Source Code and a Screwdriver: STEM Literacy Practices in Fabricating Activities Among Experienced Adult Makers

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The maker movement is changing opportunities for literacy learning as maker literacies are openly shared, networked, and interfaced between physical and digital worlds.

Modern making is diverse. It is practiced by artists weaving sculptures, engineers designing hooks that can hold helicopters to ship decks, outdoor enthusiasts rebuilding a kayak, gardeners building a vegetable trellis, and children creating imaginary boats from cardboard boxes.

Making as a learning activity is increasingly popular in formal and informal spaces for learners of all ages (Honey & Kanter, 2013). We define *making* as engagement in the personal construction of new objects or the hacking/repurposing of existing ones, often, but not necessarily, employing digital and analog technologies together (Halverson & Sheridan, 2014). We use *hacking* to mean repurposing an existing object in which the object is altered or used in a way that the designers likely did not intend.

Representational aspects of making may be obscured by a focus on hands-on work and play with physical materials and the iterative, experimental ethos that permeates making (Hatch, 2014). Yet, maker activities are replete with literacies, particularly those related to science, technology, engineering, and mathematics (STEM) fields (Gravel, Tucker-Raymond, Kohberger, & Browne, 2015).

In making, people search for sources, take notes, make sketches, create computer-aided design drawings, and talk to others for feedback and help. People draw on the backs of envelopes to think through an idea, and they keep records of what they have done. They write blogs, create Kickstarters and Etsy shops, and post their processes and their products on Facebook (Gravel et al., 2015). Making, although focused on the use and manipulation of physical objects, remains a representationally rich activity.

People's understandings of how to use representations, to create and negotiate shared frames for making meaning in accomplishing tasks, are central to learning (Cole, 1996). A focus on literacies is a crucial part of supporting learning while making. Because literacies can be defined as people's facility with representations, highlighting and building on those skills can allow people to make connections between the literacies they practice in school and out.

However, it is not yet clear what the benefits of making, as an activity, are to literacy learning in schools. The purpose of this article is to examine more deeply

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how literacies are enacted in the activities of experienced makers. It is part of a larger three-year study on literacies in making that our interdisciplinary research team of engineering, science, and literacy education professionals is conducting.

Articulating the complex practices of experienced makers helps identify real-world literacies. Yet, schools often present literacy tasks as decontextualized. Learning from the practices of experts can become the footings on which to build bridges between learning in making and learning in schools and make those school literacy practices grounded in real-world disciplinary practices.

Theoretical Framework

In this section, we outline the ways in which we conceptualize intersections of making and literacy and identify them in practice.

Maker Movement

Humans have always constructed their worlds through making objects. They have innovated through new techniques and materials for pleasure and work (Ingold, 2013). So, why focus on making now? The expansion of relatively low-cost, high-performing, and personalized manufacturing tools such as 3-D printers, the availability of information, and connections to diverse communities through digital networks has fueled an expanding do-it-yourself movement (Dougherty, 2013).

Part of the appeal of making in educational settings has been its emphasis on personal exploration and on tinkering with the digital/material world. It has been characterized as tapping into an intrinsic motivation to learn (Dougherty, 2013). At the heart of making is a desire to learn about the world by building it.

Parents, educators, and learning scientists have likewise invested in the movement, expressing interest in experiential education as an antidote to the increase in test-driven schooling. Potential for learning STEM practices and content while making has also been widely recognized (Office of the Press Secretary, 2014).

Making Processes

Through a review of literature (e.g., Honey & Kanter, 2013; Resnick & Rosenbaum, 2013) and our own research observations, we have identified six processes related to the larger enterprise of making:

1. *Ideating:* Brainstorming or coming up with ideas
2. *Designing and planning:* Selecting and arranging elements to solve a problem
3. *Tinkering:* Playfully exploring with materials, tools, and problems
4. *Fabricating:* Physically constructing an object with a specific goal in mind
5. *Sharing:* Making one's work public
6. *Teaching:* Exchanging skills and knowledge between more and less experienced participants

These making processes provide a frame for analysis of different times during making when literacy practices might be most concentrated, complex, and relevant to learning STEM content and practices (Gravel et al., 2015). This article focuses on literacy use during the making processes of fabricating. We chose fabrication as the focal making process because in our interviews, it had the highest prevalence of literacy practices of all the making processes. In the next subsection, we outline what we mean by literacy practices in general and STEM literacy practices in particular.

