Inclusive Collaborative Learning With Multi-Interface Design: Implications for Diverse and Equitable Makerspace Education

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Abstract: While the maker movement and its associated affordable and accessible practices and toolkits have reinvigorated interest in pre-collegiate STEM, invention and creativity, many have critiqued makerspaces as implicitly exclusionary, particularly across gender, race and ethnicity. In an effort to rectify past participatory inequities, we designed a maker workshop for high school youth that capitalized upon multiple digital and physical interfaces to create simultaneously digitally and physically responsive projects, which encouraged team-based distributed creativity and development. We explore how the tools and the curricular design encouraged and fostered collaboration and inclusivity, as well as disrupted previous implicit associations around computing and creativity. We discuss the teams, the projects created and how the learning activities provided opportunities for inclusion and equity.

Introduction

The maker movement and its associated affordable and accessible practices and toolkits have reinvigorated interest in pre-collegiate STEM, invention and creativity (e.g., Blikstein, 2013; Halverson & Sheridan, 2014; Honey & Kanter, 2013; Peppler, Halverson & Kafai, 2016). Most notably, scholars have proposed the benefits of maker activities to foster collaborative learning, a growth mindset, interest-driven knowledge building, and resourcefulness (e.g., Dougherty, 2013; Halverson & Sheridan, 2014; Peppler, Halverson & Kafai, 2016). In particular, makerspaces are touted as increasing transparency in learning computation, both with the tools and activities themselves (Resnick, et. al, 2000; Resnick & Rosenbaum, 2013) and in the spaces designed around them (Peppler, Halverson & Kafai, 2016). Further, the general spirit of constructionist learning for all, as fostered through makerspace learning, has been celebrated widely for opening up previous participatory divides.

However, many have critiqued makerspaces and associated interest-driven STEM and DIY learning activities as implicitly exclusionary in different ways (e.g., Buchholz, et. al, 2014; Kafai, Fields & Searle, 2014; Richard, et. al., 2015). In other words, while maker tools and materials have opened up previous "black boxes" (Resnick, Berg & Eisenberg, 2000), the tacitly exclusionary assumptions and practices still remain. Some have engaged in efforts to increase diversity in access to makerspace literacies directly, such as through recruitment, while others have focused on ways that learning activities or spatial designs can be more supportive or inclusive to previously underrepresented groups (e.g., Kafai, Fields & Searle, 2014; Kafai, et. al, 2014; Kafai, Searle, Martinez & Brayboy, 2014; Richard, et. al., 2015). Still others have explored and capitalized on the tools themselves (particularly e-textiles) as avenues to inclusive participation (e.g., Buechley, et. al., 2008) or as disruptive to gender exclusive patterns associated with making (e.g., Buchholz, et. al, 2014).

Nevertheless, how the tools and arrangements of learning activities can support diverse participation is still underspecified. This is not an immaterial question, as the lack of equitable participation in computing and technology is still a widespread issue from pre-collegiate education and beyond, particularly for African Americans, Latinos and young women, across race and ethnicity (e.g., Heitin, 2014; NSF, 2015). Herein, we explore how a youth-oriented workshop that combined multiple maker digital and physical toolkits fostered inclusive participation. For example, most past efforts have focused on one specific tool or activity, whereas the act of creating an e-textile-based multi-interface design that is both digitally and physically reactive and responsive (i.e., bidirectional) purposefully incorporates several toolkits with differing affordances and implicit associations. In an effort to rectify past participatory inequities, the first author designed two instantiations of a maker workshop for high school youth that integrated e-textile design, coding, digital media design and simplified physical computing, each of which would elicit different interests and biases (Richard & Kafai, 2015). We explore how the curriculum encouraged and fostered collaboration and inclusivity, as well as disrupted preconceptions around computing and creativity, through our guiding research question: How does designing multi-interface bidirectionally responsive projects foster collaboration and inclusivity?

