Not my Gumdrop Buttons! Youth Tool Use in Designing an Electronic Shrek-themed Bean Bag Toss

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ABSTRACT
The Maker Movement, with a novel approach to learning and conceptualizing science, could potentially increase representation from groups traditionally alienated by mainstream science. However, only a few studies have been conducted on underrepresented groups' participation in Maker projects. In this paper, we explore how a group of Latina youths, who initially expressed an aversion to STEM and had limited knowledge about circuits, created an electronic bean bag toss. Cultural Historical Activity Theory (CHAT) provided insight into how the girls delegated and accomplished Maker tasks, used or repurposed tools, and developed expertise. Analyzing video data, student work, and group exit interviews revealed the use of non-technical terms or "insider labels" for tools described within the group. The girls were aware of their switch to more scientific language when posting online and preparing for presentations. Similarly, the young women demonstrated distinct forms of comprehension within the group when creating the project (functional understanding) versus explaining to others beyond the group (conceptual understanding).

Author Keywords
Gender; girls in STEM; Latino; art; Making; digital fabrication; design-based research; engineering education; technology; craft; tool use; cultural historical activity theory

ACM Classification Keywords
J.2. Physical Sciences and Engineering [Electronics];
J.5. Arts and Humanities;
K.3.2. Computer and Information Science Education [Computer Uses in Education, Literacy]

INTRODUCTION
The Maker Movement could offer STEM-underrepresented groups, including minorities and women, a route to engage with science in a non-traditional way. With the key tenets of playful experimentation, creation of artifacts, social learning and community participation, Making offers opportunities for hands-on learning and broadening perceptions of STEM [32]. However, the inclusive ethos of Making might not be enough to increase access. The Maker Movement could perpetuate the same inequities within conventional science if programs and activities are not carefully framed and enacted [9]. The few studies on underrepresented groups in Making reach similar conclusions on the importance of intentional framing and design, including diverse activities and levels to target a variety of interests and abilities [1, 29]. Deliberate planning with respect to people and place is also crucial, including role models and mentorship [1, 29, 38], and an accessible site and welcoming community [1, 20, 29].

Barely any studies have considered tool use within a program encouraging participation from STEM-underrepresented groups, despite tool appropriation providing insight into participation patterns. If tool oriented, the focus tends to be on developing the Maker Mindset of creative problem-solving and productive response to failure [12]. Martin, Dixon, and Hagood's research considers a problem-solving approach but also tool use with their concept of "adaptive resourcefulness" [23]. They examined how students and mentors used tools creatively and drew from social networks to solve specific problems in the design process [23]. Developing conceptual tools and applying knowledge to new situations can be challenging, and others have documented novice Makers struggling to conceptualize project goals and finding communicating, negotiating, and externalizing their ideas very challenging [36]. Grounding projects in a real-life, social context can provide structure and motivation, helping students better understand their projects and the design process [36]. In particular, young women appear motivated by creating for others rather than themselves [20], and other underrepresented groups benefit from collaborative, community-oriented designs and projects [9]. Therefore, it is important to consider both how students use tools to invent new things and how they understand their creations in relation to their group and broader community.

In this paper, we investigate the role of tool use in the context of an afterschool Maker program working with low-income immigrant Latina teens. We explore how a group of 7 Latina girls delegated and accomplished tasks, used or repurposed tools, and developed expertise when designing and creating an electronic game for a family festival. The project, with a blend of art and science, allowed for different types of participation and provided insight into youth development. We focus on how this group of novice Makers developed expertise using new tools. We examine conceptual tool use throughout the project, considering Smagorinsky's five degrees of appropriation for conceptual tools: lack of appropriation, appropriating a label, surface features, conceptual underpinnings, and reaching mastery [17, 35]. Building from Smagorinsky's work, we identify three levels of conceptual tool use in the Bean Bag Project: *Familiarizing, Labeling, and Understanding.* We argue that communicating about the products and process plays an important role in tool use and understanding beyond the creation process.

RELEVANT LITERATURE

Women in STEM and Making

There is evidence that traditional learning environments have a strong effect on girls, and over time, can reinforce stereotypes, lowering girls' ambitions towards science and engineering careers [19]. Boys and girls are now taking the same number of math and science classes in K-12, and leave high school equally ready to study science and engineering [19]. However, that has not translated into equal career trajectories for women and men in science. Women earn less than 40% of undergraduate degrees in physics and technological sciences and less than 20% in computer science and engineering [37]. Women are actually *less* likely to pursue a computer science bachelors now than they were fifteen years ago [26]. Women are also graduating to a pay gap, and are more likely to face underemployment or unemployment. These results are worse for female minority scientists, who encounter unemployment rates around 7%, compared to white men at less than 4% [26]. The gap is even more dramatic if we focus on Latina women in STEM disciplines [11].

There is a large body of research on women in science documenting that women tend to move away from the physical sciences and engineering due to the competitive and impersonal culture of academic science [5]. However, the Maker Movement could offer women a route to engage with science in a non-traditional way. With the key tenets of playful experimentation, creation of artifacts, social learning and community participation, the Maker Movement offers opportunities for hands-on learning and broadening perceptions of STEM [33]. Makers create with a variety of materials including digital tools in a learning community, resulting in a process that is both learner-centered and project-based [28, 30]. Making benefits from both the do-it-yourself empowerment of individuals and community sharing of tools, designs, and products. A playful, collaborative mindset and a positive response to overcoming failure are also key components [22]. In addition to collaboration and creativity, the Maker ethos includes resourcefulness, ideation, and problem-solving [28]. There is also a blurring of the bounds between informal and formal spaces for learning, as Making processes, practices, and tools are dynamic, multidisciplinary, and multimodal [18]. The Makerspace environment encourages "re-authoring and re-mixing practices from a wide range of experiences, both in and out of school" [9]. People use a variety of tools and traditional crafts as well as electronics and new technologies such as 3D printing [21, 22, 28].

