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The Maker Movement - A Pathway for K12 Students to Engineering Adaptive Expertise

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Lee Martin studies people's efforts to enhance their own learning environments, with a particular focus on mathematical, engineering, and design thinking. In everyday settings, he looks at the varied ways in which people assemble social, material, and intellectual resources for problem solving and learning. In school settings, he looks to find ways in which schools might better prepare students to be more resourceful and flexible in fostering their own learning.

An Exploration of Identity Development in a High School Maker Class

Making and the maker movement have garnered attention among engineering educators as a potentially promising context for the development of design and engineering skills. Making can be defined as "a class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a 'product' of some sort that can be used, interacted with, or demonstrated" [1] (p. 31). Maker projects often involve the combination of traditional hobbies, such as sewing or woodworking, with digital technologies, such as microcontrollers or 3D printers. Because maker projects are commonly infused with digital technologies, there are many content- and topic-level connections between making and engineering (e.g., 3D printing, electronics). However, many have argued that the connections go deeper [2, 3].

One important area of alignment is the shared focus on design found in both making and engineering. The influential National Research Council report on engineering education emphasizes that design should be the centerpiece of K12 engineering education [4]. Certainly, design in maker projects is not the same as design in engineering projects – it is more loosely defined, less systematic, and less-often client centered. Making is not "junior" engineering – it is a distinct set of practices with its own community, set of values, and trajectories of participation. Nonetheless, the shared focus on design, and the shared experience of envisioning, planning, and building something, suggests value in considering making as set of activities that may move young people along a pathway toward engineering [5].

Design is usually conceptualized in terms of its component parts – the ability to follow a design process, to engage in prototyping and testing and iteration. In this paper, take a different tack to explore how participating in maker activities, within an open-ended activity system, can shape students' conceptions of themselves as agents who are capable of envisioning, designing, and building things to shape the world they live in. Such identity-relevant thinking aligns with Kelley and Kelley's [6] notion of "creative confidence," where people can develop comfort with the process of design and confidence in their own abilities. A number of researchers have found that participating in open-ended science inquiry activities can bolster students' sense of themselves as scientific agents [7], and we believe that making, when it is similarly open-ended, has good potential to foster such confidence as well.

Data for this paper are drawn from a single cycle of a design research study [8, 9]. The goal of the research is dual: to refine our understanding of desired processes and outcome (for this paper specifically, identity shifts), and to refine our pedagogical knowledge of how to design learning environments to bring about these changes. Given the nature of our data, it would not be appropriate to conjecture about the "effectiveness" of maker-oriented education, or to ask, what is its influence on identify development? Such questions require experimental designs, and are only appropriate at later stages of a program of research, when key variables of interest have been defined and validated. Instead, we ask, what are possible identity pathways through a maker experience? What connections do students see between their experiences and their identities? A better understanding of the ways in which students experience such learning environments is essential for informing design principles for how to design with such shifts in mind.

The notion of identity is a complex one, with a wide variety of approaches taken by different research teams. We make use of Nasir and Hand's notion of practice-linked identities[10]. They define practice-linked identities as "the identities that people come to take on, construct, and embrace that are linked to participation in particular social and cultural practices" (p. 147) and note that such identities are tightly connected to opportunities for engagement that exist within a particular practice environment. Concretely, we look for evidence for practice-linked identities in the ways young people talk about their participation, engagement, and sense of themselves.

Context and Data Collection

Our study took place in a small, diverse, public charter high school in a major Northern California city. The school has a distinctive model, where students spend two days per week off-site at a school-sponsored internship in the local community. For our study, students spent one day per week with us, in lieu of one of their two regular internship days. Each session lasted from 10am to 2pm, and there were nine sessions spread across nine weeks at the school. In addition, we arranged for interested students to travel to and present at Maker Faire Bay Area, a large exposition of maker-oriented projects in the San Francisco Bay Area.

Participants. Fifteen high school students participated for the duration of the study. Four additional students (two boys, two girls) began the class but did not finish. Participants were diverse across several dimensions, as seen in Table 1.

Table 1. Demographic information on participants.

Race/Ethnicity	Male	Female	Transgender/ Other	Total
White	1	1	1	**3**
Black/ African American	3	2	0	**5**
Latino/a	1	2	0	**3**
Multiracial	1	2	1	**4**
Total	**6**	**7**	**2**	**15**

Workspace. The school did not have a dedicated workshop space. Instead, we brought our mobile maker workshop to the school. The workshop includes tools and materials to support prototyping in craft materials, sewing, basic woodworking, basic electronics (including Arduino), 3D printing, and laser cutting. Many of the toolsets are located on rolling carts, which allowed us to move tools into a multi-purpose room, giving students more space to work.

