as it was folded onto the design agenda by his participants.

3) Facilitating social negotiation towards novel space-making. The youth's making practices iteratively and incrementally built on each other to expand their STEM expertise and rootedness in community. Both the merging and layering of STEM and their funds of knowledge onto and into each other were accomplished not only in the design work, but also *in the attempt to change the real worlds in which the youth are working and becoming*. That some of the youth have said they want to get smarter on these topics so that they can return to their community – not leave it as they move on up – speaks to this point well. In short, new possibilities in space-making operate at the level of the making process *and* at the level of the potential impact of the youth-created innovation.

The playing field *in makerspaces* (one area of space-making) transformed for the youth as they incrementally, but systematically, refined the problem and optimized their designs in both technical and social ways, expanding their connectedness to others, and their access to ideas, tools, and resources for advancing their developing expertise. As Samuel walked through the main club rooms with his ball, kids gathered around him asking to test it out, and where and when they could buy one. His picture with the pro football star hangs on the wall, and other youth have since joined M4C to "do what Samuel did", which included "making" things and "meeting famous people." Becoming an expert involved vertical development in deepening scientific knowledge and practice. His expertise also took form as he moved his ideas and practices horizontally, weaving in his experiences, knowledge and practice from other domains, such as football, friendships, and caring for others. For Samuel, the makerspace expanded beyond the walls of the making area into peer activities on the football field. It transformed in the new social networks of people he brought into his expanded makerspace.

Emily and Jennifer generatively transformed the maker space with each new activity they took up, often in resistance to the more traditional making activities. Including fashion and bullying a part of the discourse of making transformed who, and what, were legitimized resources for the space. We see this, for example, in the criteria they applied to the selection of solar panels (e.g., flexible solar panels that could be made glamorous). We also see this in the very last technical refinement they made to their jacket: When the girls were frustrated about the lack of fashion their jacket would exhibit if they put solar panels on it, Emily found a flexible solar panel and said, "What about this? It looks fancy! It's not ugly!" And while Jennifer agreed that the flexible solar panel on their jacket could look fashionable, she also doubted if the solar panel could power the heating pads on dark or cloudy days. Emily asked Jennifer if she remembered that they had used a similar rechargeable battery pack for their scooter invention a year ago. They had used rechargeable batteries to light up LED lights that were attached to the scooter so that they could ride the scooter in the dark. As Emily later explained, "It has solar panels that are connected to the heating source. We also have batteries to store the energy from the solar energy. This is important because it lets the heating source work when you are not around the sun, such as the cold, dark walk home from school or the club in the middle of the winter."

What is more, the youth's designs helped to transform the playing field *in community* (another area of space-making) for themselves and their peers. Jennifer and Emily's coat makes warmth and fashion affordable. As they stated, "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." Samuel's football will allow his peers to practice throughout the off-season, so that they can "get better at the - for next year - for the next season they play football."

Each new iteration of design, from refining the problem space to designing a working prototype offered new and different opportunities for these practices to build towards future identity work, relationships and recognized ways of being and doing in these different and interconnecting spaces. When Jennifer and Emily became stuck on some of the technical challenges of heating the jacket, they stepped back to take on a different technical challenge suggested by their peers: to make a 3-D logo for their jacket in Google Sketch Up as their friends insisted it was important for everyone to know that their jacket was made by them. While this new task boundary was not essential to the functionality of the light-up or heat-up aspect of the jacket, it was necessary for both fashion and ownership. Like the FUBU [For Us By Us] hip hop clothing company, there was a significance to potential wearers that these clothes were designed within the community for the community.