Making also draws from other disciplines and hobbies, as Makers range "from traditional artisans to computer hackers, and encompass crafters, musicians, artists, cooks, students, welders, scientists, engineers, software developers, and circuit benders" [38]. Leah Buechley, advocate for girls in Making and inventor of LilyPad, a line of sewable electronics products, explains that Making allows people to explore science in new, appealing contexts. Her designs blend art with technology, allowing for "alternative cultures" within STEM. According to Buechley, "The best way to increase diversity in STEM is to seed new subcultures where STEM can happen and a person can keep her own identity—as artsy, outdoorsy, a people-person, or feminine" [38].

Including girls in Making does not mean restricting activities to traditionally gendered activities such as jewelry-making or fashion design [20]. Presenting a variety of activities at multiple levels is helpful for increasing accessibility [29]. Perhaps more important than activity choice is the program or project framing. Girls appear to benefit from the collaborative and community-oriented aspects of Making [38]. Girls cite helping or giving as their biggest motivation for Making, and tend to pursue projects that benefit the community [38]. For example, young women designing toys for younger children were more motivated and confronted challenges more effectively when Making and related practices were presented as supporting their community [20]. Bridging student-centered and community-oriented learning, Maker alternatives to traditional science could potentially appeal to many types of students alienated by mainstream STEM disciplines.

STEM-Underrepresented Groups and Making

Proponents advocate that the Maker Movement has the potential to "democratize access to the discourses of power that accompany becoming a producer of artifacts" [18]. However, there has been criticism of the Maker Movement as primarily "an adult, white, middle-class pursuit, led by those with the leisure time, technical knowledge, and resources to make" [8]. Make Magazine and the Maker Movement have also been criticized for promoting expensive high-tech devices and excluding Makers who are inventive despite limited resources. For example, until recently Make Magazine had not featured diverse Maker topics such as lowrider car mechanics or geometric patterns in knitting, even though these traditions include many valuable and complex STEM practices [6].

A handful of researchers have explored how Maker activities can purposely encourage participation in STEM fields by under-represented populations, including women but also ethnic minorities and people with disabilities. Intentional program design and framing appears crucial to increasing accessibility and encouraging participation [1, 9, 20, 29]. To enable youth to "remake the world around them, we must rethink how we frame making so that it more directly aligns with the interests and goals of the communities and people we hope to engage" [20]. Through intentional design, Maker programs for youth can encourage subcultures within STEM and legitimize participation. Program framing can define "not only what counts as authentic 'making' but also youth identities as makers, participants, collaborators, community-members, youth people *who legitimately belong in this makerspace*" [9].

Part of this framing includes diverse format and varying difficulty levels or tracks for participation. One university-community partnership program stressed the importance of providing diverse program formats including afterschool, workshops, and outreach events [29]. They also offered different levels and made sure to always include a level for students without previous experience. "Mixed-ability makerspaces" such as DIYAbility and Assistive Design Center at the Perkins School for the Blind recommend projects be easy to start but include increasing complexity and multiple pathways for self-expression to empower youth with disabilities [1]. Alper argues, "Mixed-ability maker culture recognizes that different bodies produce different types of knowledge" [1]. Valuing different abilities and skillsets is important, allowing students to learn with and from each other about science, technology, and art [29].

The content and rigor vary significantly from program to program, from one day workshops to a four-year math preparation and engineering program [39]. The pre-engineering program, operating for over twenty years, has had great success at providing a "jump-start to college," improving high school and college retention for low income inner city students. However, this program enrolls students with high grades that are nominated by their teachers and persist through a four-year summer program. In comparison, other programs try to reach students alienated by school science. A university-community partnership program in Amherst offers curriculum especially for those "with no previous experience or interest" in STEM [29]. They ask, "Can makerspaces help to both stop leaks and open doors along the STEM pipeline for all students, but in particular for women and multicultural students?"

For stopping leaks and opening doors, many programs emphasize the importance of role models and mentorship. Some programs present mentors as "ambassadors" for participating in STEM fields, arguing that through discussions with college students, youth learn about the culture of the field and imagine themselves participating in the future [29]. Role models and mentors promote creativity and problem-solving in Making as well as improve recruitment and retention for women in STEM fields [38]. When working with students with disabilities, mentorship can be crucial for both tackling Maker projects and feeling welcome in the Makerspace [1].

Youth-oriented Makerspaces and Maker Faires should be welcoming not only for students but also their family and others, such as therapists or aids for students with disabilities [1]. One way to increase accessibility and make spaces more welcoming is "to bring maker kits and tools to places where these underrepresented groups gather" [20]. Calabrese-Barton described the benefits of running a Maker program out of two Boys and Girls Clubs in the Midwest [9]. Students could easily interact with others at the club not participating in the Maker program, and youth brought their funds of knowledge from home, school, peers, online, etc. into the Makerspace and vice versa [9]. In these youth-oriented Makerspaces, students problem-solved based on youth histories, connected to their networks to engage with social issues, and promoted collective aims [9]. Leveraging the knowledge and community concerns of youth Makers can help redefine traditional yet undervalued practices in ways that are empowering for the individual and community [3] and challenge normative views on Making and STEM participation [9].