Data Collection and Analysis. For each session, we used two fixed cameras to videotape the classroom activities. Because of the open-ended and dynamic nature of the activities, students moved around a fair amount, and thus the video records are necessarily spotty for any individual student. Members of the research team also used small, handheld cameras to capture interesting moments close up, or to capture students answering questions that researchers put to them in the moment (e.g., "what are you working on here," or, "looks like you got that working; can you tell me about that?").

At the end of each session, we conducted short, videotaped interviews with students. These sometimes occurred individually, and sometimes within project groups. Questions varied from session to session, but always asked students for a summary of their activities for the day, and for moments of frustration, insight, and/or learning. After the end of the 9 week class session, we interviewed students individually. Interviews lasted 15-20 minutes and were audio recorded.

Data analysis is ongoing. We are currently engaged in coding segments of interviews as well as videos of students at work. We have a particular focus on moments where students get "stuck" or express frustration, moments where they talk about themselves in identity relevant ways, and moments when they seek out new resources for learning and problem solving. For this paper, we focus on interview data, both from the weekly interviews and the end of session interviews. This focus allows us to give a brief narrative account of the learning process, as well as students' sense of themselves as makers and designers, expressed in their own words. We focus on a case of two students who worked together on an imaginative project of their own choosing.

Results

Group Level Findings. In the last session at the school, but prior to exhibiting their projects, we gave students a brief, three question interview about their experience and their learning, as shown in Table 2. The numbers in the cells show the frequency of response in each of the categories across the fourteen students who completed the survey.

Table 2. Frequencies of response to the question, "After working in Maker Club, how have the following changed for you?" for each category.

	Decreased a lot	Decreased a little	Stayed about the same	Increased a little	Increased a lot
Your interest in designing and making things	0	0	0	9	5
Confidence in your ability to design and make things	0	0	1	2	11
Your knowledge of how to design and make things	0	0	0	2	12

As the pattern of results in the table shows, students reported that they gained in interest, and to a greater extent, confidence and knowledge in making things. Although self-report measures must be interpreted with caution, we see these data as a positive indication that students felt that the maker class was a positive experience, that they learned from it, and left more capable than when then began. We now turn to consider two students who worked together on a project.

Focal Students: Marquise and Cyrus. Marquise and Cyrus* were both African American boys in the ninth grade. They were close friends and chose to work on a project together. Cyrus began in week one, while Marquise began in week two. Their initial project idea was to create a flying robot that could shoot marshmallows. This plan was scaled back in a variety of ways as they changed their sense of the difficulty of the task and their priorities. The final project was a robot-like body made primarily of wood, with a head that would light up when a button was pressed (see Figure 1). After completing the maker class, Marquise independently painted the robot and painted his preferred nickname for the robot, Johnifer (a combination of Johnathan and Christopher, he told us) on its chest.

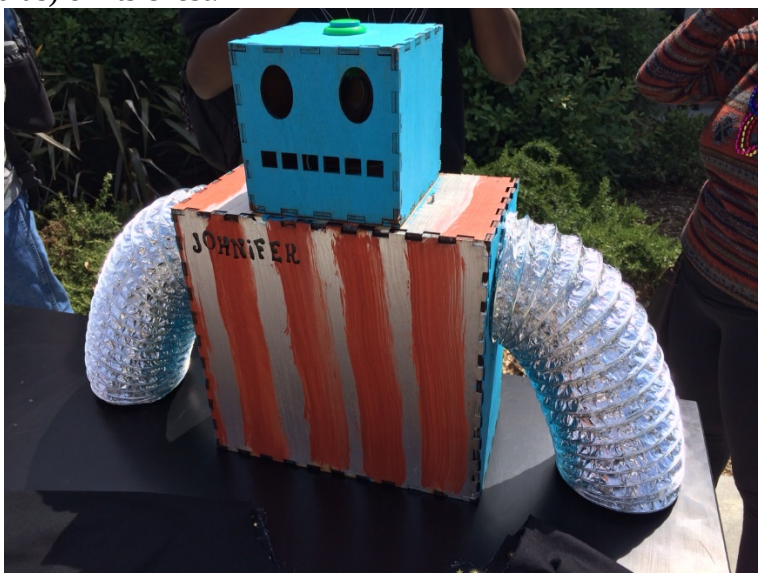

Figure 1. The robot Johnifer, as it existed at the end of project time.