Background

In recent years, there has been increasing attention paid to who participates in interest-driven digital learning activities (e.g., Ito, et.al, 2013). While makerspaces can cultivate a variety of learning processes and practices, including low tech ones, many efforts have focused on computational thinking skills and creative practices.

Equity and inclusivity in computing and making

In line with efforts to diversify toolkits and modalities, many have explored how makerspaces can promote equitable and inclusive participation. For example, research has found that integrating crafting with engineering design, in the ways enabled through the Lilypad Arduino, can change the ways that gendered interests are expressed, often resulting in sewing being seen as valuable to computation, and young men being freer in expressing these interests (Kafai, Fields & Searle, 2014; Kafai, et. al, 2014; Kafai, Searle, Martinez & Brayboy, 2014; Richard et al, 2015). Others have found that e-textiles can disrupt past preconceptions and patterns around gendered ability, access and authority in making (Buchholz, et. al, 2014). Further, researchers have explored how utilizing the Lilypad Arduino and e-textile design could create cultural connections between Native American indigenous practices and computational thinking (Kafai, Searle, Martinez & Brayboy, 2014). However, some have noted that utilizing the Lilypad and e-textile design, as a standalone activity, does not necessarily tap into a variety of interests and practices alone (e.g., Richard & Kafai, 2015).

Moreover, research has shown that it is equally important to foster culturally supportive structures in the design of technology-oriented learning spaces, in order to encourage and sustain diverse hobbyist activities and workforces (e.g., Scott, Sheridan & Clark, 2015). For example, scholars have noted that, while past efforts to engage youth in computing often included diverse participation, it did not necessarily result in more equitable computational participation (Scott, Sheridan & Clark, 2015). This lack of equitable participation can partially be explained by the design of technologies that are theoretically value free, but fail to recognize the ways they may be implicitly exclusionary (Lachney, Babbitt & Englash, 2016). In other words, inclusive participation needs to make a concerted effort to recruit diverse participation, have diverse mentors, allow learners to explore their intersecting and diverging experiences, critique and redesign media representations with accessible tools (such as Scratch) and promote an overall supportive and inclusive environment, whether this is through tapping into culturally relevant pedagogies and practices (Lachney, Babbitt & Englash, 2016; Scott, Sheridan & Clark, 2015) or through explicit efforts for inclusion (Richard, et.al., 2015).

Collaboration and inclusivity

In this paper, we subscribe to Roschelle's (1992) definition of collaboration, which is "building and maintaining a shared understanding of a problem or task, distributing responsibility across members, sharing expertise, mutually constructing, and negotiating cognition" (Van den Bossche, Gijselaers, Segers & Kirschner, 2006, p. 494). Similarly to Peppler and colleagues (2015), we see collaboration as involving effective articulation of ideas and sharing responsibility and contributions. Making involves projects that are big and ambitious, which can necessitate collaboration and division of labor between participants, skills that are seen as essential aspects of 21st century skills. We additionally contend that providing an intentional diversity of physical and digital toolkits in maker activities further encourages collaboration because of both the complexity involved in the design and integration process and also the capitalization on varying participant interests and skills. We contend that both aspects are important in meeting the goals of purposefully inclusive collaborative learning in making.

We also challenge that collaboration has to be open, equitable, interdependent, and cohesive to foster effective task performance. Effective collaboration results in deeper learning, critical thinking, collective understanding and long-term retention, and can help build group cohesion (e.g., Johnson & Johnson, 1989). However, simply placing students in groups is not sufficient for collaboration. There are social and interpersonal factors such as social relationships amongst team members, collective efficacy of the group, team cohesion on tasks and feeling of safety within the group that are equally important to collaboration, inclusivity, and team performance. Miyake and Kirschner's (2014) model of team learning beliefs and behaviors describes four factors that have positive effects on team learning and collaboration. We argue that these factors also can have positive impact on inclusivity: making team members feel that they are a valuable part of the team while promoting a safe environment to share their ideas, knowledge and opinions, and take risks. These four factors are psychological safety, cohesion, interdependence and group potency.