The Maker Movement offers various ways to learn and conceptualize science, and could provide alternative or additional ways to engage in STEM for underrepresented groups. However, the educational side of the Maker Movement is still in its infancy, and educators and researchers are struggling with how to best implement and assess these learning practices [18, 28]. Substantial research is needed to prepare educators to lead Maker-type activities [28], maximize resource use to engender deep rather than superficial understanding [4], and draw from underrepresented groups' funds of knowledge [9]. Much more remains to be explored in relation to underrepresented groups in Making. In particular, there is very little research on Latina young women and their ways of speaking and acting associated with engaging in collective, artistic, community-oriented Maker projects. How do these novice Makers adopt and adapt tools, and in doing so position themselves in relation to Making or science?

PARTICIPANTS AND CONTEXT

The Study

This research is part of a larger NSF fellowship project to develop a Makerspace program at a youth center in Southern California near a major research university. The youth-oriented Makerspace was developed from an initiative to strengthen university-community ties, given longstanding disparities in income, formal education, and social services [7]. Our intentional stance is that Maker projects promote deeper connections and opportunities for social and educational development when they arise from authentic activities in the teens' everyday lives as community members. Notably, activities can still provide grounding in STEM content and literacies necessary to implement Maker projects.

Research Site

The Teen Center provides bilingual after-school programs for 100 youth in grades 6-12 and their families. Over 90 percent of the teen participants are Latino and come from low income immigrant families. Their programs address issues of youth safety and risky behaviors, low test scores and high dropout rates among Latino youth. Teens participate daily in tutoring programs, homework groups, and recreation and enrichment activities. Youth benefit from mentoring relationships, counseling, and community service or leadership opportunities. In addition to program activities, the site provides access to technology for homework and entertainment. Desktop computers provide a base for interfacing with other kinds of digital devices, such as microprocessors, and the Internet.

Participants

The group of participants were members of the all-female leadership group at the Teen Center. According to their volunteer contract, being a part of the group meant being "a Leader in your community and the voice of your peers in order to improve your Teen Center." Most of the leadership girls initially expressed a low regard for STEM subjects in school. However, they agreed to do Maker projects as part of their commitment to the leadership group. These joint Maker-leadership projects were often geared toward younger kids. According to Irene (one of the teen participants), "We usually make [things] for kids in the community." Sophie valued how the group would "tell people 'oh there's really cool stuff in science [for] little kids, inform them like 'this is what we did and this is how we did it,' let them know what's behind it." The group's participation in the Children's Day family festival demonstrates the blend between the leadership and Makerspace teams. Every spring the leadership group designs and leads booths related to Teen Center activities at Children's Day. Last year they designed and created the Bean Bag Toss as a faire game to engage families and to encourage younger children to join the Makerspace.

Figure 1. Inside and outside of the Teen Center.

Figure 2. Participating in the university Maker Faire.

At the time of the study, Irene, Esperanza, Malia, Isabel, and Sophie were 7^{th} graders while Valentina and Alexa were freshman. (All participant names are pseudonyms). Irene, Isabel, Valentina, Esperanza, and Alexa were more interested in the art and design aspects of most projects while Malia and Sophie were more technology and science oriented. Sophie and Malia were considered "smart" and "good at Math and Science" by their peers while the other girls admitted more difficulty in these subjects at school and said they were not known for their science or math abilities.

At the beginning of the year, the girls had limited or no knowledge about circuits and capacitive touch sensing. None of them had ever used electronic tools such as a Touchboard microprocessor, or associated materials of conductive paint or copper tape. Only Irene and Sophie had previously used a power drill, and only once before. They were comfortable searching for sounds on Google and browsing YouTube but were inexperienced in the process of downloading sounds and converting between different formats. When they created the poster and posted online about their project, they were already familiar with Google docs and compiling information but the "how-to" site Instructables.com was new.

THEORETICAL FRAMEWORK

Cultural Historical Activity Theory

Employing Cultural Historical Activity Theory (CHAT) allowed us to examine how the young women talked about their project, delegated tasks, and used tools to develop expertise and achieved goals over time. In this framework, identity is conceptualized through the performance of subjects, as agents who learn how to engage with others to attain goals. This requires that subjects adhere to rules or norms for how to interact, and that they position themselves by dividing their labor or roles according to group objectives and desired outcomes. More proximally, subjects author their experiences through conceptual and physical tools to achieve immediate objectives that eventually lead to more transformative outcomes. Identity is a complex and

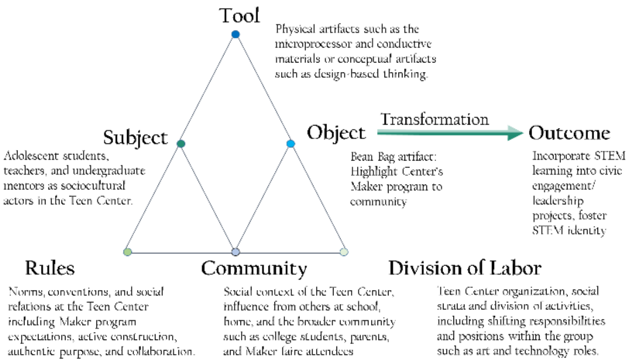

Figure 3. Representation of the components of the activity system within the Bean Bag Project at the Teen Center.

ever-changing trajectory constructed by discourse and practices, while constructing them as well [27]. From a CHAT perspective, collaboration among participants requires developing an awareness of each other's contributions to ensure successful teamwork. This collaboration is also an opportunity for team members to learn other members' roles, thus allowing for the transfer of skills and roles across participants.