At the end of week 2 (Marquise's first day), we asked each student whether they considered themselved to be a "maker." We had not defined the term in class, but rather left it open to the students' interpretation. When we asked Marquise this question, he replied, "Um, I haven't recently made anything but, like, I think I could be a maker, I haven't really considered myself a maker yet, but, soon, I think I could be a maker." He then reminded us that it was his first day. In this quote, Marquise describes himself on the cusp of being a maker – not yet there, but able to see and imagine it. This was a tentative identity statement, but one that indicated the possibility of change.

Cyrus answered the same prompt more confidently. After thinking on the question for a moment, he quickly said, "Yeah," but did not elaborate. Prompted with, "what kind of things do you make?" he described things that he had made in the maker class that day. Here, Cyrus, expressed confidence that he was a maker, but he did not yet have (or wish to provide) supporting details.

The initial idea of a marshmallow shooting robot was in place by midway through session 3, which focused largely on ideation. Cyrus stated that he was motivated to work with the laser cutter and LED lights, and that Marquise had suggested a robot. A robot made of wood that could light up incorporated all these elements. The idea of marshmallow shooting was dropped

* All names are pseudonyms.

when a third member, Michelle, joined the maker class and their group, and offered some critiques of the marshmallow idea. Michelle's attendance over the following weeks was spotty, but she did influence the project direction. Notably, for the dynamics of the relationship among the three partners, Michelle and Cyrus were dating.

Initial project work focused on learning to work with LEDs. The pair first worked with an Arduino and a breadboard, working to modify a sample Arduino sketch that controlled an LED based on a button press. Neither had worked with electronics nor programming before. As they worked, they ran into many technical glitches with their code and the wiring, as well as interpersonal ones. Sustaining engagement through these problems was a challenge for both students, and Cyrus was more likely to disengage. In a post-session interview, Marquise noted his frustration with Cyrus's lack of focus on the task.

As work progressed, it consisted of a similar mix of progress and frustration as they moved from a cardboard prototype of the robot body to creating the head in laser-cut plywood, and worked to create a working set of LED lights controlled by a button. Cyrus described this process in the final interview:

> *"All I did was take the piece of cardboard use two wires and connect it to another cardboard to see if it just would work. At first I tried no extra batteries and it didn't work, I tried extra batteries and it didn't work. I was okay. For some reason one of the lights looked like it was one steroids because it was way brighter than the other lights. I was like okay why does it look like that? I talked to [a mentor], she said I need more resistors. I was like, figures."*

Here, he related in substantial detail the nature of the troubles he encountered as he attempted to add more LEDs to his circuit. The level of detail suggests that this episode was highly memorable to Cyrus. The particular problem he described, with one light unexpectedly bright, led to a discussion with a mentor and guidance through comparisons of serial and parallel circuits (summarized here as "more resistors", needed for a parallel circuit). His playful summary, "figures," captured the persistent conceptual struggles he worked to overcome around building circuits and understanding the nature of various components, as well as his growing comfort with the ways that such problems typically got solved (i.e., adding more resistors).

The pair encountered a number of other difficulties as they worked to complete the robot, but their struggles with the LED lights typified those experiences. Later, when time was running short, Cyrus unexpectedly told Marquise that he no longer wanted to work on the LEDs, which had until then been his sub-project. Despite his frustration with this change, Marquise began working to understand and improve the circuit on his own. With support, he learned how to power an LED strip left over from another group's project, including learning to solder and compute the needed resistance for the strip, all in a short period of time.

A critical question in our analysis of this case was, how did these two boys relate these experiences in the maker class to their own sense of themselves and their future plans? Data from interviews shed light on this question. During the final, end of session interview, we asked Marquise if he thought designing and making things would be part of his future. He told us:

> *Yeah, for sure. It's really fun. I've always been in-between on what I wanted to be, whether it was psychological or actually hands on stuff or, as in like making or creating stuff like, something, like good, like a psychologist would be good work, career, or something but uh, I don't think it would be fun … if I'm making stuff and building stuff all the time, that would be fun, you know? I mean sometimes it would be hard, because there's always that hard part, but, it'd still be fun, you know?*

Here, Marquise ponders two career paths. Both are focused on doing good in the world. Both would be "good work." But only one, making things, would be fun. We asked him if the maker class had changed his sense of what he was capable of. He said,