Social conditions and team-level beliefs about interpersonal relations with team members, collective belief on the efficacy of the group, team cohesion on tasks at hand and a feeling of safety within the group are equally important to collaboration and team performance. Effective risk taking (Kreijns, Kirschner & Jochems, 2002) requires a sense of safety with team dynamics. Team psychological safety is defined as a "shared belief that the team is safe for interpersonal risk taking" (Edmondson, 1999, pp. 350). For example, team members may not feel comfortable with each other, or, conversely, close-knit team members may isolate others. Promoting a sense of psychological safety has been found to improve team performance and innovation. Akin to psychological safety is a sense of assurance in the group's ability – or group potency (i.e., collective self-efficacy) – which can lead to perseverance during predicaments and conflict (Shea & Guzzo, 1987). Additionally, Miyake and Kirschner (2014) suggested a shared commitment to a task leads to better learning

and performance. Team cohesion has two dimensions: task and social cohesion. Task cohesion emphasizes the commitment to and enjoyment from the collective effort by all members to work collaboratively towards completing a task. Social cohesion, on the other hand, refers to group cohesiveness resulting from the emotional bonds and friendship, which tends to be motivated towards completing tasks just to appease others. Tasks themselves can viewed differently by team members. For example, task interdependence can lead to more communication since groups see interconnections between sub-tasks that contribute to overall group performance, whereas, positive outcome interdependence can lead to more constructive conflict since individual members' benefits are associated with collective successful task completion (e.g., Van den Bossche, et. al, 2006).

Methods

Setting and participants
The setting was a hybrid formal/informal learning experience for 9th graders in a large city in the Northeastern United States. Participants (10 girls, 8 boys from diverse ethnic, racial and socioeconomic backgrounds) were students from a science magnet high school. As part of the school's required out-of-school learning experience, students could choose from an assortment of informal workshops coordinated through a partnering science museum, covering a variety of science and technology topics and offering various forms of instruction. The workshop ran for eight weeks, once a week, for about 2 hours (time and duration limitations imposed by the school). Eighteen students enrolled in the workshop and 17 completed all course activities (one left the school), working on teams of 2-3 students to create final projects (artifacts).

Curriculum
The workshop had been taught previously but redesigned to respond to limitations during the previous instantiation of its experimental curricula (Richard & Kafai, 2015). The novel curriculum of both instantiations was designed and taught by the first author, and focused on utilizing novice friendly digital and physical toolkits to teach youth how to create bidirectionally responsive projects. In other words, students learned how to create projects that were responsive in multiple physical and digital interfaces. While past efforts have taught students how to create projects with digital and physical interaction, this curriculum was unique because they had to engage in designs that were simultaneously responsive in both environments (Richard & Kafai, 2015).

Learners worked with Scratch, a block-based coding and media creation platform, the MakeyMakey, a physical computing plug-and-play device that can make anything conductive control the computer, the Lilypad Arduino, a microcontroller to create e-textile-based wearable physical interfaces, and ModKit, a visual, block-based coding environment, to code the Lilypad Arduino. The purpose was to encourage learners to create digitally and physically responsive wearable games, which would mirror many of the kinds of design and development practices utilized in creating current high tech wearable products. Further, we wanted to foster the kinds of computational literacies involved in both designing these kinds of technologies and also in working collaboratively on a team to do so. However, they could also interrogate and redesign the systems behind them. Moreover, we felt they would learn that design involves the distribution of expertise, and how to collectively negotiate ideas and divide responsibilities. We anticipated that the process of team-based design would integrate their unique interests and skills, making each part essential to the whole, so they begin to see the value of crafting, engineering design, art and media making, and coding as equally valuable to the final product.