Figure 4 summarizes this notion of an activity system [14] constituting our Makerspace. Accordingly, we considered the young women participants, undergraduate facilitators, graduate researchers, and staff as socio-cultural actors in the transformative activity system of the Teen Center. We explored how students built an electronically-mediated object and how conceptual and physical tools interacted with norms, division of labor, and community relationships to generate a new and enduring social space for STEM identity development.

In particular, tool use in fabricating bean bag artifacts provides insight into project development and the young women's enactment as novice Makers. Appropriation, or the ways people take up and modify tools, is key to understanding the learning process and how people develop social practices [35]. Active participation allows students "to reconstruct the knowledge they learn, thus transforming both their conception of the knowledge and in turn that knowledge

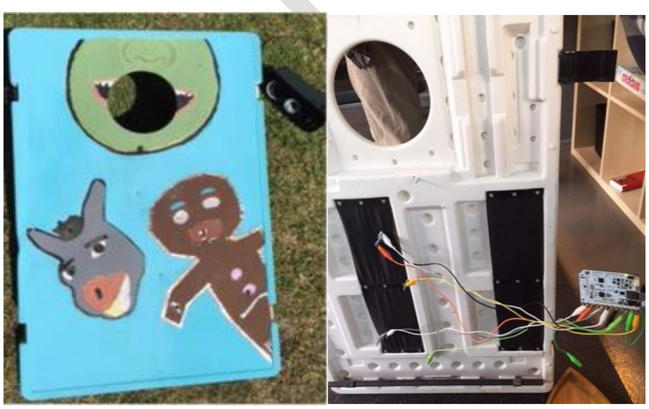

Figure 4. Front and back of Bean Bag Stand, painted with conductive ink and connected to Touchboard microprocessor.

as it is construed and used by others" [35]. We examined conceptual tool use throughout the project, considering Smagorinsky's five degrees of appropriation for conceptual tools: lack of appropriation, appropriating a label, surface features, conceptual underpinnings, and reaching mastery [17, 35].

Sense, Analyze, and Act

We also considered tool use in relation to a "sense, analyze, and act" framework which explains how electronic entities sense cues, process information, and respond [25]. Even simple robot hardware and an electronic circuit can interpret electronic signals. Electronically controlled devices chemically, electrically, and physically sense environmental information, process and analyze sensory information, and actuate, creating an output that makes something happen in the real world [25]. This type of framing can help students develop an understanding of tools such as microprocessors and associated concepts such as capacitive touch sensing.

METHODS

We observed 7 Latina students (aged 13-15) in the bean bag project activity, collecting ethnographic notes on the young women's design process during the project. We traced dialogic exchanges and multimodal practices across time [16], to examine how youths worked collaboratively. We studied how participants adopted tools and scientific practices tied to their unique and shared group experiences, and to their emerging technical expertise as Makers working with electronics and fabrication.

This paper addresses the following research questions: How did this group of novice Makers develop expertise using new tools? How did the young women use conceptual tools in relation to the physical Maker tools?

Data Sources

The data sources are from a yearlong ethnographic study, with particular focus on the quarter-long Bean Bag Project. For the Bean Bag Project we examined 7 hours of video data, recorded on 10 days, spanning 3 months. The videotaped sessions provided an account of interactions and project development. Reviewing the video data "allowed us to revisit salient episodes of students/teacher interaction that were essential to how scientific meaning was discursively constructed" [31].

We also collected digital photographs of final student products (Bean Bag Stand), as well as products throughout the process (sketches, notes from brainstorming, lists of roles, web posts). Other data sources include undergraduate field notes, analytic memos, and focus group exit interviews with the youth participants.

Qualitative Analysis

We first performed descriptive coding [32], transcribing video segments and then constructing representations of events to consider chains of actions [2]. We created transcripts to depict micro-level communication and event maps to illustrate larger scale activity [16]. An overall event map was created to reveal the progression of different projects, as well as a minute by minute event map for sessions to indicate patterns of activity and roles. In our findings, we provided examples of transcript dialogue and descriptions as evidence of student use of internalized conceptual tools, of appropriated ways of talking and acting that demonstrate scientific practices and ways of thinking [31]. These examples illustrate the ways participants articulated their projects and employed scientific sensemaking by "appropriating collectively co-constructed practices that they had a part in defining" [31].

After descriptive coding, we used MaxQDA12 software to direct code the video. We performed emergent coding in alignment with CHAT to designate themes [32]. The preliminary coding scheme was refined through group discussion. Next pattern coding was used to organize codes into smaller sets [32]. A second researcher went through one session's video and coded independently for calibrating purposes. Disparities prompted discussion which helped to refine codes. Then the second researcher independently coded randomly selected video segments. Researchers agreed on over 80% of codes, providing a satisfactory degree of inter-coder reliability. After coding all 6 videos, we returned to the earliest videos and checked codes to account for a potential "definitional drift in coding" [15]. The codes from the videos were triangulated with text from the analytic memos, field notes, and student focus group transcript to verify across sources and warrant claims about outcomes [13].

RESULTS

Building from Smagorinsky's degrees of appropriation [17], we identified three levels of conceptual tool use in the Bean Bag Project: *Familiarizing, Labeling, and Understanding.* Familiarizing included everyday connections and innovative applications to capture how the young women applied what they knew from other contexts in both conventional and unconventional ways. Carrying out the project and communicating about it revealed both internal and external components. Internal to the group, the girls used non-technical terms or "insider labels" for materials and tools, while switching to more scientific language when posting online and preparing for presentations. Similarly, the girls demonstrated distinct forms of understanding when creating the project within the group versus explaining to others beyond the group.