> *"Yeah, for sure. Cause, like, I wouldn't have really thought that I could make stuff like this, I for surely didn't think I was going to make a robot. I thought I was going to make like maybe a box with some cool, like a chest or something you could put something in, like nothing, nothing really cool or which buttons work and stuff like that, but once I found I can, you know, that really changes the things I can do. So now I know I can learn, more, easily, or, not easily but, you know. Like I can learn more stuff, in, time, yeah?"*

In a self-report situation such as this, with the researchers present, there is a bias toward social-desirability that will encourage students to say positive things about their experiences. As such, we take his positive evaluation with a grain of salt. Even with this caveat, it is interesting that he made the particular claim at the end of this quote – the learning experience showed him that he can learn, not easily, but "more stuff … in time." We take that to mean that he gained a not only particular competencies in making things, but also a sense of the efficacy of effort toward learning in this space, toward the goal of making things.

In Cyrus's final interview, he, like Marquise expressed his surprise at how much they got done:

> *"First when we came up with idea, I looked at Marquise and I thought there is no way, we're probably never going to get near finish with this but actually it turned out, like it actually worked out… I learned that it's not so hard to make things after you put in enough effort into it. Like it's not challenging…cause in my mind I'm thinking like it's a gigantic forest but really it's only a few trees. A few really tall trees."*

Here, he expresses a shift in his sense of what he could do. Like Marquise, he expresses a sense of balance between a need for effort, and as such not being easy ("really tall trees"), but also being not as challenging as expected. This pairing of an appreciation of how the work was more difficult than expected, along with a sense of accomplishment for how much did get done, was a theme across many interviews in this group.

We also asked Cyrus if the maker class experience changed his sense of what he was capable of. He replied, "Well, usually I honestly don't-. Every time I make something I mess up, I'll be like, alright, I'm never doing this again. Like I try it, I mess up, and you know what, forget it, I quit.

But like I just learned to just stick with something all the way through, try a little harder. It shows result[s]."

Cyrus's claim here is that the experience helped to develop persistence, broadly. He elaborated on this by giving an example from school, where he persisted on a difficult presentation assignment that normally would have prompted to quit:

"I was doing it, I kept getting stuck, you know. So I just took a break really fast because my brain was fried from irritation and stress. And you know, I finished it, and I'm glad I did, and at first I was like, 'Look, dude [to his partner], you're going to have to do it.' But you know, I actually managed to pull through on that because I hate doing bibliographies. So it was just like kind of a skill I picked up during the program."

It is striking that Cyrus identified a global change in his ability to persist through difficulty, and that he attributed it to his experience in the maker class. Certainly, lasting and domain general changes in patterns of dispositions such as persistence are difficult to achieve (although not impossible), and as such there is call for skepticism about Cyrus's claim. Ultimately, the veracity of the claim is less important than the fact that Cyrus made it – that he reported this felt experience whereby he had been changed by his time making. His sense of growth is made more poignant given Marquise's expressed frustration with Cyrus's lack of focus and persistence throughout the project.

Discussion

Clearly, we cannot draw broad conclusions about the effectiveness of maker-oriented education, or even of our particular intervention, based on the data presented here. Nonetheless, we see in Marquise and Cyrus an important story of possibility: the kinds of shifts that Marquise and Cyrus reported, and their attributions of those shifts to their experience in the maker class, portray a movement toward a sense of agency and creative confidence within the domain of designing and building. We see these as practice-linked identities, coupled to the particular maker space and experience they had. Yet, to our surprise, both of these young men extended these identities beyond the class context. Marquise entered the class as a markedly persistent young man, always ready to learn and to try again after repeated frustration. His self-perceived payoff was a sense of fun-infused confidence – I can do this and I can enjoy it – one that extended into the near future, with a desire to continue making things, and into an imagined future of career choice.

In Cyrus, we have a young man who brought enthusiasm and humor to his project work, and who saw himself struggling with follow-through and persistence. Through his time in the maker class, and particularly in his pairing with Marquise, he saw his start-and-stop efforts on the project reach fruition, and this (he told us) granted him a newfound confidence in his ability to stick with challenging tasks.

Such identity shifts are challenging to quantify, especially when they are not as clearly expressed as they were by Marquise and Cyrus, and they do not align in tidy fashion with learning goals laid out in standards documents. Moreover, we suspect these shifts may not sustain themselves in the absence of further opportunities to engage in such practices within a nurturing environment.

Despite these concerns, we believe that identity shifts such as these represent an important foothold for young people – if they can believe in their ability to try and to move ideas along, they have a better chance to become the designers of the worlds they inhabit. As such, they represent an important area of inquiry for educators interested in the potential value of maker-oriented education.

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