In the previous curriculum, youth learned how to use each of the toolkits during the first half of the workshop, where they would engage in both didactic instruction and project-based work. However, based on the novelty of the curriculum, it was more akin to problem-based than project-based learning. Between the first and second version of the workshop, the first author trained and worked with a former graduate student to create buildable models of each aspect of the curriculum. During the second iteration, discussed here, students learned the material primarily by engaging with project-based work from model designs, such as a simple textile glove that could connect to Scratch with the MakeyMakey and conductive fabric, and a standalone e-textile project with the Lilypad Arduino that would control LEDs with conductive fabric. They also learned how to remix in Scratch, how to create basic interactions, such as movement, and how to create customized sprites. Finally, they learned how to connect all of the pieces together with a more complex e-textile glove that produced lights, sound and vibration while controlling a Scratch game. They spent half of the fifth class learning design-thinking principles and creating storyboards of their design ideas. Afterwards, they chose their own teams, and negotiated their designs in order to start the final project creation process over the final three classes.

Methodology
Data utilized here is in the form of video recorded class observations and interviews with 16 students who consented (pseudonyms used to protect identity). A total of 3 fully bidirectional and 3 unidirectional projects

were created (unidirectional projects only utilized Scratch and the MakeyMakey to create wearable game controllers with no physical responsiveness). This data analysis focuses on the bidirectionally responsive games, of differing complexity, and one unidirectional game, as case studies for the kind of affordances that can be fostered through *bidirectionally responsive making*.

In line with our research question, we explored observations and interviews to understand whether and how collaboration and inclusivity were encouraged through the workshop and toolkits. We utilized Miyake and Kirschner's (2014) team learning model as a frame for understanding these interactions. Further, we explored whether team members felt safe to explore their own individuality within the group (psychological safety) and if the team helped cultivate an environment for open communication, diverse ideas, and supportive and constructive feedback. Further, we analyzed whether teams valued task cohesion or social cohesion and how their choices may have affected overall team performance. To explore inclusivity, we looked at evidence of a change in computational perspectives (Brennan & Resnick, 2012) and perceptions of computing as a field (Kafai, et. al., 2014). We utilize perceptions to understand how the workshop fostered digital identity formation (i.e., technology self-efficacy), which is instrumental to equitable participation in computing (Goode, 2010).

Findings and discussion

Bidirectional projects

The "Dino Party" (see figure 1) project is a pet care game where players utilize a carefully crafted, visually-responsive, wearable bracelet to command a dinosaur pet to play and eat in a digital Scratch game of their design. The team designed the physical controller so that both the MakeyMakey and Lilypad were connected. When different conductive fabric buttons were touched, the pet sprite would perform a sequence of actions in the digital environment, which they had coded in Scratch and connected to the fabric with the MakeyMakey, and, simultaneously, the tricolor LED would change color in the physical environment, which they had designed the e-textile circuit to do and coded in the Lilypad Arduino through the ModKit coding environment. Project members consisted of 2 girls (Sadia and Elisa) and 1 boy (Andre). The "Dino Party" team consisted of team members who were mostly inexperienced with programming, digital design, e-textiles and circuitry. Andre and Sadia, for example, did not have experience in any of the content areas, while Elisa had some background and experience with Scratch and circuitry. Sadia explained that in the beginning "just Andre sewed, I made the glove and then Elisa programmed, but we alternated" so that everyone "got a fair chance of doing something." Sadia, Elisa and Andre were initially "clueless" about their final project because all their ideas had "pros and cons." They "listed the pros and cons and…the challenges," divided up the tasks and also switched tasks. The division of labor and the opportunity to perform other sub-tasks such as sewing, programming and designing shows that the team promoted a safe and collaborative group learning environment. The team created a practice of collaboration where decision making was structured into a cost benefit analysis. Sadia described that the team had "different ideas" regarding the sprite design though they "didn't really argue too much." The team dynamic was such that during instances of constructive conflict the team "compromised" and "talked it out." The team also was not punitive when somebody "didn't code right" and instead were "supportive of each other."
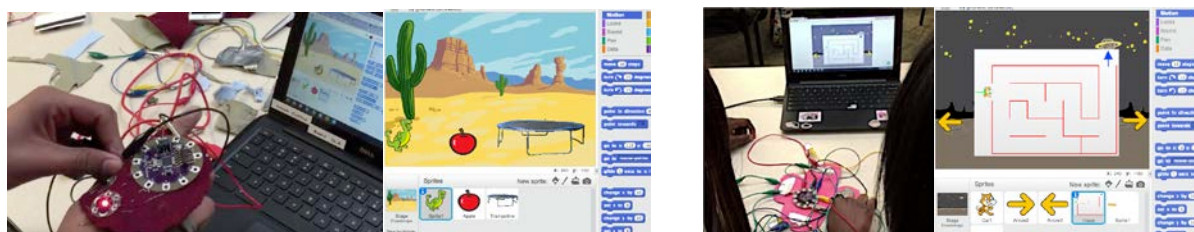