Literacy Practices

We understand literacy practices to be goal-directed social activities that center on the use of texts and representations. People use texts and representations to accomplish and participate in tasks that are part of the larger social and political world, including building new objects or hacking old ones. Texts and representations become psychological tools for people to think with and through (Kozulin, 2001).

Literacy practices are constituted by the purposes, identities, and tools, including ways of communicating, valued in a particular place and time (Gee, 1996; Street, 2003). Thus, the construct of literacy practices connects particular literacy events (Heath, 1983), or time- and space-bound interactions around multimodal texts, with broader social and cultural values about reading, writing, and communicating (Barton & Hamilton, 1998) in ways mediated by local values and purposes. One way in which literacies are constructed is through disciplinary practice. We use the term *STEM literacies* to indicate those literacies valued in academic STEM settings.

STEM Literacies

The intersection of STEM and literacies in education has emerged as a focal area of study (Richardson-Bruna & Gomez, 2009; Varelas & Pappas, 2013). Literacies are also integral to the work of scientists and engineers yet are often not foregrounded in making accounts.

Some work on engineering literacies with high school students has explored how literacy practices such as annotations can help students in design tasks (Wilson, Smith, & Householder, 2014) and how engineering classes for high school students learning English as a second language can draw on their family, community, and recreational funds of knowledge (Wilson-Lopez, Mejia, Hasbún, & Kasun, 2016). Likewise, intersections of arts and literacies are gaining prominence, in part through greater attention to the increasingly multimodal and digital representational landscape in which developed countries live (Rowsell, 2013).

We argue that repertoires of STEM literacy practices are needed to navigate makerspaces and that makerspaces provide opportunities for particular kinds of literacies. As people work in makerspaces, they participate in literacy practices valued at the forefront of STEM fields. We posit a set of literacy practices to show how maker activities connect to STEM practices and content learning (see Table 1).

One may argue that by focusing on STEM literacy practices of accomplished makers, we reinforce a limited set of practices that fails to recognize the literacies, resources, and sensemaking that young people bring to their learning. We agree that imposing a ready-made framework on what learners do may limit understanding of learner agency. One of our research goals is to test and revise our framework for understanding STEM literacy practices in making through multiple applications and iteration of design. The framework presented in this article is a result of that work.

Two research questions guided this study:

1. What are the STEM literacy practices of makers from a cross-section of fields when they engage in the process of fabrication?
2. What might a focus on STEM literacy practices of adult makers mean for teaching and learning in and out of schools?

Table 1
Definitions of Science, Technology, Engineering, and Mathematics (STEM) Literacy Practices

STEM literacy practice	Definition with sample quote from an interviewee
Posing and solving problems in the world and in the design process	Using texts to identify and solve emergent and/or unanticipated problems while making: “There was a lot of trial and error with the CNC [computer numerical control] stuff, where I realized that it was cutting in the wrong place, I needed to figure out how the software works, and I had to figure out how to calculate things more accurately.”
Identifying, organizing, and integrating information across sources	Searching for information on the Web; using reference guides, material specification sheets, and product manuals: “Maybe, like, it’s some mixture of finding resources and trying things, and then the resources span from, like, textbook to, you know, random people on the Internet and then talking to people, observing things.”
Creating representational forms and traversing representational systems and materials	Producing a symbolic representation of any aspect of the project as an aid to making (measurements, notes, drawings) or transitioning between different modalities, such as talk, sketches, and formal designs: “Over time, it just became part of my practice when it comes to sketching things and developing ideas. Half the time, I use a pencil, and half the time, I use pieces of wood and scraps and paper and whatever else. It’s just a way of working out ideas in the physical world.”
Communicating information in new ways to different audiences	Demonstrating made artifacts, producing Web pages or using social media to promote work, and peer-to-peer teaching; providing or seeking advice: “Blogging about it, I’m not as active on the keyboard forums as I mean to be. We have a regular mailing list that we send to our users, to our potential customers, people who’ve signed up for it.”
Documenting making processes and/or milestones	Photographing, writing about, or recording the steps, processes, and output of a project for oneself or as a reference for others: “Documenting and then just uploading it onto, like, a Facebook and adding a description, and that sort of to me like encapsulates that process.”