Conceptual Tool Use	Sublevels
Familiarizing	Everyday connections Innovative applications
Labeling	Insider labels Scientific labels
Understanding	Functional understanding Conceptual understanding

Table 1. Levels and sublevels of conceptual tool use.

Familiarizing

In this section we describe *Familiarizing*, or becoming acquainted with new tools and applying, repurposing, or remixing associated practices. The two sub-constructs of familiarizing are *everyday connections* and *innovating applications*. In everyday connections, we present examples of the young women realizing commonalities between the Maker tools which initially seemed very foreign and sometimes intimidating. We also describe how they applied existing knowledge to new contexts in similar ways. Innovative applications illustrated how the young women transposed what they knew to novel contexts in unconventional or unexpected ways.

Everyday Connections

Even though the concepts of "engineering design" and "Making" and the related electronic tools were new, the young women often found similarities between the new materials and their everyday experiences. For example, when the teacher introduced the lithium ion battery, Sophie and Irene realized that they had seen it before in "cheapy phones…when they're falling and the battery comes out." Often the young women applied this everyday knowledge to use new materials in conventional ways. For example, the girls with the most artistic experience, Alexa and Irene, applied what they knew about acrylic painting on posters to using conductive paint within the new context of the bean bag stand. Even though they had no experience doing a Maker project that integrated technology with art, they were able to leverage their art abilities (perspective, design elements) to develop new types of expertise and share them with others.

Innovative Applications

Other times the lack of experience with the new materials or tools led to alternative or unconventional solutions. The use of the drill was unconventional, where the screws did not serve the typical interlocking purpose. Instead, the girls inserted screws to link the painted front of the stand to the wires and Touchboard on the back. Also, after Sophie accidently broke the pilot-hole drill bit, the girls decided to use screws and a hammer to make the pilot holes. This resulted in some crooked screws, which might have been problematic if the screws were designed to hold two pieces together. However, it proved a good solution since the screws were only used to link the wires from the Touchboard's electrode terminals to the front of the stand. The young women innovated based on their budding understanding of hand tools, to solve the problem given the constraints.

Labeling

Labeling represented how the young women and the facilitator referred to tools and materials. The two types of labels were *insider* and *scientific*. Insider labels were informal and only used within the group, while scientific labels were more formal and only used for outside the group purposes such as posting online.

Insider Labels

After gaining familiarity with the new tools, the young women would often devise their own labels. While the facilitator referred to the materials and tools by the official label of "alligator clips" or "Touchboard" the girls used more familiar labels. For example, they referred to the alligator clips as "wires" or jokingly called them "los cables." They called the conductive paint and fabric as "special" rather than "conductive." They referred to the Touchboard and other parts interchangeably as "thingy." Many of the girls continued to refer to the Touchboard as "Makey Thing" or "Makey" even though the group had transitioned away from using the MakeyMakey brand version after the first day. After the facilitator pointed out it was not a MakeyMakey, but a Touchboard, they referred to it as the "board thing" or "touchpad." The young women were connecting the physical tools correctly, but using a modified vocabulary to refer to these tools that was easier to understand and more accepted by the group than their technical terms. It wasn't until they needed to make their materials and process visible to others that they referred to the microprocessor more consistently as the Touchboard, and the fabric and paint as conductive.

Scientific Labels

The appropriation of the more "scientific labels" didn't happen until the girls were expected to explain how the project worked to other people. They understood that others would not understand their terms, even though these terms made it easier to communicate and built up a sense of group membership during the project. When Irene and Sophie practiced explaining for Children's Day or the Maker Faire, the facilitator introduced more scientific labels, and the girls were focused on using terms others could understand. The girls also worried about their audience and language when writing the online tutorial. Sophie worried that "They'll be like 'This sucks!...They'll be like 'More description!'" She wanted to be accurate and communicate in a way that was clear to others outside the group. Therefore, she listed out the "supplies" using formal labels rarely used while constructing the bean bag toss. Alexa, Sophie, Irene, and Malia asked the facilitator questions or looked up details about tools and materials to include more information in the tutorial. For example, including "Lipo Battery (3.7v)", or "acrylic" and "conductive" as the paint labels. Some names were negotiated at that point, such as "Plastic Bean Bag Stand." These labels were designed to clarify parts and steps for others to replicate the project, but also helped the young women realize they were part of a bigger community using these labels. When Sophie switched from "special" to "conductive" and searched for "conductive paint" on Google, she realized that other people were using and talking about the same materials. She exclaimed, "That's *our* paint!" and noted that they were part of a bigger group of Makers sharing their ideas and creations.

Understanding

In this section, we discuss the different types of understanding the young women demonstrated throughout the process of building the artifact. We divided understanding into *functional* and *conceptual* components.

Functional understanding refers to a more limited understanding of a tool, developed from the concept of "surface feature appropriation." In this type of learning, the student "is making some effort to grasp the official conception, yet is succeeding in doing so only at the surface level" [17]. The learner might not fully understand part-whole connections between different features of the tool or project but is able to appropriate tools to create a functional product. In contrast, conceptual understanding requires a theoretical grasp of the tool's purpose. Conceptual understanding is more abstract and equips learners with the ability to apply what they've learned to new contexts.

To connect the components and produce a working game, the girls needed some degree of functional understanding, but not necessarily any of the conceptual understanding. However, they did need an understanding of the science behind their project (e.g. capacitive touch sensing) to explain to children and parents how the project worked. While functional understanding was important throughout, it was foregrounded during the construction process. Traces of conceptual understanding appeared during building, but most evidence occurred after construction was complete when the young women were practicing their presentations or creating informational displays.

