Full length article

Recognition in makerspaces: Supporting opportunities for women to "make" a STEM career

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A B S T R A C T

Making is a playful exploration of tools and materials to design personally meaningful artifacts, providing a particularly impactful entry point for traditionally underrepresented youth in science, technology, engineering, and mathematics (STEM) fields. However, it remains unclear how these constructionist explorations translate to eventual professional and educational STEM opportunities, especially for women. This paper tracks an exemplary case in a makerspace to theorize, describe, and analyze the behavioral patterns of young women as they engage in making and move toward expertise in STEM. Building on a material-based and constructionist notion of making, we use mediated discourse analysis to examine how recognition (materialized in artifacts as displaying, legitimizing, and circulating emergent STEM expertise) leads to transformational development over time. We introduce the notion of *tinkering with development*, which conceptualizes playful project design, spatial project placements, and emergent online project sharing as drivers of human developmental trajectories. Implications of this work include a set of design principles to support makerspaces and other constructionist learning environments to foster participation in STEM. Further, implications for constructionist theory and STEM gender representation are discussed.

Among the hustle and bustle of a digital filmmaking course, a few youth crowded around an artifact that was pushed against a wall in the urban youth-serving makerspace: a digital jukebox piano, a technology-augmented player piano that played pop songs and lit up an LED light strip when users pressed keys. The artifact was constructed out of an upright piano similar to those commonly found in schools and was covered in black chalkboard paint that featured drawings of the White House and the US flag. Other emerging technologies were layered on the jukebox piano (see graphical abstract). Most centrally, a Makey Makey computational breakout board adorned the top center and an LED strip was taped along the piano's fallboard. The Makey Makey board and the LED strip were connected to the copper tape-covered piano keys by the visible wires and alligator clips typically used in prototyping. Inside the piano box, copper tape was precariously soldered to the alligator clips, and a bunched up white shirt was placed on top of unused keys to prevent them from sounding notes. When turned on, the screen that was mounted onto the piano's musical board displayed songs that anyone could play by pressing individual piano keys. Once selected, the LED strip lit up to the rhythm of the music. A small, neatly written card on the upper-left corner read the artifact's name and

the name of its maker: Sierra,[1] a 15-year-old aspiring photographer who was one of the first female participants at the makerspace who had little interest in electronic tinkering when first joining the program. This lack of interest shifted into a desire to study electronic engineering in college. In what ways did the construction and placement of the digital jukebox piano change in impact Sierra's developmental trajectory?

1. Introduction

Despite recent efforts of educational reform movements to foster inclusive engineering and computing cultures, most STEM fields remain a predominantly masculine domain with an incorrigible gender gap, especially in the United States (Bix, 2014; Sax et al., 2016; US Bureau of Labor Statistics, 2015). Promisingly, the broader maker movement taking place in K-16 settings has shown notable exceptions with engaging young girls in STEM, including accounts of circuitry learning (e.g., Peppler & Glosson, 2013; Barton, Tan, & Greenberg, 2016; Buchholz, Shively, Peppler, & Wohlwend, 2014; Kafai, Fields, & Searle, 2014; Kafai, Fields, & Searle, 2014; Pinkard, Erete, Martin, & McKinney de Royston, 2017) and other core STEM disciplinary concepts and

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practices (e.g., Tseng, Bryant, & Blikstein, 2011; Evans, Lopez, Maddox, Drape, & Duke, 2014; Martin & Dixon, 2016). A prominent study of girls within maker and STEM activities highlights that changes in the materials associated with STEM can change how STEM learning is practiced and by whom with improved learning outcomes (e.g., Buchholz et al., 2014). Across the studies a focus lies on initiating engagement of women in STEM related activites through creative projects. Youth-serving makerspaces offer playful explorations of STEM tools and materials to design personally meaningful artifacts that can be shared with others (Peppler, Halverson, & Kafai, 2016; Halverson & Sheridan, 2014; Sheridan et al., 2014), which is well-aligned to constructionist theory (Papert, 1993).

Prior studies on making and maker education, however, have typically focused on either the role of projects or the effectiveness of pedagogies in generating experiences that can affect future STEM disciplines (Bowler, 2014; Martin, 2015; Tai, Liu, Maltese, & Fan, 2006; Vossoughi, Escudé, Kong, & Hooper, 2013). To date, it remains unclear how such informal and constructionist explorations translate to eventual professional and educational STEM opportunities, especially for women. Furthermore, while constructionist approaches to learning have theorized open sharing to have a transactional role in the internalization of knowledge structures, the processes of sharing to support learning and its impact on developmental trajectories in future career opportunities have been underspecified. To better understand and support the development of STEM experiences, with implications for the design of in- and out-of-school learning environments, we need to better theorize the opportunities within makerspaces that support particular traditionally underrepresented learners to move from being technology-averse to seeking future opportunities in the field.

This paper takes a case-based approach (Bassey, 1999) to theorize, describe, and analyze the emerging patterns of activity as young women engage in making and move toward expertise in STEM. Building on a material-based and constructionist (Papert, 1980) notion of making as well as mediated discourse analysis (Wohlwend, 2013; Scollon, 2001), we examine how recognition (materialized in artifacts as displaying, legitimizing, and circulating emergent STEM expertise) leads to transformational development over time. As part of a larger ethnographic study on Open Portfolio assessment in makerspaces that included the investigation of three cohorts of youth and their sharing practices (Keune & Peppler, 2017; Keune, Thompson, Peppler, & Chang, 2017; Peppler & Keune, 2019), this paper presents a close analysis of the development of one woman, Sierra's, into an aspiring engineering undergraduate major across three years. We consider the role that the remodeling of a traditional classroom piano into a digital jukebox and its placement in the makerspace played in her transformation. While similar to other cases at this makerspace, Sierra's transformation was exemplary as it laid the groundwork for other female makers to follow and build on. We analyzed semi-structured interviews of Sierra and makerspace educators, photographic and written observations, and time-stamped online posts about and by the makerspace to examine how the artifact and its physical placement in the makerspace reflected this transformation. We show how the artifact's materials displayed Sierra's emerging STEM experiences and expertise, how the placement of projects in space legitimized these experiences and expertise, and how circulation between the local makerspace and global maker communities extended her engineering recognition beyond the particular projects and learning space. In theorizing this, we introduce the notion of *tinkering with development,* which conceptualizes playful project design, spatial project placements, and emergent online project sharing as drivers of human developmental trajectories. Implications of this work include a set of design principles to support makerspaces and other constructionist learning environments to foster women's participation in STEM. Further, implications for constructionist theory and understanding the transactional role of sharing in learning are discussed.

2. Theoretical perspective

Constructionism is an approach to learning in which learners come to know the world through design as they create personally meaningful artifacts that can be publicly shared (Papert, 1993). Using technological tools and construction kits, learners can become designers by turning materials into "objects-to-think-with" that allow them to explore and internalize the inherent properties and formal ideas of digital and physical objects (Papert, 1980). This process also allows learners to become epistemologists who observe their own learning, as constructionism values multiple ways of knowing and the different kinds of knowledge being produced (Harel & Papert, 1991). The iterative design process encompasses imagining a project, creating a prototypical representation, playing with it, and publicly sharing it with others (Resnick, 2007).

In constructionist learning, sharing is reciprocal as it serves the purpose of deepening the engagement in construction and therefore potential disciplinary experiences (e.g., Resnick, 2007). However, the components of sharing to support the process of the learners' growing expertise as well as the concrete impacts sharing can have on learning have been underspecified. For example, as learning emerges from the individuals and their engagement with the provided material environment, it is unclear how to specifically direct sharing toward intentional learning outcomes. Our work explores material, spatial, and digital aspects of sharing and how they work to foster the development of people within constructionist learning environments.

Although constructionist approaches to learning do not set limits on when learning can happen and across what time spans, scholars have predominantly focused on shorter-term developmental phenomena also due to funding cycles and the cost of longer-term engagements. Examples of this include circuitry learning through electronic textiles within a 20-h afterschool workshop (Peppler & Glosson, 2013), goal setting through bursts of engagement with museum exhibits (Bevan, Gutwill, Petrich, & Wilkinson, 2015), and learning to program through a 7-week robotics curriculum (Sullivan & Bers, 2017). While such short-term engagements have shown important implications for learning about fundamental aspects of engineering, it results in knowledge gaps about the impacts of longer-term engagement on development and the mechanisms that support such longer timescales. Our work theorizes how the longer-term co-development of artifacts and people can create a transformative process for recognition, especially when people have access to high-quality constructionist learning environments.