Methods

We used a qualitative-interpretive approach to collect and analyze data from interviews with 14 experienced makers. Such an approach allowed us to build analytic themes by interpreting and comparing participants' meanings through constant conversation with one another, as researchers, and the data.

Research Team

The research team consisted of a researcher in literacy and science education (Tucker-Raymond, first author), a researcher in makerspace construction and engineering education (Gravel, second author), a graduate student research assistant who had been a woodworker (Kohberger, third author), and a visual artist (Browne, fourth author). The multidisciplinary team allowed us to analyze data from multiple perspectives in conversation with one another. For instance, we used the artist's expertise to understand the processes of the more arts-based participants, and we drew on the engineering educator's expertise to contextualize the practices of participants who identified more as engineers.

Participants

Participants were included based on reputational case sampling (Miles, Huberman, & Saldaña, 2013), which allowed us to tap a resource among makers, their networks. We asked advisory board members, project partner organizations, and colleagues in the maker world to refer us to people who were experienced makers from any field and people who might know other makers. We also went to local Maker Faires—festivals where makers show off their wares—and talked to presenters. We sought participants who might represent diverse perspectives. Criteria for diversity included a range in the types of objects made, gender, and ethnicity so we could outline maker literacies broadly and deeply. We interviewed all of the people who responded to our requests.

Two people, the materials engineering professor and the sound artist/instrument builder, did not explicitly identify as makers. Others, such as the keyboard maker, did. There were nine men and five women. Three men were of African diaspora descent, and two women were Asian Americans. The rest were of European American descent. See Table 2 for the professions and sample made objects of the participants.

In each interview, we asked questions about the maker's background. For example,

Table 2
Interviewees' Profession and Central Object Chosen by Them to Represent Their Work as a Maker

Interviewee's professional identity	Made object discussed by the interviewee
Engineering educators	
Professor of computer science	Stage for recording stop-motion animation movies
Professor of engineering/software entrepreneur	Pizza box Skee-Ball game
Professor of materials engineering	Zine
After-school aquatics engineering program teacher	Firefly nightlight garden
Engineering graduate student	Kayak
Engineering undergraduate	Daft punk/Tron helmet
Entrepreneurs/small business owners	
Biologist/entrepreneur	DNA replicator (miniPCR)
Keyboard maker/serial entrepreneur	Ergonomic keyboard
Community organizers	
University crafts house student director	Metal and glass table
Community makerspace organizer	Software program for representing physical movement in 3-D
Artists/craftspeople	
Weaver	Large elephant
Sound artist/instrument builder	Phonoharp instrument
Woodworker	Earrings
Entrepreneur/biologist	DNA replicator (miniPCR)
Keyboard maker/serial entrepreneur	Ergonomic keyboard
Metal sculptor	Copper Chinese dragon

- How did you get into making things?
- How long have you been doing it?
- Why do you make things?

Although we did not ask participants to bring an object to the interview, we asked detailed questions about an object they had made that they felt represented their skill set and experience as a maker. For example,

- Can you tell me some of the things you made, and think about one project in particular that we can talk about in more depth?
- What is your planning process for a new thing? Can you give me an example of how you use representations?
- What is your fabricating/making/hacking process? Can you give me an example of how you use representations?
- How do you share your work? Can you give me an example of how you use representations?