<u>Figure 1 (left)</u>. "Dino Party" project; <u>Figure 2 (right)</u>. "Scratch Cat…" project.

Overall, the team seemed to be motivated more by task cohesion. The group had devised a strategy around the division of labor such that "Andre sewed, [Sadia] made the glove and…Elisa programmed" but they "alternated" so that everyone had a "fair chance of doing something." Sadia further described that the team "took a couple of weeks to get [the project] programmed, coded, [and] sewed [with] the conductive fabric" but they felt "accomplished." Andre mentioned that the team worked on "three different things going on at the same time" and Elisa said that it was "fun to associate [all of the components] together." All team members described feeling proud of what they had accomplished together, with Sadia stating that she felt "successful of what [she] made." The Dino Party team had also high levels of group potency. While, according to Sadia, combining the LilyPad, the Makey Makey, and Scratch was "sometimes overwhelming" because of "all these wires and coding" and the constant "plugging it up and unplugging," the team pushed through it. Further, all members of

the Dino Party team expressed positive shifts in perceptions of computing. For example, Sadia, who originally thought computing was "boring" or something "computer geeks do," realized that working with computers is "actually a lot of interactive work with your people." While Elisa and Andre wanted to pursue careers in medicine, they saw new diversity in how computing could be applied in their lives: Andre saw computing as including "tangible real world objects" and Elisa felt the workshop "helped [her] in engineering" so she can now say "you can do it this way instead of that way."

"Scratch Cat Screeches at You" (figure 2) is a maze game, where players utilize a petal-like controller, with conductive fabric that serves to move the Scratch cat sprite up, down, left or right (figure 5). The project is bidirectional in that the e-textile controller is connected both with the MakeyMakey and Lilypad, and both Scratch and the Lilypad are coded for responsiveness. For example, pressing the upward facing petal on the textile controller would trigger a "when [up arrow] pressed" sequence of events in Scratch, as well as turn on an LED connected via the Lilypad. Project members were two girls (Evelyn and Jackie). The "Scratch Cat…" team was a unique case, consisting of a member with lots of experience in coding and media making in Scratch but no experience in circuitry and e-textiles (Evelyn) and another member with no background in any of the domains (Jackie). Jackie described how Evelyn set up the Lilypad and did most of the Scratch coding while she "designed the controller to be a flower." Jackie also connected the "trilight [tricolor LED] to the thing that made everything light up [the Lilypad Arduino]" with Evelyn's help. Evelyn stated that the project was "very collaborative": they "split off, the Makey Makey and the programming because Jackie could sew better than [Evelyn] could and [Evelyn] could program better than [Jackie] could." Similarly, Jackie wrote a "few Scratch commands" because she felt it was not "fair to have [Evelyn] do all the Scratch work." Overall, they appeared more motivated by task cohesion, partially because they didn't have social bonds before the workshop. However, there was evidence of a lack of psychological safety in the team dynamic. Due to Evelyn's prior experience with Scratch, Jackie did not feel confident working with it because she feared that she might "mess" things up. Evelyn was highly invested in her Scratch coding expertise and this unspoken hierarchy was enforced in the team. While she did ask Evelyn to let her write a "few commands," she gave up because she could not code one of the sprites. Jackie also complained that Evelyn "sometimes...didn't listen to [her] ideas" and vice versa, and that Evelyn "moved too fast" or they would "moved on" to other tasks without communicating.