2.1. Makerspaces as constructionist learning environments

Makerspaces are typically intentionally designed constructionist spaces located in a range of educational settings for youth to design and share projects using high- and low-tech tools and materials (Peppler et al., 2016; Halverson & Sheridan, 2014; Sheridan et al., 2014). Here, youth are provided the opportunity to explore emerging technologies alongside others while creating personally meaningful projects, making learning that might otherwise go unnoticed count (Halverson & Sheridan, 2014). Frequently, it has been conjectured that these experiences become hubs of technological inventiveness that make high-technological tools and materials — including 3D printing and laser cutting — available to the youngest learners. High-tech, digital fabrication tools have become part of the iconography of the maker movement. However, looking beyond predominantly positioned high-tech materials such as 3D printers and laser cutters, makerspaces also feature seemingly discarded materials and other craft/hobbyist materials, including broken appliances. Through making, formerly discarded materials frequently take on new purposes and opportunities for personally meaningful artifacts similar to the piano described above.

From a constructionist perspective, these artifacts present evidence of the kind of experiences and learning that youth have engaged with, including understanding production processes and when to use one tool

over others. Exhibiting and sharing personally meaningful artifacts with others plays a reciprocal role in that sharing served the purpose of deepening engagement with the construction by providing a way to talk about one's work while also receiving new ideas for continued production (Chapman, 2009; Resnick, 2007). Capturing artifacts and construction processes in personal portfolios can make the rich learning in makerspaces visible to a range of audiences, promising to make the experiences meaningful across learning environments, including potential future employers and institutions of higher education (Keune & Peppler, 2017). Emergent work on open maker portfolios has begun to demonstrate that portfolios of youth work can stretch across digital and physical spaces, where physical artifacts displayed across learning environments can become part of a larger portfolio of work that encourages student reflection, makes peer feedback more easily accessible, and provides opportunities for audiences to interact with youth projects (Keune & Peppler, 2019). When youth design with materials to create projects that can be exhibited, the spatial set up transforms and facilitates new possibilities for learning and sharing.

This is similarly reflected in recent research that showed that everyday actions actively construct learning spaces and further theorized the role of this continued spatial development for learning (Ma & Munter, 2014; Taylor & Hall, 2013). Particularly in the context of youth-serving makerspaces, Jones et al. (2016) have investigated how community processes were created at a makerspace in a predominantly Latinx and African-American neighborhood and how these processes informed design changes for the space to produce opportunities for equitable engagement in learning. Adding to this body of work, our study particularly focuses on how physical placement of portfolio artifacts can drive digital capturing and future learning opportunities and investigates how the intersection of digital and physical sharing impacts developmental trajectories for women. This is of particular interest, as the new generation of makers appears to be more gender diverse (Keune & Peppler, 2019).

2.2. Underrepresentation of women in engineering & the potential of the maker movement

Traditionally a far more masculine field than other STEM disciplines, engineering remains an area in which gender representation remains consistently lopsided, particularly in the United States (Bix, 2014). In 2015, for example, 12% of engineers were women (US Bureau of Labor Statistics, 2015). Since the 1970s the representation of women in engineering majors has only slightly changed, although the proportional representation of women in engineering has grown due to an increase in women's enrollment in college and a decline of interest in engineering by men (Sax et al., 2016). Those women who are enrolled in undergraduate engineering majors are twice as likely to switch their majors to other fields (Cech, Rubineau, Silbey, & Seron, 2011). The underrepresentation of women in engineering is particularly problematic as diverse workplace environments have been linked to national economic security and productivity (Sax et al., 2016).

Recent research suggests that informal and out-of-school learning opportunities play an important part in broadening the diversity in STEM careers (Dasgupta & Stout, 2014). In particular, making expertise and experience visible across learning settings holds a great deal of promise in successful STEM pathways (Bell, Bricker, Reeve, Zimmerman, & Tzou, 2013; Saavedra, Araújo, Taveira, & Vieira, 2014). We argue that the underrepresentation of women in engineering is due, in part, to a lack of recognition of their expertise and a lack of honoring and associating their engineering experiences in STEM within learning settings. By contrast, constructionist learning environments, such as the makerspace presented in this paper, can support equitable engagement of traditionally underrepresented youth in STEM through "critical, connected, and collective" (Barton et al., 2016, p. 39) activities in physical spaces that afford youth opportunities to decide where to conduct their explorations, and, thus, to question established

boundaries. This work starts to uncover the importance of the physical makerspace setting in artifact construction toward STEM experiences that may lead to future opportunities. Our work investigates remaining questions about the reciprocal role among artifact construction and artifact sharing within physical and by extension, digital makerspaces, for fostering the recognition of women's STEM expertise and pathway development.

2.3. Mediated discourse theory to recognize experiences and expertise

An artifact's histories of use are layered onto its materials in ways that influence its future users and uses; that is, the histories of practices used to make a thing or how, why, or where it is used shape how it is expected to be used and who can use it (Rowsell & Pahl, 2007). These sedimented layers of use can be unpacked through mediated discourse analysis of artifacts not only as objects-to-think-with that reveal a maker's developing concepts and design decisions, but also a maker's trajectories of developing expertise and social histories of participation in maker cultures and STEM fields. They produce observable evidence, which can be theorized, captured, and analyzed for processes and conditions where semiotic and social transformation occurs (Norris & Jones, 2005). Projects in makerspaces are analyzed as texts-in-contexts that display their makers' experiences as well as recognition by other makers. Such artifactual displays, then, present spaces that materialize and absorb the experiences of their makers in ways that honor and legitimize the associated expertise and open up the potential to transform the maker and the community as the messages that are layered onto the artifact can be circulated and talked about (Pahl & Rowsell, 2010; 2011). Just as changes to an artifact's design reflect a merger of production practices in the material's and maker's interaction, changes in where, how, and whether an artifact is displayed within a space reflects its value as a marker of (a maker's) expertise within the makerspace.

By tracking the uses, designs, and placements of artifacts in their cultural and sociopolitical contexts, *mediated discourse theory* explores the possibilities for positive change by uncovering the working of power in everyday practices (Scollon, 2001). To do this, mediated discourse theory looks at how social practices develop, how social practices materialize tacit expectations for participation and recognition in everyday actions and artifacts, and how seemingly small changes in an action or artifact can shift power relations and broaden access to learning (Norris & Jones, 2005). Learning is multimodally expressed beyond text and speech, including sound, visuals, proximity and posture, and intersections of these modes can further presents ways to express semiotic messages (Kress, 2009). For example, when makers construct personally meaningful artifacts, they use social practices such as sewing or woodworking to create artifacts but also to develop their own expertise as they think with the multimodal meaning potentials of objects to alter the surrounding physical environment. In the process, they emphasize an object's sensory properties, its conventional meanings within a particular culture, as well as its histories of uses and users and its trajectories of circulations across spaces. In this process, artifacts become more than objects-to-think-with; they become semiotic aggregates, which suggests that the intersection of material artifacts, semiotic means, and social practices can produce affordances for action and learning (Scollon & Scollon, 2003).

Together, this suggests that mediated discourse theory can operationalize the learning and recognition of engineering experiences and expertise by women within makerspaces, suggest how personally meaningful artifacts can evidence this expertise, and point to starting points for characterizing longer-term sharing processes that foster the development of STEM pathways through displaying, legitimizing, and circulating experiences and expertise.

3. Methodological approach

This qualitative ethnographic study was guided by a mediated discourse approach (Scollon, 2001) and a constructionist approach to learning to investigate the opportunities within makerspaces that display, legitimize, and circulate young women's recognition as engineers. Research questions guiding the study covered three topics:

1. *Displaying expertise.* How does the placement of materials on a project display a young woman's development of new experiences and expertise in engineering?
2. *Legitimizing expertise.* How does the placement of the project in space legitimize the experiences and expertise of a woman in engineering?
3. *Circulating expertise.* How does circulation between the local makerspace and global maker communities extend engineering recognition beyond particular projects and learning spaces?