Analysis

Flexible lists of a priori codes for making processes and literacy practices, presented in the Theoretical Framework section, were applied to the interviews. Data were analyzed through multiple rounds of reading data and refining thematic patterns (Charmaz, 2006). To reduce and sift through data, we first coded for making processes. Then, within those making processes excerpts, we coded for literacy practices. As we coded, we looked for disconfirming evidence and relevant data that may not have been covered by the a priori scheme.

We began our analysis by reading three transcripts page by page and discussing codes. We then developed examples and refined definitions of each of the codes to guide further coding. Thereafter, two of us coded the remaining 11 interview transcripts one by one, with the third researcher joining in every three transcripts. All differences were resolved through discussion.

We used the software program Dedoose to help us identify and display co-occurrences of STEM literacy practices and making processes within this set. We identified particularly code-dense co-occurrences as a place to begin the next round of data analysis (e.g., creation of representations [literacy] during fabricating [making]). Two researchers then coded excerpts of each co-occurrence separately for emergent themes. Excerpts were again checked for confirming or disconfirming evidence that they were examples of the codes. Unrelated codes were thrown out. Codes were also cross-referenced with examples of the same literacy practice in other making processes and with examples of the same making process with the other literacy practices. This resulted in collapsing some codes; for instance, we created the theme problem solving through communication because there was so much overlap between how people talked about their problem solving and what they talked about with others. Other themes came up in problem solving, such as tinkering and iterating on designs, but these were not necessarily related to literacy and were not as prevalent as themes of working with others or asking others for help.

We then searched those excerpts for emergent thematic patterns within the making process of fabricating. For communicating, some examples of emergent patterns were sharing for testing purposes, brainstorming and generating ideas, and asking for help. We subsequently generated memos on each STEM literacy based on patterns within those themes. For instance, we found that within the literacy practice of communicating, interviewees spoke to different people to help them solve their problems while making. This led to our analytic focus on the importance of participants' networks.

Findings

Table 3 is a matrix that shows the number of excerpts that we coded for each literacy/process co-occurrence in all interviews.

The table shows that the making process of fabricating had the highest number of discussions of literacy practices, 37% of the total. Designing/planning contained 23% of total mentions of literacy practices, and sharing had 19%. Ideation also accounted for 13%. Making processes of tinkering, teaching, and managing were the least prevalent.

In the distribution of STEM literacies that experts talked about, the most prevalent were representations (31%); communicating (23%); identifying, organizing, and integrating information (19%); and problem solving and posing (15%). Documenting accounted for 4% of total literacy codes. We have included examples and findings from identified literacy practices within the making process, fabricating. We use those examples not to illuminate the particular categories from our scheme but to highlight larger themes of literacy practices in fabricating that formed through analysis of those codes: problem solving through communicating; documenting, open sourcing, and community contributions; and creating and traversing representations in physical and digital worlds.

Problem Solving Through Communication

In fabricating, problem solving is social and is accomplished through communication with a network of peers. Making something, especially for the first time,

Table 3
Code Co-occurrence Matrix: Science, Technology, Engineering, and Mathematics (STEM) Literacy by Process

STEM Literacy practice / Making process	Identifying, organizing, and integrating sources	Creating and traversing representations	Posing and solving problems	Communicating for feedback or help	Documenting for self and others	Total
Ideation	18	20	7	7	0	52
Designing/ planning	28	52	11	21	0	112
Tinkering/ playing/ experimenting	8	13	6	8	1	36
Fabricating	48	47	23	26	8	152
Sharing	4	35	6	40	10	95
Teaching	3	9	7	10	0	29
Managing	0	7	1	10	3	21
Total	109	183	61	122	22	497

can often seem like solving one problem after another. It includes not just the problems that makers intended to solve but also when makers find themselves solving novel problems. To make is to get stuck on a problem, to solve it, and to work until the next problem arises. Participants in our study indicated that solving problems is often what making is about for them.

The literacies in problem solving point to traditional forms of visual literacies, such as creating sketches or three-dimensional models. They also point to the ways in which success is often predicated on access to information, which in turn is often predicated on who one knows.