The team experienced instances of high and low group potency throughout the design process. Jackie felt that "it was good" working with her partner because she helped her "deal with challenges." The team was effective at "keep [her] on task" and "helped her learn...about Scratch and Modkit." Evelyn commented that "it was frustrating" working with ModKit and Lilypad Arduino "because [they] never worked" and they were "angry at times" when combining the environments. However, the team pushed through their difficulties, finished the project, and even thought their partnership was strong enough to team up for a science fair. Moreover, despite some of the limitations in team dynamics, both team members expressed shifts in their perceptions of computing. Jackie originally thought computing "would be boring or just dry" but afterward realized that it could be "fun," "challenging," and something she could "learn" from. She even discussed creating gloves on her own that could keep someone warm in the winter. Evelyn felt the workshop helped her "work through" computational creation, and "felt better" about computing, which would "definitely" play an important role in her future aspiration to be an astrophysicist.
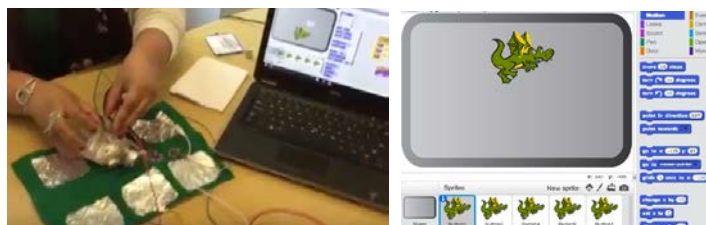

Figure 3. "Whack-A-Dragon" project.

"Whack-A-Dragon" (figure 3) was a game akin to whack-a-mole that utilized dragons and ghosts instead of moles. Sprites would randomly appear on the screen in Scratch: hitting a dragon sprite would reward you in the game, whereas hitting a ghost sprite would penalize you. A colorful felt-based board with conductive fabric served as the physical interface, where you could hit different parts of the board with a mallet created from a recycled water bottle. The conductive fabric corresponded to screen coordinates in Scratch, and, when hit, would trigger a musical sound in the physical environment (through the Lilypad Buzzer) and sounds and actions in the game. Three boys (Jeremy, Hayden and Eric) made up the project team. Most team members had no prior experience with any of the domains or competencies associated, except for Jeremy, who had some minor circuitry experience and also had previously designed a car out of recycled materials. Hayden described

that "the work was shared [amongst the] group," such that he was "the one who did Scratch" and the team "wanted another person mostly to do the sewing." Observations showed that Eric coded the Lilypad in ModKit with Jeremy's help and Jeremy did all of the sewing exclusively. As Hayden explained, team members "would contribute equally [to] each [of] their roles, and then other people would help them with their roles sometimes."