These research questions guided our analysis of parts of a larger data set that we collected during a three year ethnographic study of three youth-serving makerspaces selected from 55 makerspaces that responded to a maker site survey (Keune & Peppler, 2017; Peppler & Keune, 2019). The larger study aimed to understand the use and function of portfolio assessment within in- and out-of-school makerspaces. We selected an educational single-case study (Bassey, 1999) from four similar cases we followed at the same site throughout the study as an instrumental case (Stake, 1995) that demonstrates how female makers choose STEM careers at this site, and it details how makerspaces can foster pathways for young women in engineering more broadly.

3.1. Research site

The setting of this study was an urban out-of-school makerspace in the eastern United States. The makerspace was established in 2013 as part of a revitalization movement to turn former recreational centers into spaces for technical and creative learning. The makerspace services 6- to 18-year-old youth from across the city, including youth from low-income communities, in two areas, one for 6- to 10-year-old youth and another for 11- to 18-year-old youth. We worked most closely with the area that served older youth. At the time of the study, this area of the makerspace had 66 members (65% male, 35% female). The makerspace offered these youth a space for creating personally meaningful artifacts with high- and low-tech equipment — ranging from 3D printers, laser-cutters, and computational boards to cardboard, pipe cleaners, and popsicle sticks — through courses lasting from 6-weeks to a semester as well as open-ended maker programs. Throughout the physical setting of the makerspace, youth projects are displayed on shelves and walls as well as tucked between furniture and beneath tables. Some of the youth projects stood out to visitors of the space, including the digital jukebox piano, a technology augmented and chalk-paint covered classroom piano with copper-tape poking out beneath the piano's keys.

We selected this space as our study site in part due to its low representation of female participants as well as the educators' commitment to mindfully fostering broader enrollment by female youth. This presented an ideal environment to investigate the opportunities for makerspaces to foster STEM pathways for women despite low female enrollment, and is particularly important for other makerspaces with similar gender gaps that seek to expand opportunities for young women in engineering but have faced challenges doing so.

3.2. Participants and case study selection

At the time of the study, the makerspace serviced 66 youth, ages 11–18, including 3% Asian, 55% African American, 38% White, and 5% Latinx youth, of which 65% were male and 35% were female. The ethnographic approach of the larger study engaged with a group of 22 youth at this site to investigate their project construction and portfolio capturing practices from their personal perspectives. We captured semi-structured interviews with youth, reflective field notes of participant observations, photographs for the space (including periodic 360° photographs of space and detailed pictures of youth projects and engagement), and copies of youth portfolios, including their personal websites as well as online posts about the youth and their projects. Makerspace educators recommended specific youth to us based on their exceptional projects and portfolio practices. These youth had been regular participants at the makerspace and captured their projects more frequently or in more depth than other youth. We selected four youth for further case-study analysis because their practices represented a range of approaches for sharing projects — including digital documentation of their work and prominently featured artifacts in the makerspace that served as examples of how the space honored youth experiences through open display.

The case study presented in this paper represents one youth who created a highly visible project by layering emerging technologies, such as computational breakout boards, onto a musical instrument that makerspace educators intended to discard, turning an undervalued artifact into a high-profile showcase. This young maker, Sierra, a white female participant who was 14 years old when she joined the makerspace. Sierra told us it was her mother's idea that she join the makerspace, as a means to bolster her college applications with a technology-focused out-of-school activity, which Sierra was hesitant about at first. Her case is similar in many respects to the other cases we observed, including young women who also developed engineering expertise, such as biomimicry, mobile game development, and robotics while at the makerspace. However, all of these youth joined the makerspace after Sierra and referenced her and her work either directly or by building on the possibilities she had initiated for other female makers at the makerspace. Because her project was emulated and expanded upon by other females, Sierra makes an intriguing instrumental case for female making and engineering. This pioneering and historic nature of Sierra's case makes an instrumental case. An in-depth analysis of her development is particularly important for makerspaces that are seeking to foster engineering opportunities for young women. Specifically, the focal case of Sierra in this paper illustrates how young women's experiences and expertise in engineering can be strengthened in makerspaces and other constructionist learning environments. The case presents a moment to unpack in order to understand what the conditions that could support such transformation and that could be replicated in other technological learning settings.

3.3. Data sources

As part of the larger qualitative and ethnographic study, we collected data from a range of sources, including semi-structured walking interviews with youth participants, photographic and retrospective written observations by the first author, as well as youth online documentation of projects and activities. The research presented here uses a single-case study approach (Bassey, 1999) to analyze a particular part of this data related to Sierra.

3.3.1. Participant interviews

Semi-structured interviews were conducted with all four focal youth, including Sierra, and four makerspace educators, each lasting up to 30 min. During the interviews we asked the youth to walk us through their personal portfolios and educators to share the makerspace portfolio, to tell us about their favorite projects and how they were constructed, including the tools and processes that youth employed. When possible, we also asked the youth to show us their projects in the physical makerspace. The interviews were inspired by a walking interview approach (Clark & Emmel, 2010; Rieman, Franzke, & Redmiles, 1995) and were video recorded, transcribed, and coded for recurring themes, materials used, and challenges encountered.

3.3.2. Photographic and written observations

Throughout the study, we captured photographic observations of youth engaging in the construction of personally meaningful artifacts that others could view and talk about as well as the final products. In all, 640 photographic observations were captured, and 66 of these included depictions of Sierra and her piano project. The photographic observations were described in detailed reflective field notes of 56 h of participant observations of youth over 36 months. The photographic observations recorded direct engagement of the youth with engineering related materials and provided evidence of the constructed artifacts and how they changed over time. We also captured 34 photospheres that showed 360° still views of the makerspace's physical arrangement over the course of the site engagement at 16 timepoints, including 6 photospheres that the makerspace educators captured when first moving into the space and shared with us during the research. Of the photospheres, 19 included Sierra's project within the makerspace at 16 timepoints. All photospheres showed youth projects as well as the discarded materials used in their creation. They did not depict people. The photographs of Sierra, her project, and the space were uploaded to an online collaborative slideshow for asynchronous coding by the authors.

3.3.3. Online documentation of projects and activities

We downloaded the personal online portfolios of 22 youth, which included written and photographic documentation of their personal projects created at the makerspace as well as descriptions of their processes. We captured these portfolios as part of a larger dataset that we analyzed in relation to the effects of collaboratively created and documented work on portfolio use as well as youth motivations for portfolios (Peppler & Keune, 2019). Sierra's larger portfolio consisted of three websites with a total of 14 posts. All posts included dates, photographs, and written information that informed our analysis.

As Sierra's portfolio also included links to media archives and social media sites where she had uploaded captured videos and discussions about her work, we also performed a larger online search and downloaded social media posts that referenced either Sierra, the piano projects, or both. As Twitter was the predominant social media tool used by the makerspace and Sierra for communication about ongoing events, progress, and news worth highlighting, we focused our social media posts to this platform and downloaded all published posts that directly mentioned the makerspace, the piano project, Sierra, or a combination of these. The posts (72 in all) were published by Sierra, the makerspace educators, and other community members. Furthermore, we captured five blog posts that the makerspace educators had published about Sierra or her project on their official website. Lastly, we captured two videos recorded TEDxYouth presentations given by Sierra about her future career aspirations, one in November 2013 and another three years later, that were posted on YouTube (07:23 and 3:28 min respectively), and we archived the interactions and comments that viewers left for each. All of this online documentation by and about Sierra and her project were time-stamped and could be arranged in a progressional timeline in relation to the development of the piano project.

3.4. Analytical approach

Guided by mediated discourse analysis, we used the idea of semiotic aggregate as a unit of analysis and traced the projects' placement (Kress & Van Leeuwen, 1996; Scollon & Scollon, 2003). A semiotic aggregate is a physical artifact that accrues meaning through its materials and the ways that it is used. Using multimodal tools in mediated discourse analysis, we analyzed the material meanings of the color, shape, size, texture, and other sensory aspects of artifacts and the built environment to understand how the projects materialized public recognition of engineering experiences and expertise by a young female maker. Projects and spaces became photographic texts that conveyed their makers' histories of experiences and their developing expertise.