For instance, Kitundu (names of participants are real and used with permission; see Figure 1) illuminated a dimension of making that many participants brought up: Makers often go to their friends when they need help with solving a problem,

> Because of my particular community at the Exploratorium as an artist in residence and within the Bay Area,...I have had the good fortune to meet people who have a wide range of capacities and abilities, and I'm lucky to call some of them friends. I generally call upon my friends. It's usually not cold calls to strangers.

For Kitundu, solving a problem involves communication with a close network of colleagues and friends. It is not just finding the appropriate online forums and communities. For others, identifying the right expert community is an early step in seeking help or information.

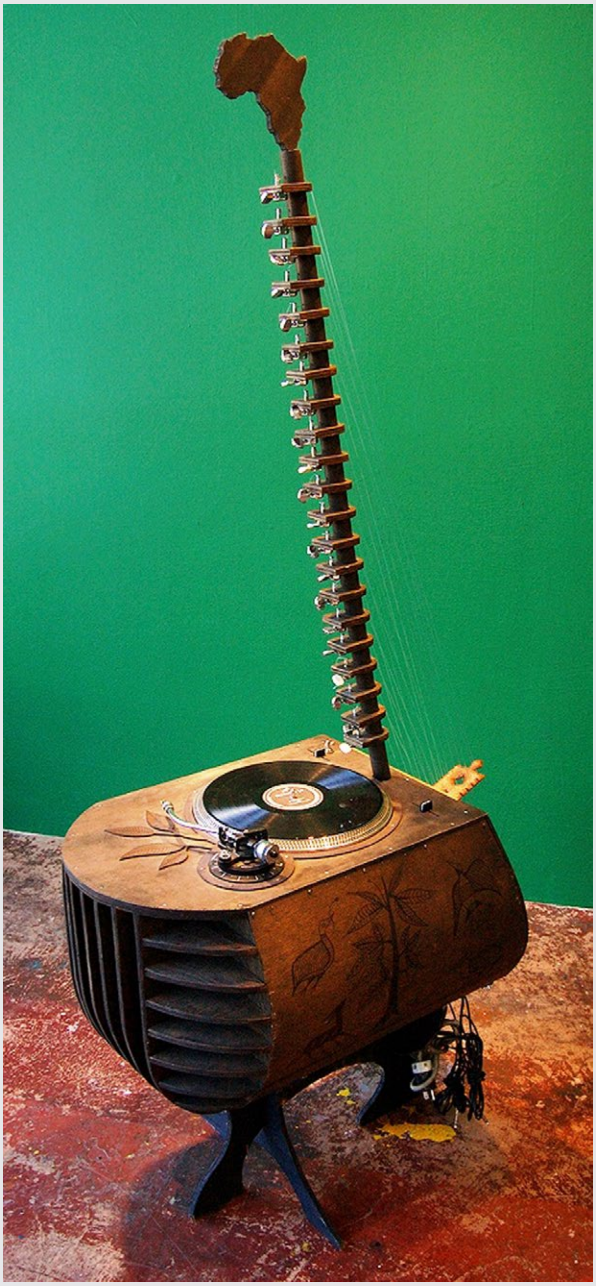
Making is interdisciplinary and project based; there is not one community or set of experts. Identifying the domains that one works in and what groups of people compose those domains is crucial to solving problems. Being open to where information comes from helps broaden the scope of possible useful answers. Yet, skilled makers develop a network of people to whom they can turn for expertise or help. As a literacy practice, this means valuing the skills and knowledge of others, knowing who is good at what, and knowing how to communicate with them.

What is less evident is the extent to which makers establish themselves as expert in one area and to what extent that gives them access to other experts. That is, do they have access to expertise because they themselves provide expertise to others who seek it?