Equally as significant are the playing fields of STEM, both real and imagined (a third area of space-making). The youth's practices served as new tools to expand the very purposes and goals for engaging in science. Learning science has purpose broader than "doing school" or even, in the progressive sense taken up in the Next Generation Science Standards, learning how to explain how the world works so that one can engaged in informed citizenry. At the heart of each youth's design is an effort to work at the intersection of science and the public good, as a way to transform both (through the production of new structures that support & legitimize their practice, such as the very artifacts they create). Their engagement with the problem was not simply motivated by individual interest. Engagement was framed, in part, through collectively formed interests as they sought out feedback from a wide range of others, at the powered boundaries of race, power, care and danger. These tensions demanded greater engagement with STEM as they demanded more complex problems to be considered. At the same time, these tensions made possible recognition within STEM worlds while also exposing the challenges youth face in seeking recognition in these same worlds. The light up football served as a pathway into non-gang friendships as well as a potential steppingstone for acceptance into engineering at the local community college and university.

As Jennifer and Emily sought feedback on their Google Sketch Up logos for their jacket, Jennifer was able to show off her tech expertise, something she was very proud of. As she sought feedback on the logos, others (mentors and peers) positively responded to the logos, recognizing this expertise. But, because the logo was also for a fashionable, light up heated jacket, she had further opportunities to remind people of this other important work she was engaged in. When we asked Jennifer about this she noted that if you ask others what she is known for they "will probably say fashion." When she brought earlier design work home, she reports that her sister exclaimed loudly, "Oh My God! <u>You</u> did this??!!"

This kind of repositioning in STEM amidst these tensions is important. Dominant discourses position the youth as outsiders and non-experts in science and engineering. As a young black male growing up in poverty, Samuel is supposed to like football, but he is not expected to like or work hard in STEM. He is not expected to care for the environment, even though lower-income communities of color continue to face some of the greatest environmental injustices (Schlosberg, 2013). While his peers readily took up the football as an attractive piece of sports equipment, Samuel was unable to bring his football to school, ultimately continuing to restrict the value of community insiderness in school settings. That his *physical education* teacher but not his *science* teacher was interested in the football suggests the profound difficulty that Samuel continued to face as he sought more formal recognition for his work in school settings. While we do see recognition of Samuel's expertise expanding across his growing social network, he still faced challenges. The local football star found his football acceptable, but his peers pushed for more revisions. This reality suggests how deeply entrenched low expectation for young people's engineering efforts might be, even by allies. He worked hard on his project for over 100 hours after school delving into more complex design concerns. This example also shows how complicated the spaces of STEM can be for youth: Samuel had to negotiate becoming an expert among his peers, but then had to seek recognition from a wide range of others in doing so – from science teacher to physical education teacher, to football start – and with varying degrees of success.

Jennifer and Emily faced related, although somewhat different challenges. Prior to work on this project, Jennifer was clear on how intersectionality shaped her opportunities to learn and become in science. She recalls negative recognition from media (in a general sense) when she told us that "[I recognized that] Girls can't do science and engineering…It's another TV show. On one episode, all these boys, they let one girl in science club cause she was girly, and they said girls wouldn't [do] good at science. They were teasing the girl." Jennifer is neither girly nor the prototypical "tomboy." Her place at the science table as set up by media is much less clear. However, Jennifer further related experiences in school where she felt that her teacher did not recognize what she brought to her science class in terms of expertise. She stated, "My teacher is like, Jennifer, do you know all this? Then why are you in fifth grade? I know a lot! So you don't know me! Please, please stay in your place! She is mean. She's always picking on black people! She thinks we are stupid." Emily, who is white, but living in poverty, further stresses how her school positions her without opportunities to expand her science and engineering:

> We're different from all the other middle schools because we only get 4 teachers, and I think most get 6. And we don't really get to do that much stuff. We don't have after school clubs except for Girls Scouts and Boy Scouts. We don't get to do stuff that other schools do. Our school is, like not to be mean, like ghetto. Like bad.

Their jacket increased their opportunities to "do stuff" –explore, create, and innovate with STEM –and to be recognized by their peers, their mentors, parents, community members and science and engineering experts for their work (see also Vossoughi et al., 2013).

In many ways, what we see in both of these examples is a reinhabitation of the spaces of STEM; one that deterritorializes STEM routines and practices, making "physical entry into and living in previously forbidden places" a process of taking back and reclaiming the space of STEM in ways that recognize and care for the rootedness of young people (Perumal, 2014, p. 26).