3.4.1. Analysis of participant interviews

Following the framing of a personally meaningful project as semiotic aggregate and Sierra as a purposeful designer, we first turned to Sierra's and the makerspace educators' semi-structured interviews. We transcribed the interviews, and our analysis focused on identifying the projects Sierra considered meaningful, as well as the materials she employed and those she found challenging. We looked at a traditional musical instrument that transformed into a polysemic and multi-purpose artifact. Sierra's interview provided a first-person perspective of the experiences Sierra had when creating the piano and what she learned while engaging with the artifact construction. Our analysis of the educator interviews focused on identifying the meaningfulness of the artifact to the broader makerspace community and triangulating timelines.

3.4.2. Analysis of photographic and written observations

During our analysis of the photographic and written observations we focused on project photographs and observations of the makerspace to locate emplaced objects as potential sites of transformation. We analyzed the transformation of the piano into a digital jukebox and as such, a semiotic aggregate, through a multimodal analysis (Kress & Van Leeuwen, 1996; Scollon & Scollon, 2003) that mapped converging practices and histories in the project as evidence of supporting or competing social discourses and materialized markers of displayed experiences and expertise. We particularly focused on the way materials were placed where they "should not be" for the piano to remain a traditional piano. In addition to observations related to the piano project, we also looked at materials displayed at the makerspace that were similar to those that Sierra layered onto the project. Examination of changes in the artifact's histories of use could identify Sierra's use of publicly available design features to try out multiple new practices that could display her work and, by extension, herself as a contributor to the makerspace.

Looking beyond the placement of materials on the project to what was produced by the placement of the project in space, we used the 360° photographs to reconstruct a birds-eye-view floorplan of the space, which we augmented with the positions of the project within the makerspace over time. On the floorplan, we tracked the changing position of the digital jukebox piano and persistent adjacent material arrangements, such as furniture-like areas, through code preference and emplacement analysis to illustrate how they partitioned sections as mediators for displaying Sierra's experiences and expertise.

3.4.3. Analysis of online documentation of projects and activities

Following the notion of semiotic aggregate (Scollon & Scollon, 2003), we combined material mapping of the piano's placement in the physical site with a placement analysis of the project in virtual space across digital networks. The online documentation of projects and activities served three analytical purposes: 1) triangulating the project placement in space, 2) connecting digital communication to the physical project placement over time, and 3) illuminating emerging learning opportunities.

First, we drew on social media photographs of the piano to triangulate the movement and development of the project prior to our site engagement. The photographs included visual information (e.g., wall drawings) that helped locate the piano position in the physical makerspace at different timepoints. This allowed us to more accurately define the movement of the project in space in relation to both time and display opportunities.

Second, we used the timestamps of the online posts to reconstruct a timeline of the posts and linked those timestamped online posts about the project and Sierra to the placement of the project in space. This provided a way to illuminate how the project was absorbed into the makerspace as well as when and where opportunities for legitimizing Sierra's experiences and expertise happened, further illustrating when and by whom Sierra's experiences were taken up and circulated in the

wider makerspace community.

Third, we analyzed the online documentation of both the project and Sierra's activities, looking for emergent learning opportunities that supported the circulation of displayed and legitimized discourses between the local makerspace and global maker communities. This deepened our analysis of circulating discourses as it helped reveal in what ways the project designer became an expert in the wider cultural space and how her experiences and expertise were recognized beyond a single project.

We progressively examined intersections of gender and expertise through layers of analysis and created a form of triangulation that traced the inter-relationships among the participant's emergent expertise, the materials of the project, and the positions of the project in space. This illustrated how learning opportunities were propelled by displaying, legitimizing, and circulating engineering experiences and expertise at the makerspace.

4. Findings

4.1. Introducing Sierra's emerging expertise

As one of the first female youth at the makerspace, Sierra joined the program in October 2013 without any experience with engineering technologies. When she joined the makerspace, Sierra aspired to be a photographer. In her personal portfolio, titled "My Life Adventures" (Fig. 1) that she created at the time (10/2013), she shared some of her macro photography (close-ups) of blooming flowers, in which she played with angles and natural sunlight to produce dramatic compositions and detailed anatomy. Other photographs were of beach scenes and railway tracks that she took during family holidays. These photographs were overlaid with inspirational quotes by well-known poets that spoke about the role of traveling to learn more about oneself. In her introduction, she explained that her portfolio was intended to share everyday encounters through photographs as a way to support her curiosity to "learn new things each and every day." In other posts she described photography as something that she had a "true passion for" and stated that she shared her passion publicly in an attempt to inspire others. The way she shared this passion was by communicating directly through her photographs, sharing the completed artifacts, the products, as message-bearing texts to her portfolio. This did not, however, convey information about the tools, specific locations, and processes she employed to create them.

Sierra's experiences with photography shifted as her engagement with the makerspace grew, and she attended after-school sessions two to three times per week. She enrolled in a foundational course, where she explored creating an LED circuit. She continued to collect experiences and expertise with emergent technologies and ultimately began work on her favorite project, the digital jukebox piano. Sierra captured

Fig. 1. A screenshot of Sierra's photography portfolio (10/2013, Sierra's portfolio).

the production process of the artifact on a new portfolio page dedicated to this artifact. On this page, she displayed detailed images of the technical set-up, embedded a video she created to document the technical functionality of the artifact, and updated every iteration of the project. For example, after working on the project for five months (seven months after joining the makerspace), Sierra captured her work process on her portfolio page:

> I first painted the piano white and then came up with the idea to cover the piano keys in tin foil and use the Makey-Makey for the circuit. We discovered that the wires were not sticking too well to the tin foil and always coming off when the keys were pressed. It was getting aggravating so I decided to solder the wires to copper tape and would hot [g]lue that onto the keys. (Sierra, 05/2014, Sierra's portfolio)

This excerpt evidences the technical fluency and comfort with iteration that Sierra considered worth sharing, especially when she accurately names technical tools (e.g., "Makey-Makey"; Silver & Rosenbaum, 2012) and technical processes (e.g., "solder") as well as identifies challenges (e.g., "wires were not sticking") and alternative solutions (e.g., "solder the wires"). Later, she posted an update (no timestamp available) and elaborated on the progress of her design: "I wanted to add LED lights to it so I soldered the LED strip to a microphone (to have the lights go with the sound of the music) …" This stands in direct contrast to the product-centered sharing that her photography portfolio conveyed, where she did not highlight the technical equipment she used to produce her photographs, including camera and lens type or exposure time; her photography portfolio instead focused on sharing completed products and the meanings they could convey to others. By contrast, the new, technical portfolio focused on production processes and iterations that captured moments of frustration and failure as well as emergent ideas for workarounds that made use of practices commonly associated with engineering (e.g., soldering wires). This seems to underscore a shift in experiences and highlights a new-found expertise that working with the project made possible: similarly to final products, solution-finding processes could also be inspirational for others.

Beyond developing personal experiences and expertise in engineering, Sierra sought to inspire other participants like her, namely young women, to participate in STEM activities. The makerspace highlighted Sierra's interest in the role of girls and women in STEM through a blog post about her role in establishing an all-girls maker program at the makerspace. The post quoted Sierra:

> I started this group as a way for girls to be more comfortable here, to become more united, and to take action in the STEM industry. (…) I believe that many girls enjoy it, but are pushed away because it isn't a typical female activity.