While class observations seemed to indicate a lack of psychological safety and cohesion, all members indicated that they felt safe to communicate and negotiate. For example, Eric felt confident within the group to "ask questions" to team members and share "creative ideas." He also described that one of the benefits of teamwork was that he could "count on them to figure it out" if he "didn't understand something." Jeremy recalled some disagreement when it came to the project but, while "com[ing] to an agreement… was pretty hard," they "voted" and were able to resolve it fairly easily. While they demonstrated levels of task cohesion, such as when Hayden expressed feeling "good" about "figuring out" how to create the final project, they overall evidenced social cohesion. For example, Eric expressed that it was good to "collaborate with [his] friends…because you can ask your partner's questions and have creative ideas," as well as work on different components of the project in order to make "it into 1 big thing to show what we've learned and what we can now do." Jeremy felt the workshop "changed the design of the group" regarding "how [they all] worked together" in a "positive" way. While the literature asserts that task cohesion leads to better learning and performance behavior (and the team did struggle with staying on task), by the end of the workshop, they all expressed significant positive changes in their computing self-efficacy and identification. For example, Jeremy felt the workshop "definitely" changed his perceptions of computing in that he "never really knew it was that simple to program" and was now "going to expand [his] experience." Similarly, Hayden felt programming was "something [he had] wanted to get more into" and the workshop "helped reinforce [his] feelings about it." Eric felt Scratch "was fun" and enabled him to "create anything." He also enjoyed working with the Lilypad and e-textiles because "it brought more [of] the real world [where] you [can] create an actual game you can play using physical objects not just in the computer." While he contended that he now thought "computing [was] more fun," he also felt "it was more difficult" because "there's so many possibilities," though he could "take advantage of it." He was especially motivated by design "because…you can have so many options and just be creative," particularly with wearables because they "make it more realistic."

Figure 4. "Bad Hair Day" project.

Unidirectional project

"Bad Hair Day" (Figure 4) was a creatively designed wearable game that utilized the MakeyMakey to control Scratch. The textile controller repurposed a hat to represent the kinds of embodied interactions involved in getting your hair done. Touching different parts of the hat would result in having a character on screen get her hair shampooed, blow dried and styled. Three girls (Aminata, Tyra and Mia) were project team members. The "Bad Hair Day" team had some past experience with some of the domain competencies and practices. While Mia had no background, Aminata had had some limited experience with Scratch and Tyra had some experience with circuits. Surprisingly, Mia took on the group leadership role, encouraging the other members to collaborate and distribute aspects of project creation, while the other two members were mostly otherwise directed when she was not in attendance (due to her high school athletic obligations, she often missed classes). While Aminata was instrumental in coming up with the design concept during the design thinking aspect of the workshop, she found Scratch to be challenging, describing it as "hard for [her]." She also knew that she "would give up easily" if she worked alone, but her teammates encouraged her and - in her words - said "let's try it out."

There were some arguments between Tyra and Aminata: according to Tyra, they were not "compromising," and, according to Aminata, they had "different ideas." Although there were arguments, constructive conflict and negotiation between Tyra and Aminata's differing ideas meant that team members felt secure to voice their concerns. For the most part, this group demonstrated more social cohesion than task cohesion, which may partially explain why their project ended up being unidirectional. For example, when asked about challenges with working the team, Tyra responded that they had to "sew everything on" and that "somebody had to take it home" and remember to bring it the next week. They "had to text each other" to remind people to bring the hat to class. Similarly, when asked about troubleshooting practices, Mia mentioned

that they "had to" to code with a forever loop to create sounds that mimicked shampooing, washing, and blow-drying when different parts of the hat controller were touched. This frequent emphasis on having to do something implied that the team was more driven by social cohesion than task cohesion. However, they started to evidence task interdependence. Tyra expressed that her group "took turns sewing everything together," "helped each other" and did "everything together." Aminata explained this was because if a team member "did not understand something…maybe [their] friend will" and they would "correct it." This task interdependence meant that team members "taught each other" when some team members "were stuck" or "didn't understand something." Over the course of time, they expressed more task cohesion, coupled with group potency. Determined to finish the project, Aminata "slept over" at Tyra's house "every Saturday…to work on [their] project" outside of the workshop. Class observations showed that Mia and Tyra were initially more active workshop members while Aminata had checked out early on. However, after the team adopted her hair salon idea, she was more engaged and rallied the team to complete the project. Tyra described that, initially, they could not connect the MakeyMakey to the computer because "every time we would almost have it, it would be a problem so we had to start over again." However, they kept "com[ing] back" to the task and finally "made it work." According to Aminata, the team had nearly "[given] up" but decided that it was worth completing and when "it all came together" they were "proud."