Documenting: Open Sourcing and Community Contributions

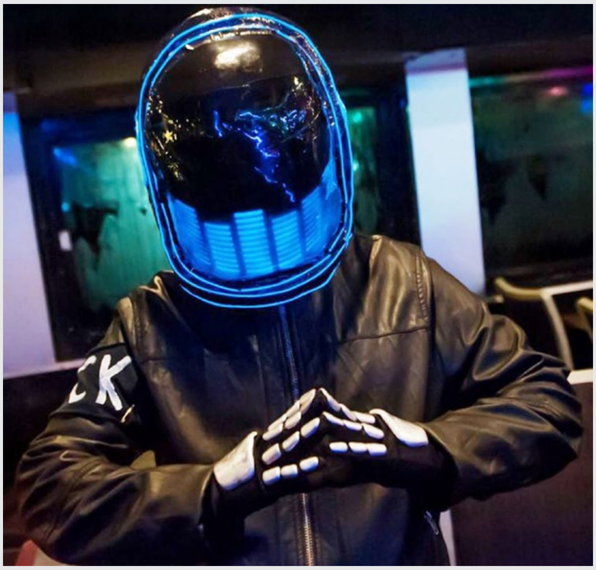
Documenting includes the representations that people create to track their own process of making an object. Documenting is also an example of the ways in which maker literacies are socially oriented. Helena, a mechanical engineering undergraduate and cosplay (costume play) enthusiast, discussed a helmet that she made with a visual equalizer on the visor that responded to music (see Figure 2). In cosplay, participants often dress

Figure 1
Kitundu's Phonokora Instrument



Note. Photo courtesy of Kitundu.

Figure 2
Helena's Daft Punk/Tron Helmet



Note. Photo courtesy of Helena.

as fantasy, manga, or science fiction characters. Helena wore her helmet to cosplay meetups and conventions and on Halloween.

Helena attempted to make the helmet through a type of fabrication process that she had not done before, by creating a mold. She was not satisfied with the blogs and instructions that she found on the Web, and wanted to create a complete record of her process that would show the difficulties she had in completing each step.

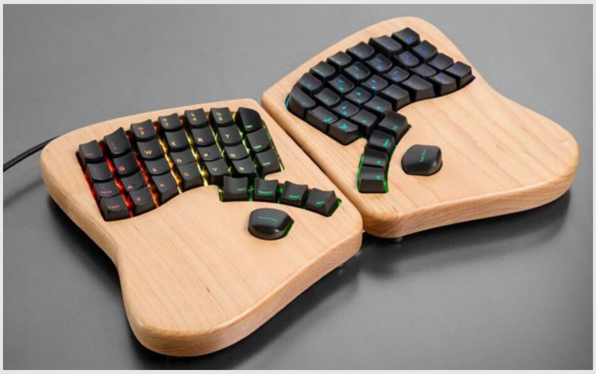
> I made this mistake in the first couple of products that I ever made where I only took progress shots after I had finished a process, like, "Look what this hat did," "Look what this process did." But it turns out that the final product doesn't really give a lot of insight as to how much work you put into it and what all was necessary to do it. You look at that helmet, you can't imagine what the mold looks like, you can't imagine how long it took. You can't imagine what it looked like when it was a sad, plastic, white thing. And so, just taking pictures of the entire process has been incredibly useful.

Helena hoped that her documentation would be an educational resource for others attempting the same process. She explained her processes to others in case they wanted to replicate what she did. She wanted to help others learn from her missteps. It was also useful for her in reflecting on the techniques she used.

Helena's statement was representative of makers in our study. They all valued sharing what they made with other people. Their personal making is both for themselves and others, contributing to the community of people who engage in cosplay, for instance.

Another maker, Jesse, shared with others by making everything in his product open source so anyone could

Figure 3
Jesse's Ergonomic Keyboard



Note. Photo courtesy of Jesse.

hack or improve the keyboards that his company made (see Figure 3):

> It also means that we're not the only people who can fix a problem or extend the product....We believe pretty strongly in making and the maker movement, and so, very few keyboards let you change their firmware. So, if...you want to integrate a password manager into your keyboard...or have it start flashing at you when you make too many typos,...the keyboard firmware is written in Arduino C, and so if you are comfortable playing around with an Arduino, you'll be able to change how our keyboard works....The way we describe it is all of our keyboards come with source code and a screwdriver.