This excerpt reflects the personal experiences of a women who first merely used digital technologies (i.e., digital photography) and then learned to produce them (i.e., jukebox piano), while continuing to seek out additional opportunities (i.e., applying to engineering majors in college). Establishing a platform for other young women to follow in her footsteps presents Sierra as a catalyst, pioneer, and spokesperson for fostering gender equity in STEM education. As an historical case, an in-depth analysis of her development is particularly important for makerspaces that are seeking to foster engineering opportunities for young women. Specifically, the case illustrates how young women's making experiences and expertise in engineering can be strengthened over time through regular opportunities to engage a project in makerspaces and other constructionist learning environments. During our 36-month engagement with the makerspace, Sierra continued to develop the artifact and decided to apply to engineering majors in college. To better understand how this transition into engineering happens, next we turn to an analysis of the artifact and the experiences and expertise it made visible.
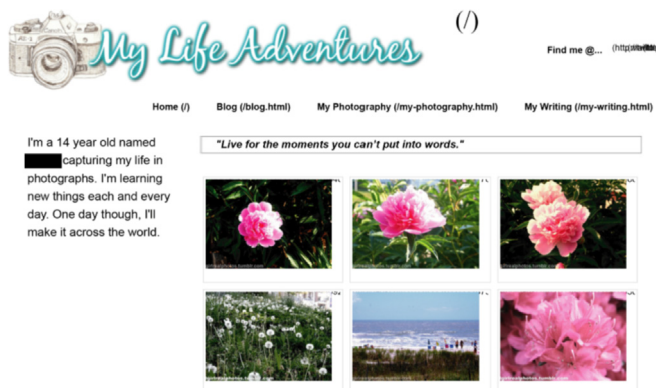
4.2. Displaying engineering experiences and expertise

Sierra began her work on a traditional classroom piano, layering emerging technologies onto an undervalued artifact to create one of the largest and most openly shared showcase projects of the makerspace community: the digital jukebox piano, a technology-augmented version of a player piano that played pop songs when piano keys were pressed, accompanied by lights that flashed to the rhythm of the music.

In the semi-structured walking interview, Sierra highlighted major iterations as well as the materials that marked those iterations from an upright classroom piano to a technology-augmented jukebox piano: "Every time (I) changed something major about it. When I added the lights, redoing the wiring, painting it, that is an iteration to me." In this excerpt, Sierra suggested that transformation of the artifact was directly related to technological materials. She referred to the LED light strip that was designed to flash to the rhythm of the music, the wires that connected copper-tape-covered piano keys with a Makey-Makey breakout board, a computer used to trigger a pop music playlist, and the paint she used to cover the piano in order to turn the instrument into a large three-dimensional canvas. For Sierra, it was the playful integration of lights, wires, and paint that composed the transformation from traditional classroom piano to the digital jukebox piano. Paying attention to these materials as the project progressed pointed to how Sierra not only produced the artifact but how she wielded emerging technologies to create an opportunity for displaying her experiences and expertise in recognizable ways. The piano became a semiotic aggregate with intersecting practices and discourses that were connected to Sierra and could be read by other people (see Fig. 2). In the following section, we analyze these intersecting practices and discourses to illustrate how the project displayed Sierra's design experiences and growing technological expertise, focusing on the final artifact. In subsequent sections (4.3 and 4.4), we present a temporal and spatial analysis of how Sierra's making layered these practices and discourses onto the piano over time. The presentation of the layered discourses on the final piece is important to establish a baseline for the reader.

4.2.1. Chalkboard paint and national discourse

Sierra covered the piano with chalkboard paint similar to other makerspace furniture and added illustrations of the White House and a US flag. Reading the illustrations from left to right referenced a hopeful and promising developmental progression: The White House was where the piano was and the flag where it could go. This developmental and national discourse intersected with art making discourses with the piano as canvas, which was further highlighted by the placement of Sierra's name on the project, a practice that stood out at the makerspace where none of the other projects were attributed to particular makers through visual markers, which represented a genre mixing, where

Fig. 2. The digital jukebox piano as semiotic aggregate with intersecting practices and discourses. (Sierra, 07/2016, photographic observations).

signing traditionally fine-art pieces is common, while less common in technical art making. This introduced an art discourse to the project, intersecting it with public discourse more often found in making (Bardzell, 2018). While it communicated that "Girls can make anything," it equally communicated that an individual created this project. These intersections created an articulation of experiences that could be recognized at the site of the piano by onlookers and connected to Sierra as the purposeful designer.

4.2.2. LEDs and art discourse

The light-emitting diodes (LEDs) that Sierra placed on the piano's fallboard positioned materials that are predominantly featured in other makerspace projects in the center of the piano. Visually, it created a horizontal line that suggested the significance of this technology augmentation, cutting across the entire frontside of the piano. The placement of the strip at first sight revealed little about its technical functionality and production process, but it resembled high-end interaction designs displayed at international art and media centers that frequently invoke products over process. At the site of the LED strip, technology and art practices intersected, providing an opportunity to explore technology-art experiences. We frequently observed that creating a basic circuit to light an LED by tightly connecting positive and negative ends of an LED with the positive and negative sides of a coin-cell battery was a foundational activity at the makerspace. Other projects that integrated LED light strips included the large cardboard sign that spelled the acronym of the makerspace's name, centrally positioned on top of a bookcase across from the entrance. The cardboard sign was connected to the space's social media account and lit up in a range of colors in reaction to mentions of the makerspace in social media posts. Perhaps inspired by the interactive properties of this project, Sierra also added responsive qualities to the piano's LED strip. Here, the LED strip flashed to the rhythm of the song being played on the piano, requiring the use of computational materials. The LED strip integration was a step beyond that activity, because it required additional technical explorations that the foundational activities did not cover. Thus, the LED strip on the piano displayed experiences that went above expected expertise.

4.2.3. Makey Makey and game design discourse

Sierra used a Makey Makey breakout board — which was used at the makerspace as an entry-level maker material — to create interactive toys. The Makey Makey breakout board is a simplified computational board that can be connected to a computer with a USB cord and to everyday conductive materials using alligator clips, thereby turning mundane materials into tangible interfaces for controlling digital bits (Silver & Rosenbaum, 2012). Through the rapid feedback and playful integration of known materials, the tool makes it possible for youth to create personal inventions that infuse STEM activities with personal interests (Resnick & Rosenbaum, 2013). The board's website presents its users as imaginative inventors. Sierra used the breakout board to produce a tangible interaction that triggered digital pop songs by pressing piano keys connected to the Makey Makey, copper tape stuck on the piano keys, and a computer with colorful alligator clips. She called the wires that visibly toppled across the piano the "guts" of the tangible interactive artifact. Sierra placed the board above all other technical augmentations, in the horizontal center of the piano. Following the idea of projects as texts-in-context, the central placement of the board read much like a badge and highlighted Sierra's new technical skills. Layering new digital technologies (i.e., Makey Makey) onto the traditional mechanical technology (i.e., piano) further communicated that Sierra recognized that objects in the world are designed and that she could be a designer who could change such designs. This design agency is an empowering realization for a young person. The display of the piano's inner workings highlighted her newly gained technical skills. Furthermore, looking closely at the graphical representations that were printed onto the board, the Makey Makey visually referenced hacker and gamer culture through popular arcade game characters and
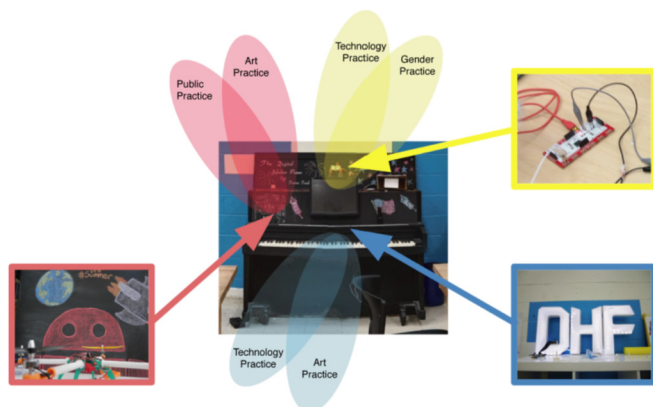
breadboard graphics, an area of technology expertise which has been criticized as masculine and exclusionary (Jenson, de Castell, McArthur, & Fisher, 2017). Communicating proficiency with tools that are culturally connected with male practice introduced an underlying discourse around gender in technology that could be read from the physical features of the artifact. Thinking with materials to produce her project allowed Sierra to transgress a predominantly male STEM space.