Functional Understanding

Functional understanding, or grasping how the project worked as a whole and how the pieces fit together, was most prominent in the middle of the project. At this point, the young women had finished downloading sounds and were adding conductive materials and connecting the Touchboard. During these sessions, the discussion was often about how to make the project work, which included what certain tools did, and their role in the project. First, the young women needed to understand the cause and effect of placing screws in key areas, then painting around them to broaden the conductive area. In the Instructables entry that Sophie and Malia wrote to describe how to create their project, they wrote "We drilled holes on the places we wanted to hear a sound. We put screws into the holes. for example we put three screws in Shrek's face." They did not explain the science behind the process, but they made a connection between where they drilled and the sound effect. They further instructed: "The screws and the touch board were connected by alligator clips. Don't forget to test it out before to make sure the sounds are right for each character" illustrating the connection between the screws in the bean bag stand and the Touchboard with the sounds. They also stressed the importance of this step, checking which points trigger which sound, or attaching the wires from the desired electrode terminal on the Touchboard to the correct screws to pair up correctly. They then explained the purpose of using conductive materials and painting around the screws to broaden the electrically conducting area that the bean bag could strike:

> we also used conductive paint on the top side of the screws. we used conductive paint so that all of the board makes a sound when anything conductive touches it. you have to use conductive fabric wrapped around the beanbag so that it worked when it touches the conductive paint.

This explanation of the conductive paint and conductive bean bags as creating bigger targets and triggers demonstrated understanding of the interaction between components, and the beginnings of conceptual underpinnings of conductivity and touch capacitance. Adding the conductive paint was a key step in the project, where the girls juggled including the conductive paint in a way that increased each electrode's trigger area, did not interfere with surrounding trigger points, and looked aesthetically pleasing. Alexa, Isabel, and Irene were part of the art group outlining the figures with electrically conductive materials, and had the longest discussions about how to outline figures without crossing paint or copper tape lines. Irene called this, "the hardest job." The facilitator explained the design constraints in a few different ways, including explaining the science behind the process, but Irene and Isabel did not understand until Sophie presented a more straightforward explanation that focused on concrete steps. The facilitator started by explaining:

> What you don't want is for these two to touch each other, so if you're going around that's good but don't do it going around and to each one. {Gesturing, pointing at Shrek}…So, when you're going around you want it to touch one of them but not all of them. Cause if you touch two, it's going to short circuit so electricity is not going to go where you want it to. {Pointing to gingerbread man}

Though the concept of electricity and short circuit was alluded to by the facilitator, there was not further explanation about what a short circuit means electrically, or why it would not allow an electrical circuit to operate as intended. After Isabel expressed confusion, the facilitator focused on the specific process needed to complete the section rather than further explaining concepts:

FACILITATOR: So you don't want this, that's going around, it can touch one of these and then have (a) break and touch another one but you just don't want it to be touching the same (screw) {Isabel looks confused}
Sophie: Okay, so you want to outline this and touch that, okay? But if you like outline it again with the same color and it touches this it won't work.
Irene: I still don't get you there.
Isabel: Oh, so this one, while touching this one can't touch this one. Okay I get it.

Ultimately, it was Sophie who helped the others understand this crucial part of the project. After this discussion, the girls finished adding the conductive materials and began to test their product. While creating a working electronic bean bag stand demonstrated functional understanding and conceptual underpinnings, deeper conceptual understanding wasn't made explicit until they were asked to explain their project to others.

Conceptual Understanding

Conceptual understanding goes beyond the *how* of making the project and includes *why* the tool and project worked, or a scientific or theoretical understanding of the tool. Awareness of certain scientific processes can emerge from understanding how electronic devices sense cues, process information, and actuate [25]. In this section, we examine the progression of dialogue and expression of different parts of the "sense, analyze, and act" process. The conversations revealed gradual understanding of the functioning of the Touchboard microprocessor and the basic science behind electricity, circuits, capacitance, and permittivity. In particular, Sophie and Irene's participation illustrated distinct ways of understanding the "sense, analyze, act" process. Sophie focused on conductive material sensors while Irene honed in on the analyze step, making connections between the Touchboard and other touch sensing devices.

Sense, Analyze, and Act

When the young women first started, they were new to most of the materials and tools. Though they expressed the general concept of *actuate* by saying, "We're making Shrek have a sound," they did not have the conceptual understanding of how that happened and voiced dissatisfaction with their own explanation. When the site coordinator questioned how the Shrek-themed bean bag toss could attract new participants to the Makerspace, Malia demonstrated dropping the bean bag into the hole, "Look, when it goes in, it's going to say something, yah. And they're going to go, 'That's cool!' And we're going to go, 'Join [the program]!'" At this point the site coordinator lacked confidence in their ability to explain the project to children because the girls were solely focused on the *actuate* part of the process, or triggering the sound.

A week before their demonstration at Children's Day, Irene and Sophie were still unable to explain what was happening on a conceptual level. The site coordinator stressed the importance of explaining the project and Sophie flippantly responded that she would tell children and families, "What's up homey-g?" Irene was terse in her explanation, "It's a project that we did, okay?" Others expressed dissatisfaction with Irene and Sophie's explanation and suggested that Malia or Alexa man the booth instead because they were more articulate. However, with prompting from the facilitator, Sophie and Irene were able to explain what *senses* and *analyzes* in order to produce the sound and why certain materials were used:

FACILITATOR: But beyond the conductive fabric, what's happening when --you touch it?
Sophie: --Um, it has the special paint.
FACILITATOR: Yah, it has conductive paint, conductive fabric and conductive paint.
Sophie: And they pair up and it makes noise.