Both Helena and Jesse identify as part of a community of makers. Helena indicated that her documentation is to help others doing similar projects, and Jesse indicated that he built his product, and included the documentation, to be used *and* to be altered by consumers, if they wished. Helena's and Jesse's communities value participation and reciprocation. Literacy practices are enacted within, and enable commitments to, open-source sharing. Their work is part of a larger group of projects and people that inform and are informed by others.

Creating and Traversing Representations in Physical and Digital Worlds

Makers used representations in different ways. The most prevalent of those uses were the creation of representations (e.g., sketches) and traversals across representations (e.g., using a sketch to make a scale diagram).

Creation of Representations. Many makers produced computer programs that communicated between digital and physical worlds for multiple purposes. For instance, one way was for the program to respond to people interactively (e.g., a program that manipulates a digital turtle in 3-D spherical space through sensor technology and recognition of another individual's physical movements). Another reason why makers created representations was for machines to talk to each other (e.g., a design for a CNC [computer numerical control] mill to precisely cut wood). Alec, who was working on the digital turtle on a sphere project, remarked on how he created multiple representations to check his work in physical/digital worlds:

> One of the nice things about symbols, interfaces, is that they make it very easy for you to do kind of a sanity check. Like what if I plug in zero here? What if I plug in infinity? Do all of the right patterns come out? And that overlaps back to the physics sort of "back of the envelope" mind-set...the idea that there are multiple representations that you check your problem with.

Alec produced representations that include the computer code, mathematics equations, and estimates implied in his "'back of the envelope' mind-set," and he generated feedback from output of those algorithms, in different forms, to measure his progress. The production of representations, then, becomes part of problem solving, where creating multiple representations can help people think through problems in multiple ways. This practice argues for literacy within disciplines to be flexible and for teachers to use writing as a learning tool rather than an end in itself.

Traversing Representations. Traversals indicated moving across representations, such as from sketches, to measured design engineering drawings, to computer/machine language that would tell a machine where to cut. For instance, Jeff described the process of making a pair of earrings for a designer client based on her sketches:

> It started with a sketch from the woman that I'm doing it for, and then I had to turn that into a digital two-dimensional drawing to be able to start the CNC process, which eventually turned into a three-dimensional model. Then, throughout that, as I was trying to learn how to do these certain things, I was having to both tell the people in the shop about my problems and describe what was going on and also having to describe it through written word, the Internet, to try to get specifics out of Google.

Jeff's objectives, and his need to learn, drove his literacy practices. He did not usually use literacy practices when he knew how to use a machine or what shape he wants to make. He used them when he wanted to develop his skills. In this case, Jeff took a paper sketch and made a vector drawing, then he turned that into a representation that the CNC machine could read. The CNC mill enabled him to create a 3-D representation of the earrings that he could discuss with the client. At the same time, he also had to get help on the CNC mill, a machine that he was not so familiar with.

Traversals that our participants highlighted suggest the need for familiarity with a number of materials and ways of representing the complexities of a single problem. Traversals also point to the focus in much of contemporary making on creating representations that help machines, computers, and people interact between physical and digital worlds. Teachers then can engage students in creating multiple representations about one topic, asking them to think about ways in which the representations complement or reinforce each other.

Discussion

Making education has promise for creating a learning environment potentially inclusive of a wide range of learners. We argue that educators must pay attention to the heavy representational demands of project-based learning in STEM domains. They must also pay attention to the web of resources that people bring to making. If teachers do not, then learners in those spaces, especially those already on the margins of education, will be further marginalized. Our study not only highlights the literacy practices of adults but also points to potential pedagogical practices for K–16 education.