Highlighting the wires, lights, and paint in her speech and on her personal online sharing platform as valued productions, together, these elements displayed a convergence of technology, art, public, and gender discourses that were new to Sierra and that she connected to a changed career path. Sierra explained:

> I learned that I like circuitry a lot. So I never used to like technology, but like messing around and soldering wires and figuring out how to make it into a circuit was exciting. I decided that my major in college is going to be electrical engineering and that probably has something to do with it. That was 9th grade. I'll start applying mid-August. (Sierra, 07/2016, semi-structured interview)

This excerpt shows that Sierra did not originally view technological practices as either enjoyable or part of her imagined future. Her view changed when she started to tinker with the materials and design of the project; her new-found expertise presented a way for her to identify and display something "exciting." Immediately following this transition, Sierra began talking about her plans to major in engineering in college, which aligned with her newfound delight with the practices and materials that are closely linked to engineering, suggesting that Sierra directly linked the production of the digital jukebox piano to a transformation of her expertise and a path toward a technology-related career. What this does not reveal is what set Sierra up for taking this leap and, in the following section, we elaborate on the history of this development to illuminate the processes that worked to legitimize her engineering experiences and expertise over time.

4.3. Legitimizing engineering experiences and expertise

Looking across the 360° pictures and photographic observations of Sierra's project revealed that the piano shifted its placement within the makerspace five times. The makerspace staff changed the physical set-up of the space frequently to try out new facilitation techniques and to accommodate emerging educational needs, including those promoted by new technologies (Keune & Peppler, 2019). These changes in turn had an indirect effect on the placement of other materials in the makerspace, including the piano. The movement of the piano was a negotiation of several factors within the makerspace. These changes in the physical placement of the artifact created certain constraints and affordances for the visibility of the artifact and its connected experiences and expertise. The physical placement analysis illuminated how the artifact's placement in relation to other activities at the makerspace presented opportunities for legitimizing the female maker's expertise as engineer and as a contributing member of the makerspace community. The dates throughout the following analysis refer to the position of the piano in the makerspace at different times as illustrated in Fig. 3.

The makerspace educators moved in with the aim to turn the former underutilized recreational center into a constructionist learning environment where youth could create personally meaningful projects with emerging technologies. The wooden piano, commonly used to practice scales in traditional classroom settings, was left behind by the recreational center staff and contested the digital fabrication and online technologies they wanted youth to explore in the renewed out-of-school setting. While an instrument of high mechanical engineering ingenuity, the traditional upright piano was moved to the sidelines on move-in day (11/2012). We overheard one of the staff members reflect on the piano at that time:

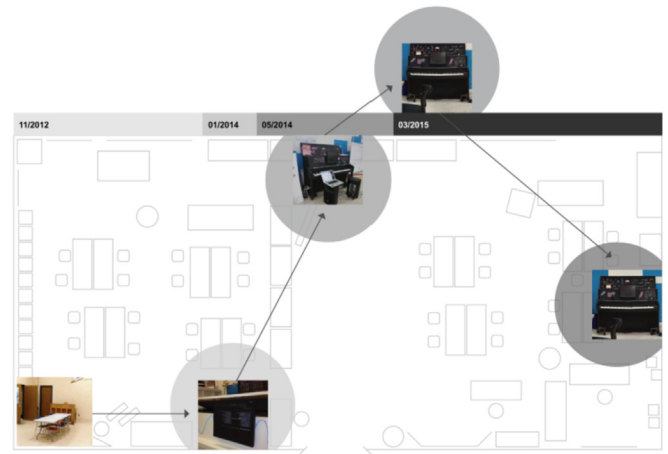"It was trash. It didn't work. It didn't function as a piano. Because

Fig. 3. The changing placement of the piano in the physical makerspace across three years.

there were keys that were broken and … we, like, couldn't get rid of it. We tried many times; no one wanted it."

With its keys facing the wall, the piano was excluded from meaningful participation and creative practices. As an undervalued artifact, the piano remained there until Sierra started to engage with it.

When Sierra began to transform the piano into the digital jukebox, the artifact shifted places next to the entrance of the makerspace (01/2014). Within a few months, Sierra painted the piano white and layered wires, a screen, and the Makey Makey board onto the artifact. Sierra engaged with art and technology discourses as well as gender and technology discourses and explored how these could be presented on the piano project. In this location, the piano turned into a project that things were being done to. It was positioned away from the wall and turned to face diagonally into the room, perhaps so that all sides were easily accessible for production purposes. However, it was positioned behind a shelf in an area of the makerspace that was commonly used for staff meetings and instructional planning. While conveniently positioned away from daily youth programs, this place for production also meant that the artifact was hidden from the sight of youth participants and makerspace visitors, and in this way obscured the display of emergent experiences by its makers.

Within a few months, the piano was moved across the entrance of the makerspace (05/2014), a visibly predominant space that anyone entering the space first looks at. Here, Sierra added paint and lights to the piano and rewired the technical connections of the jukebox functionality. The piano remained in this location for about a year. The drawings on the piano changed with the seasons, reading "Say Hello to Summer 2014" or "Winter Weather," which suggested that the piano became a display that started to be appropriated as an announcement board, highlighting its functionality as a canvas and suggesting that the piano started to become a legitimate player at the makerspace that could be displayed and shown off. However, the piano was positioned between two of the predominant partitioned areas of the makerspace. We observed staff planning meetings, furniture construction, and program preparations being frequently conducted to the left of the piano. By contrast, on the other side of the piano, youth programs and professional development sessions were facilitated. The placement of the piano in between the spaces suggested that it belonged to neither of the areas, although it was predominantly and visibly curated at the space.

In March 2015, Sierra was nominated to present the digital jukebox piano at the White House Science Faire. In preparation for the move, Sierra signed the piano and illustrated the White House and the US flag on the piano's chalkboard canvas. This event meant publicly presenting the piano outside the makerspace to people who occupied some of the highest public offices in the United States. The final physical change to
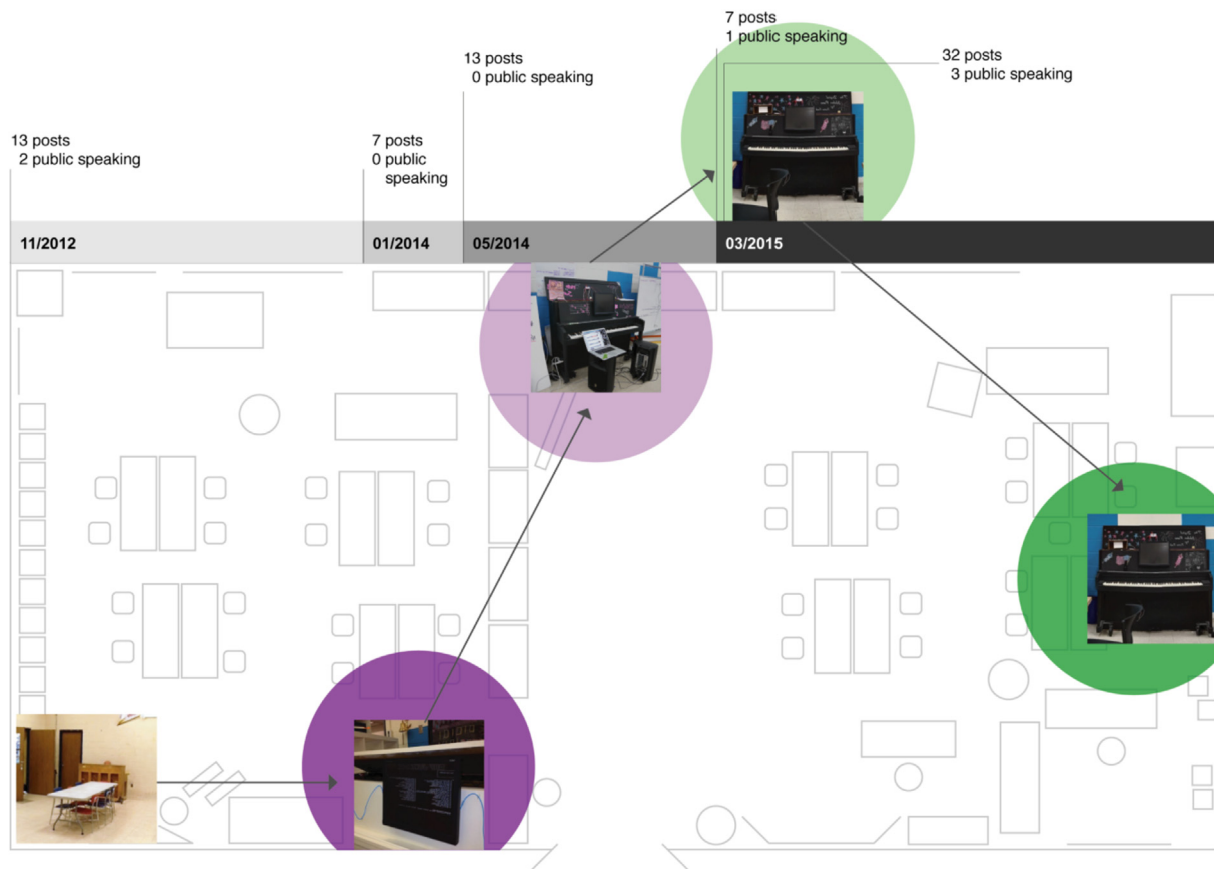
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Fig. 4. Representation of the broader circulation of the project and Sierra's expertise in relation to the project and its placement at the makerspace.

the piano was made at the makerspace, in its position across from the entrance, before the artifact moved to the White House.