Sophie demonstrated an understanding of capacitive touch sensing and needing a certain type of object, which is "special" in order to produce a response. The "special paint" acted as a *sensor* and the noise, or *actuation*, didn't happen unless there was an interaction. She stated that a person's finger or the bean bag "pair up" with the conductive paint to make noise. The Touchboard *analyzed* this incoming information, which was part of the "pair up" necessary to act, or produce a sound. The facilitator continued along this line of logic:

FACILITATOR: Remember how it works like your phone, with the --touch sensing?
Irene: --You mean like the touchable, itouch, --iphone
FACILITATOR: --So you can tell people it works like your phone, it senses your finger is interrupting the electric field.
Sophie: Except with this thing it's conductive stuff.
FACILITATOR: Yes, yah, that's it. Conductive, but your finger also works, right? {Sets off Gingy sound: *Tell me! Not my gumdrop buttons!*} So your finger you're interrupting the electric field around the electrode on the board or this is, anything that conducts electricity will also interrupt the electric field. Just like your phone, if you try to do it with the fabric gloves on it doesn't work because your finger isn't interrupting or --making issues with the electric field.
Sophie: --With the frabric. Fabric.

Afterward Sophie asked about a material that hadn't yet been mentioned, showing she was digging deeper and making connections about the sensing process beyond what was discussed:

Sophie: What are we going to tell them about the tape?
FACILITATOR: So, what do you think?
Sophie: It's like the same thing as the paint.
FACILITATOR: Yah, so it's made of copper, the metal conducts. You could have done it with steel, iron, any metal, but copper is easy to make into tape. That's a good thing to show them too, that it's not just the paint but also the screw is made out of metal, the copper tape is made out of metal.
Sophie: So basically it has to have like a metal something?
FACILITATOR: Yah it has to conduct and metal is a really good conductor. But you also conduct electricity. There's a lot of things that conduct but metal conducts really well.

These conversations revealed applications to other materials and contexts, such as that all metals conduct electricity well, or that other touch screens use capacitive touch sensing. When further prompted, Sophie proceeded to explain how touch capacitance worked in her own words:

FACILITATOR: Okay, so what do you guys say when someone says, "How does this work?"
Sophie: "You have conductive fraaabic…Fabric. And then the conductive paint thingy and when you hit it, it makes a noise with the touchpad, and the touchpad is like your phone that gets it but instead with your finger works with the conductive stuff. BOOM. {high fives Irene}

Sophie related the Touchboard to a phone with a processor that "gets it," or *analyzes* after the screen *senses* someone's finger. She specified that a finger can trigger the response, but so does "conductive stuff." Conductive materials "work with" with the Touchboard, where the conductive paint is the sensor set off by the conductive bean bag. As she stated earlier, the conductive elements "pair up." After *sensing* and *analyzing* the change in permittivity, the Touchboard *acts* by producing the sound effect. That's where the magic happens, hence the "BOOM." After further discussion that emphasized the vocabulary of "capacitive touch sensing" Irene wrote on the poster: "The sensor senses objects that change the electric field. It can sense anything that is conductive or that has a significantly different permittivity than air. Any touchscreen device also works with capacitive sensing."

Although the process is complicated, the young women demonstrated an understanding of the Touchboard as a processor within a family of devices that all sense a change and process this information. Their understanding of a capacitive touch sensor as "sensing a change in the electric field" might seem surface level, but they articulated that the paint and copper tape acted as a sensor, and that a conductive material triggered a response from the Touchboard.

These conversations about the Touchboard and capacitive touch sensing were considered conceptual underpinnings rather than deep understanding or mastery since it was the young women's first Maker project and they were missing more in-depth and nuanced understanding about electricity, circuits, capacitance, and permittivity. But this project provided an entry point, and the expectation that they could explain the project to others provided rationale and encouragement to understand on a deeper level beyond making the project work.

Beyond the Project

Since conceptual understanding helps learners apply what they have learned to new contexts, we briefly considered applications outside the construction of the Bean Bag Toss.

In the exit interview, two of the girls mentioned learning about circuits in Physics, and most of the young women expressed increased confidence in their abilities to operate the Touchboard. Valentina stated that she felt differently about herself as a Maker at the end because "cause I know how to use the Touchboard" to which Alexa responded, "Yeah so now like if we're working on it at school be like I know how to do that." The facilitator validated their experiences and competence with the tool by stating, "Yeah you guys can be the experts in that." The facilitator positioned the teens as experts in relation to other classmates, and on their way to developing a deeper understanding in future projects. However, despite developing confidence with the Touchboard, most of the young women expressed in the exit interview that they needed to master more tools to have the skillset of "hundred percent" Makers. They embraced their understanding and skillset, while realizing that claiming an identity or mastering something is a long-term endeavor. Still, it is worth noting that the young women have continued to participate in long-term Maker projects and three of the five eligible girls were accepted this year to an elite engineering academy within a local high school.

DISCUSSION

This study provided insight into how a group of young women adapted and adopted new Maker practices and tools while positioning themselves in a collaborative, artistic project. Whether working with paint, power tools, or microprocessors, the girls applied their existing knowledge to develop familiarity with new tools. Sometimes the young women superimposed an existing framework to apply to another domain with similar applications, while other times they repurposed tools to suit their needs. The variety of project materials and tools allowed for various ways of engaging and personalizing the project. Drawing and painting were tasks the girls had more experience with, and using materials such as conductive paint provided an entry point to new digital fabrication tools. The girls shared art-oriented advice related to design and perspective while referencing art in daily life such as painting nails, putting on makeup, or building furniture with relatives. Incorporating drawing and painting to the digital fabrication process appeared to leverage "'women-centric knowledge' without an overreliance upon women-dominated activities" [20]. Overall, the artistic and collaborative elements helped the young women relate to and feel more comfortable with new materials, demonstrate their design skills, and gain expertise in areas previously unfamiliar to them.