Our study has shown that making literacies are intensely social literacies. Such a stance, that making is done with others or at least with their help, is important when considering young people's access to information. First, the maker movement has widely valued open-source sharing of information. Not only are makers expected to share information, but also, people such as Helena and Jesse willingly contribute their experience, resources, and knowledge to maker communities. Jesse even shares that information with his customers. Open sourcing, derived from the practice of open sharing of computer code among programmers, is a reciprocal endeavor.

Second, access to expert communities enhances access to information. In working within the context of a tinkering studio, DiGiacomo and Gutiérrez (2015) described the ways in which relational equity, the fostering of equitable relationships between older facilitators and younger school-age participants, contributes to learning and engagement. We extend this idea to consider networked relational equity as a necessary component of making education for young people. For young people in schools, this means building out their networks of resources.

Adult makers rely on the expertise of people with whom they have built professional and social relationships. Who makers can contact and talk with, particularly those they consider friends, contributes to the ways they can access important information needed to undertake and complete projects. Building those networks of access to information is crucial to helping young people develop literacy skills they need in multidisciplinary STEM contexts. It starts by identifying what expertise youths can already access and then aligning those with the kinds of resources professionals use, including online discussion forums, university experts, other professionals, and peers. Setting up an e-mail pen pal program with a university department could be one way to begin this process. Using the Take Action! activity included in this article could be another.

Media scholar Jenkins (2009) argued that contemporary digital culture requires the literacies of networking and collaboration. Anyon (1981) argued that such networks were already constructed at prep schools for the upper class where the educational experience is as much about meeting the other scions of the high-powered elite as it is about academics, contributing to the perpetuation of class inequality. Young people from all walks of life, especially those most marginalized by and in schools, need to know how to network—to build and maintain relationships with a variety of people—to facilitate their mobility.

Implications for tangible literacy practices include orienting learners toward offering something, even when seeking help from others. We wonder what a network of friends as experts would look like among novice makers in youth-oriented makerspaces. Could it exist in a similar way to the ways in which Kitundu and his friends interact? How do we integrate networking opportunities into learning experiences for young people?

Finally, many representations that the adult makers in our study worked with served to help digital and physical worlds communicate. Working with computer code that lets digital and physical objects talk to each other is a literacy for many (Burke, O'Byrne, & Kafai, 2016). This literacy includes knowing how to program computer code and converting analog representations, sketches, or drawings into digital representations. One must learn a variety of tools to generate files for a CNC mill, 3-D printer, or laser cutter. Of course, not all makers operate at this intersection. Some work in the physical world and others purely in digital. Yet, knowing how to create and understand representations in both worlds provides more flexibility than in one world alone. In schools, young people should be learning how to make digital and physical worlds communicate with each other as part of their core literacy curriculum.

Fabrication is but one process in making. The kinds of literacies engaged in other making processes expand what we have discussed here. Like all literacy practices, maker literacy practices operate as part of social worlds and enact particular values and ideals. Our work contributes to a framework for understanding, documenting, and drawing lessons from the ways in which literacies are practiced by makers and the ways in which competency in those literacies might be addressed by organizations and institutions that serve young people.

TAKE ACTION!

1. Making literacies involve collaboration and networking. Have youths draw a "network of expertise" map.
2. Begin with the youths putting themselves in the center of a piece of paper. As a model, brainstorm a few people you have asked questions of in the last few days. Have each student list 10–15 people with whom he or she interacts and what kind of information the student asks for. Have the youths also write down what kind of information they could provide.
3. Emphasize an individual's responsibilities to maintain network ties.
4. If the students do not know a person's expertise, have them ask the person for it.
5. Create a next layer of possible sites of information, including public institutions and private businesses (e.g., library, theater group, hardware store). Have students identify possible resources at each of these places and reach out to at least two institutions/businesses to conduct an informational interview.
6. Create a classroom map that includes sources of expertise relevant to the topic/space.
7. Have students identify gaps. Students may then find more distal resources/sources of information and add them to the map.
8. Propose different project ideas that would take advantage of the varying resources, and ask youths to identify the sources of expertise that they would seek.
9. Require youths to use the map when they need to find information for inquiry or research.

NOTES

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