Back at the makerspace, the piano was moved to the center of the left wall of the makerspace (03/2015 #2), where it remained until after our engagement with the makerspace came to a close. In this location the piano was within close proximity of makerspace programs where people snapped and shared pictures of their projects in progress and of themselves with the piano artifact in the background. The project's placement in the high-traffic area of the makerspace means that more people were able to see the artifact and therefore recognize Sierra's experiences and expertise. Its open display of technological features, the White House drawing, and Sierra's signature all referenced where the project had been and communicated to onlookers that "girls can do anything."

We observed youth as they stepped around the piano and glanced at the technical setup inside the piano box, where copper and tin foil were taped to keys and connected to the screen and the Makey Makey using alligator clips. To other youth, the artifact transparently communicated its technical set-up and the fact that any one of them, including girls, could create projects similar to the jukebox piano. Youth spoke about the digital jukebox piano as an inspiring story, reporting with wide eyes that the piano was featured at the White House Maker Faire. When others were surprised by this, youth pointed at Sierra, projecting her as a role model maker. One 11-year-old boy explained his encounter with the jukebox piano: *"My brother did this [attended the makerspace] before me and so I went to go and check everything out and like I saw it there [pointing at the digital jukebox piano] (…) she [Sierra] kind of strung it all together."* The youth explains that his first interaction with the jukebox piano happened while his sibling attended the makerspace. After joining the maker program himself, the youth had a chance to examine the piano more closely, to see Sierra as someone who could be talked to and about, and to observe the materials she used to hold the project

together. The marked history of the digital jukebox piano was visibly accessible to other youth in the space through its position in the makerspace. Cables and raw materials of the project on open display, made it possible for the youth to identify which tools were used to create the project, recognizing the tools they themselves learned to use just weeks prior. The physical presence of the project in the space makes the extraordinary story of the artifact tangible. What is more, they knew Sierra and could refer to her presence as just "over there," framing her as one of their peer learners at the makerspace. The physical object references an aspirational and promising story that, by affiliation, extends beyond Sierra and the material presence of the project to all youth of the makerspace. The position of the artifact highlighted Sierra's expertise as an example of possible transformation: As the piano's maker she was someone who did not know how to use electronics and microcontrollers, but who nevertheless created a project that was highly visible and valued at the makerspace. This perpetuated the idea that the project, while special and noteworthy, is an example of the kind of project any of the youth can make if they continue making. The digital jukebox piano became a staple conversation piece at the makerspace and was included as part of tours for visitors and newcomers. The artifact was absorbed into the makerspace and legitimized the young woman's expertise, framing her as a contributing member to the makerspace community. Although the artifact was several years old at the time of our visits to the makerspace, it continued to draw attention and we could see an increase in its legitimation through migration.

4.4. Circulating engineering experiences and expertise

Where the changing location of the piano project within the makerspace placed it in higher and higher prominence and led to the project being absorbed into the makerspace as well as legitimizing Sierra's experiences and expertise, the project also circulated outside
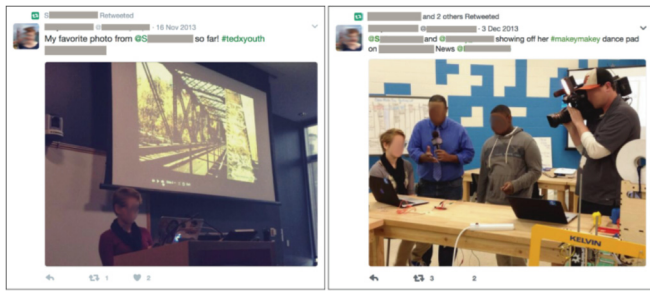
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Fig. 5. Online post of Sierra's photography TEDxYouth talk (left) and local newscast (right).

the makerspace across the wider maker education community. This extended circulation further contributed to the recognition of Sierra as an engineer. While the circulation of the project outside the makerspace was proportional to the legitimization process, it also opened up learning opportunities that detached Sierra's expertise from the project and the makerspace. Fig. 4 illustrates how the broader circulation linked to the project and its position at the makerspace.

While positioned *against the wall*, the piano artifact was not circulated outside the makerspace through social media or online posts. Instead, educators shared Sierra's mastering of maker tools, such as the Makey Makey, on the makerspace Twitter channel. Furthermore, public speaking opportunities endorsed Sierra's art and technology interests as she presented herself as an aspiring photographer in a TEDxYouth talk and shared her technology projects in a local newscast, in which she featured a project created with a Makey Makey breakout board (Fig. 5). Both public speaking opportunities were facilitated by the makerspace educators and presented opportunities for the makerspace to show the youth's engagement with the activities offered. These learning opportunities also afforded Sierra opportunities to communicate her expertise in artistic explorations as a photographer and in deepening her newly learned technological practices. Art and technology practices were supported and publicly circulated aspects of Sierra's repertoire inside and outside the makerspace. While Sierra's TED talk highlighted the photographic experiences that she brought to the makerspace and shared on her personal website, the local news media broadcast focused on the early technical explorations she experienced at the makerspace and framed her as a recipient of innovative educational interventions.

When positioned *next to the entrance*, the project was shared beyond the physical makerspace through Sierra's personal website and one social-media post created by a makerspace educator as an emergent project there. This suggested that the process of developing experiences through production was the focus, further substantiating that at this physical space and in this stage of the project, Sierra's experiences and expertise were emerging and were not yet displayed or serving to legitimize, because the artifact was still in progress and hidden from site.

Across from the entrance, construction of the artifact continued. By contrast to the prior production space, the construction intersected with recurring circulation of the artifact online beyond the physical makerspace. The piano was frequently featured in the background of photographs shared by visitors, news media, and staff members of the makerspace, including collages and individual photographs that were taken during events (Fig. 6). The photographs demonstrated that the jukebox piano had become a staple piece of furniture that blended with the other materials of the makerspace. The circulation of the project in the online public space further contributed to legitimizing Sierra's contribution to the makerspace. The project was absorbed by the makerspace.

The *White House Science Faire* framed Sierra's project as a young woman's dedicated involvement with technology, which circulated the gender and technology discourses that were displayed at the site of the artifact across the broader maker education community. The makerspace advertised this exceptional experience on their blog and, during

the event, photographs of Sierra and her project circulated online (Fig. 7, left). Most of these were posted by the makerspace educators and Sierra herself. Some posts were further circulated by prominent figures in the maker community. Presenting her work and expertise at the Science Faire also opened up additional opportunities for Sierra to demonstrate her expertise. Sierra was invited to participate in a public panel focusing on girls in making (Fig. 7, right). The makerspace blogged about these events, quoting Sierra: "it was the first time I was getting recognized for the work I was doing." Where the White House event linked the gender and technology discourse directly to the piano project, the panel was the first time, Sierra publicly presented her aspirations for fostering gender equity in STEM pathways without the piano being physically or visually present.