Conclusions: Mobilities of criticality

For many of the youth with whom we work, gaining access to STEM is an uphill battle. The youth's making practices, as rooted in community, allow for the reconstruction of the spaces of STEM, making and community, in how the movement of people, ideas, and relationships interrupt practices and ways of being. The heated jacket is evidence that the two girls possess robust scientific and engineering expertise, a direct countering of their marginal school science student status. That their hope was to "change things" about beauty and fashion so that people would not be bullied also speaks to engagement with other issues of criticality in their young lives as youth from low socioeconomic backgrounds. The beneficiaries of the design would be people like themselves who cannot afford trendy clothes and who are bullied because of it.

The youth remind us that we need to pay attention to the ways in which how they are rooted in community matters to how they engage with science and engineering. The youth further remind us how learning takes shape across spaces and time, in ways that desettle expectations for what it means to know, do and have expertise. This desettling is at the heart of a more expansive view of learning. The youths' practices were meant to not only alter their own possibilities for becoming in STEM, but also to make such possibilities available for others. Their practices sought to transform the outcomes of learning – which includes one's science identity, making these outcomes inclusive of the knowledge, products, actions, relationships, and ways of being legitimized for themselves and for others. At the same time, their stories reveal that such a project is deeply political, for how youths' mobilities of learning expand is tied to institutional, sociohistorical, and in-the-moment power dynamics. The youths' engagement in mobilities of learning were undergirded in mobilities of criticality, a consequence of who they are and how they are positioned in the salient spaces of their everyday lives.

While the youth are in constant critical dialog with the different spaces they inhabit (and as they move ideas, resources across these spaces towards making a difference), this critical dialog involves a negotiation of what they hope to accomplish and what is realistic. It involves a deep understanding and care of their community and desire for their community to be transformed. It involves a way of seeing themselves as people who occupy multiple spaces simultaneously, while never losing sight of their home space as they hope for something better.

The criticality that youth brought to their scientific and technical work, is not unlike some of the concerns proposed in the National Research Council's report on Engineering for Sustainable Communities (2010). As they write:

> Unless local knowledge is taken into account, the outcome is not likely to be sustainable. Even if a project has an appropriate goal, one may look back and find that the intended beneficiaries had not been served. . . What is needed in engineering education is an integration of expertise and techniques from the social sciences so that engineering projects are better defined." (National Research Council, 2010, p. 8)

The youths' work, alongside the NRC report, suggest that leveraging both community insideness and scientific expertise is about much more than bridging these two worlds. While such bridging is important, it is in how this bridging makes possible new and more expansive opportunities to learn and to become in STEM. Indeed, in many ways that youths' criticality speak back against the accounts that frame their communities in deficit ways. At the same time, their enactment of their criticality through their making practices call attention to the prosaic and micro-level processes involved in making spaces – STEM, maker, and community – more habitable.

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Table 1
Table 1: Participants

Year	**Location**	**Total Participants**	**Demographics**
2013-2014	Michigan	14 youth	2 White 10 African American 2 Biracial
2014-2015	Michigan	21 youth	2 White (both returning) 17 African American (8 returning) 2 Biracial (returning)
	North Carolina	15 youth	14 African American 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 • Makerspace Community Events	72hrs/yr 8hrs	70hrs 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	

Table 3

FOK & Discourse	**Key threads**
Family	• Keeping children safe • Working with hands & powertools • Sewing • Energy bill practices
Geocultural community	• Knowing where to play safely • Knowing why kids join gangs • How to be safe in the dark • Community includes people & animals • Weather & climate impacts on play & safety • Sustaining Discourse: Learning STEM not to move out of community but to stay in and help community
Peers	• Bullying (where, why, how) • Gangs • Fashion (what kids where, what kids like) • Sports (how to play football, and what a good football is) • Solidarity • Studenting
Pop culture	• Fashion (“FUBU”) • Sports (football star) • Tech/Internet (google, pinterest, bing, and using smart phones for information)
Relationships	• Who knows what • How to access people