Various forms of expertise also helped to expand the definition of Maker and provide "alternative cultures" within STEM for young women [38]. The girls were performing as Makers and science people when considering different uses for materials, operating and connecting components, creating instructional guides, and explaining how the tool or project worked to others. They negotiated and made visible their competence by engaging in scientific practice and discourse. They were recognized by their peers and people outside the group as Makers, which some researchers consider as important as mastering STEM content [12]. In alignment with other studies, identifying as Makers helped our youth integrate diverse learning experiences [24] and positioned them as technologically and scientifically capable of creating things for themselves or others [12].

Successfully producing a functional bean bag stand was also important because it fostered a sense of pride and motivation to share. Sharing was crucial to developing a deeper level of understanding that went beyond the surface features of the tools and how they worked together. On its own, creating the project allowed for engagement, innovation, and the understanding necessary to produce a functional bean bag stand. However, the context of the final faire demonstration as a learning experience shared with younger children appeared to be the largest motivator for developing scientific understanding and communication. Girls in other Maker projects have expressed a preference to make for others rather than themselves, and tend to find the community orientation motivating and sustaining [20, 38]. Our research supports this motivational aspect for young women when designing and completing their project, and adds the importance of dialogue with community for deepening learning and improving scientific understanding. The girls were motivated by the need to accurately communicate to others outside the group how the project worked. They realized that the terms used in their working group would not make sense to outsiders, and adjusted their speech and online posts accordingly. Teaching others also positioned the young women as more expert Makers and mentors for younger children and family members who attended the Children's Day or Maker Faire festivals.

Other researchers have documented increased dedication and learning from children teaching others in comparison to learning for their own benefit [10]. Referred to as the "Protégé effect," the phenomenon has even been demonstrated with middle school students instructing online "teachable agents" such as a computer program called Betty's Brain [10]. The researchers hypothesized that guiding the teachable agent Betty motivated learning by promoting responsibility, encouraging revision, and protecting against failure [10]. The idea of increased responsibility is especially relevant, where the young women realized they represented their group and the Makerspace as a whole when trying to recruit younger children. Multiple times the girls presenting the information were scrutinized by their peers to present an explanation that everyone felt comfortable with. Being held responsible to others was a motivating and guiding influence, and the site coordinator often provided criticism by asking the group to consider how others would understand their design. These discussions helped avoid the issue mentioned in other Maker projects where teachers were unable to assess relevance and worried about hampering creativity by providing feedback. When presenting their final products, those students "were unable to discuss the complexity of the context, the qualities of their output, or their choices during the process" [36]. In contrast, in our project the outside audience helped structure feedback from staff, mentors, and other students. The audience provided a context to reflect on decisions and to practice and refine explanations. In general, the specific audience could help mitigate the "process-related challenges" in Maker education, including delineating the project scope, communicating and negotiating ideas, and expressing and critiquing designs [36]. Productive failure and redesign are well-known learning devices in Maker programs, but it is also important to consider failure and revision in relation to *communicating* about the products and process. In this sense, the communication process can be considered a conceptual tool to tinker with and ultimately better understand the science beyond making a functional end product.

CONCLUSION

In this article, we presented the three levels of conceptual tool use, *Familiarizing*, *Labeling*, and *Understanding*, as important processes for both creating the electronic bean bag game and explaining functional and conceptual components to others. Building on previous knowledge resulted in both conventional and innovative applications and allowed for engagement in relation to artistic, technical, and scientific factors throughout the project. The program framing drew from a body of research on alternative approaches to include women in science [5] and a handful of recent studies on engaging underrepresented groups in Making [1, 20, 29, 38].

Our program included intentional framing and design and targeted a variety of interests and abilities, improving accessibility to novices [1, 20, 29]. Undergraduate and graduate student mentors provided project-related guidance and general STEM-related mentorship [29, 38]. Also, like the Makerspaces developed in Boys and Girls Clubs, our program occurred at an afterschool Teen Center, a place the young women considered accessible and welcoming [9]. We drew from students' individual and collective interests and embedded cognitive program goals while still allowing the students to maintain control and ownership. This combination led the students to develop the functional and conceptual understanding required to build the project and explain the science behind it to others. The community audience embedded a challenge and yet clearer teaching and learning goals.

Maker education, especially in afterschool settings, can be portrayed as student-centered with minimal guidance. However, we presented an example of a successful collaborative project guided by adult mentorship and framed by a community audience. We fostered student engagement and ownership while offering intellectually useful tools to carry out goals. Although our study was limited in generalizability due to only looking at one site and 7 Latina young women participating in the project, our findings could apply to Maker projects both in afterschool sites and schools, especially when working with girls and other underrepresented groups. Regardless of the site, we advocate for projects that include an authentic audience and time dedicated to practicing and revising communication with this audience.

Still more research is needed to understand how underrepresented groups adapt and adopt new Maker practices and tools. In particular, we should consider how groups traditionally excluded from STEM position themselves in community-oriented Maker projects, and how participation could increase accessibility and ultimately equity in STEM fields.

ACKNOWLEDGEMENTS

We would like to thank the participating students, facilitators, and Teen Center staff involved in this research.

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE 1144085. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors(s) and do not necessarily reflect the views of the National Science Foundation.

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