While the team initially struggled, by the end of the workshop, each member expressed newfound positive changes in their perceptions of computing to varying degrees. For example, while Aminata wants to be a doctor and feels that she has not been "good at computers," after participating in the workshop she "like[s] them because [she] was really into [them] here." Similarly, Mia, who still has reservations about a career in computing, expressed wonderment in what she learned during the workshop: "Until, like we came to the workshop, I didn't know… I could be standing over here, and… doing something on my computer from right there." She especially enjoyed creating wearable technologies, which she thought were "fun." Tyra who "didn't have anything really to do with computers or technology and stuff," apart from schoolwork and entertainment, felt better about a career in computing. She previously thought that programming was a "basic job" where people "sat at a desk and typed some stuff up and that was it." After participating in the workshop, Tyra's perspective is of admiration and appreciation, stating that programmers are "doing a really good job" because it is "hard." Her perspective shifted from "know[ing] nothing about computers" to thinking "wearable technology is fun," and enjoying seeing "the wires and everything…[and] really play[ing] around with [them]."

Conclusion

Findings indicate that bidirectionally responsive making shows significant promise for fostering inclusive collaborative practices in makerspaces by implicitly scaffolding and distributing making activities, and helping learners better appreciate the creative, diverse and meaningful ways computing could be used in their lives. For example, the tools themselves encouraged the distribution of activities, while also being attuned to the whole, enforcing task interdependence and often encouraging individual and group self-efficacy. Further, for most teams, there appeared to be changes in the ways that gendered interests were expressed, as other studies discussed previously have found. While the all boy team still expressed interest in the technical aspects (i.e., "real world" and "tangible" connections over crafting), the mixed gender teams were more purposeful in distributing tasks and expressing diverse interests. However, unlike other interventions that integrate one toolkit or maker activity (such as standalone e-textile work) as a means of diversifying access or changing perceptions, bidirectionally responsive making encourages learners to distribute activities, such that collaboration is an essential aspect of design work. This process also helps integrate learners from their areas of interest or expertise. While this can sometimes create friction, it can also produce opportunities for meaningful peripheral learning, both of which were evidenced on the "Scratch Cat…" team. Furthermore, learners from groups underrepresented in computing (on teams such as "Dino Party" and "Bad Hair Day") expressed stronger computing identity and self-efficacy. We contend that having a shared artifact of their efforts can be a powerful motivator and serve as evidence of mastery, regardless of their design team roles. We see this across teams whose members expressed not only a greater understanding of computing and the diverse application it had in their lives, but also awareness of aspects of the development process that were appealing to them, whether it be crafting, design, engineering or coding. During both instantiations of the workshop, allowing members to choose their own teams mostly ended up being an added benefit, which helped them finish their projects. However, there is always the concern that some students will be left behind. While not all groups were focused on task cohesion, most eventually demonstrated a shift from group cohesion (or friendship-oriented goals) to task goals, such as with the "Bad Hair Day" team.

An important limitation in our findings is the cost associated once multiple maker toolkits are integrated in the curriculum. This is an important consideration, despite the increased cost accessibility of maker

and DIY materials (Blikstein, 2013). Once each toolkit is factored in, the total cost of materials per team is estimated between $100-150 (or $30-50 per student); on the other hand, having a purposeful team-based activity allows learners to distribute the costs as well as the benefits of learning a variety of tools. Another limitation happened when the school stopped providing PC laptops in favor of Chromebooks. However, Chromebooks cannot download software, such as ModKit. Incorporating the Raspberry Pi in the curriculum would add a layer of complexity but also benefits such as learning computer hardware and providing a more affordable and extensible Chromebook alternative. A future direction for our work will be to further understand the benefits and limitations of bidirectionally responsive making for inclusive collaborative learning for older and younger learners and with alternative toolkits and materials, such as paper or squishy circuits and Raspberry Pis.

Acknowledgements

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