Back at the makerspace, positioned in the *youth program area*, the jukebox featured even more frequently in the background of photographs that were shared online by visitors and makerspace educators, most notably perhaps in the background of a Department of Education conference and selfies by makerspace participants and their parents. Furthermore, visitors and makerspace staff shared photographs that showed the project in the foreground, including collages of the makerspace and portrait-like images of the project. Together, the frequency of sharing and the content of the posts highlighted the artifact's important role in making the makerspace. A potential risk of this recurring circulation of the work outside the makerspace was that Sierra could become divorced from her labor. Makerspace educators counteracted this, however; they facilitated opportunities for Sierra to publicly express her experiences and expertise, including a second TEDxYouth talk on gender equality and a keynote speech at a Girls Scout summit (Fig. 8). Furthermore, the makerspace blogged about Sierra and highlighted her as the catalyst of an all-girls maker program that she initiated in response to noticing that many female participants left the makerspace. This was a transformational moment for the makerspace and the recognition of Sierra as an equity-oriented maker. All of the public learning opportunities contributed to strengthening the intersection of technology and gender discourses that her project displayed, that were legitimized by the more and more highlighted positions of the artifact at the makerspace, and that circulated beyond the makerspace through learning opportunities. Notably, the public learning opportunities (i.e., the TEDxYouth talk, the Girls Scout summit, and the all-girls maker program) referenced the intersection of technology and gender discourses without a dominant link to the piano project. The ways Sierra presented her expertise were uncoupled from the piano project; the intersecting practices and discourses stood alone; and Sierra applied to an engineering program in college.

5. Results and discussion

In constructionism, sharing plays a transactional role in the internal development of students. Showing and talking about personally meaningful artifacts makes it possible for youth to deepen their knowledge of materially embedded ideas and, in turn, to foster further construction possibilities. Sierra's case illustrates that the sharing of personally meaningful artifacts can also extend beyond the cognitive development of youth and begin to drive a new recognition of STEM expertise in traditionally underrepresented youth, especially women, that ultimately translates into further learning opportunities and career pathways for that group. Furthermore, the case presents starting points for operationalizing the mechanisms and characteristics of sharing that encourage opportunities for increased recognition of STEM expertise for women.

In the future we may consider how to improve our recognition of underrepresented populations in STEM through materialized artifacts. In doing so, we may begin to create opportunities for youth to display emergent expertise that becomes materialized in artifacts, and to honor and legitimize their expertise by a heightened presence of their work in makerspaces. Our work operationalizes sharing as the interplay of

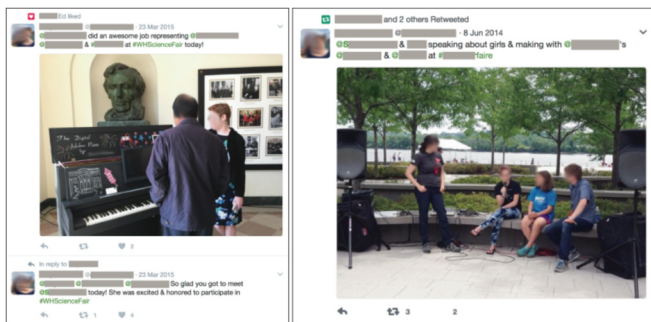Fig. 6. Online posts of the piano by makerspace visitors.

Fig. 7. Online post of Sierra and the piano at the White House (left) and of Sierra during a public panel focus on girls in making (right).
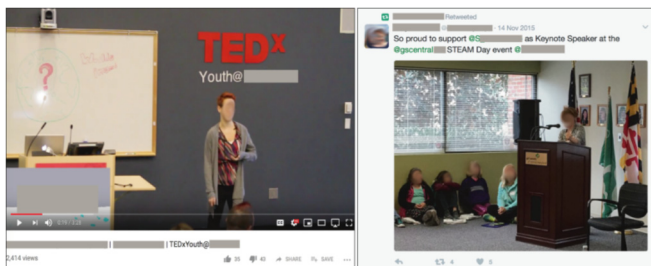

Fig. 8. Online post of Sierra's gender equity TEDxYouth talk (left) and Girls Scout summit keynote (right).

displaying, legitimizing, and circulating, where increasing the recognition of STEM experiences and expertise can impact those youth whose STEM expertise has traditionally been less honored and acknowledged.

In addition to recognition of youth expertise in STEM fields, this study also shows how long-term sharing and a long-term display of artifacts in physical makerspaces impacts pathway development. Despite the prolonged presence of the piano in the makerspace, the artifact did not lose importance. To the contrary, the changes in its placement in the space actually heightened its value to the makerspace and its members. The addition of emergent technologies on seemingly valueless artifacts and the placement of these new technology-augmented artifacts within physical spaces can lead to important developmental changes. We conceptualize this actively constructed phenomenon within the community of the makerspace as *tinkering with development*, highlighting the transactional role of sharing as materialized in both the artifacts themselves and the physical placement of artifacts within constructionist learning environments in more and more highlighted positions. The placement of materials on the artifact represented a tinkering with the project that served to bring about and display engineering experiences in relation to a concrete artifact. The placement of the project in space represented tinkering with the space that provides opportunities to talk about project-related expertise in public and opportunities to uncouple expertise from artifacts. Together, this turns what were traditionally considered barriers to participation into professional opportunities and, thus, can impact development. Artifact creation, thus, is not only about knowledge construction but also about creating opportunities to be recognized.

This could be relevant to other makerspaces that have vested interests in broadening women's identification with technical making in three ways: First, our work ruptures assumptions about the design of adult-maintained out-of-school learning spaces. Showing the significance of exhibiting youth projects for the dialectical development of the youth *and* the space frames space design as emergent in relation to youth's past experiences and practices. Youth can contribute to space transformations by tinkering with projects within the space, and as a result the space becomes a safe place for exploring new experiences in ways that are recognized by others. We recommend that makerspaces consider project location as a means to foster pathway development of youth in STEM. Second, our work illustrates the importance of makerspace educators playing with the components of recognition (displaying, legitimizing, and circulating) to impact development. Repositioning the project within a visible space encouraged proliferated sharing about the projects in online spaces, and highlights the importance of making project production visible and shiftable so that others can recognize and share each maker's displayed expertise. It further calls to consider the hidden value and possibilities that seemingly valueless artifacts can hold and the value of permanence that a longer-term presence of youth created artifacts in makerspaces can create.

Exhibiting projects in space also creates implications for enhancing traditional maker portfolios. Portfolios in makerspaces are frequently considered collections of digital artifacts that are captured and shared in online platforms and which illustrate and make visible the rich experiences of youth across contexts. Our study suggests that a portfolio could also be a physical environment to walk into, to interact with, and to become part of the making expertise. These "spatial portfolios" can highlight how expertise is displayed on projects and accentuates the transformative role of the placement of projects as important aspects of sharing an individual's making.

However, there are limitations to spatial portfolios, because space in makerspaces is limited and, thus, not all youth-created artifacts may be highlighted in the most visible areas of the learning environment at the same time. Makerspace educators must take time to rotate exhibits and make decisions about which projects to place where and when. More work is needed to better understand rotation strategies and the timing of sharing to best support recognition. Furthermore, as intersecting experiences can be read form artifacts, certain expertise may be legitimized and circulated over others, risking the loss of agency from the youth over their own learning opportunities and developmental trajectories. Lastly, there is a danger that youth may become divorced from their experiences and the recognition of their expertise. We consider that Sierra's case was so successful particularly because the makerspace did not stop at simply absorbing the project into the makerspace, but also supported the wide circulation of Sierra and her work, facilitating opportunities for uncoupling her expertise from the project and learning context.

6. Conclusion

This case study offers an in-depth investigation of one young woman's transformation from an artistic digital photographer to an engineering major. Overcoming limitations of STEM fields that have traditionally honored and acknowledged women's expertise less than men's, the work of the young woman in this case study not only became a valued showcase at the makerspace but also supported her own career pathway transition, pointing to the way public recognition of women's expertise can be advanced through material artifacts and their placement in space. It also pushes the role of sharing within a constructionist learning environment beyond affecting internal cognitive structure of learners, suggesting design implications for makerspaces and the use of portfolios for sharing making. The issue of the materiality of projects in makerspaces is as important as the field considers questions of equity, in particular how girls and women can build identities in makerspaces

and related STEM fields like engineering.

The educational value of out-of-school constructionist environments and activities for traditionally underrepresented youth in STEM has been documented (e.g., Peppler et al., Halverson, & Kafai, 2016; Halverson & Sheridan, 2014; Sheridan et al., 2014). However, it remains unclear how these constructionist explorations translate to subsequent professional and educational STEM opportunities, especially for women.

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