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Navigating worlds of information: STEM literacy practices of experienced makers

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Abstract Making as a design-centered learning activity has recently received significant attention in education. We use literacies—how individuals use representations to learn—to explore the STEM literacy practices of experienced designers and makers. Describing makers' representational practices in STEM contexts can inform the design of literacy supports for young makers that can encourage their use of representations to connect STEM disciplines and design practices. We interviewed experienced makers to describe one literacy practice central to design: identifying, organizing, and integrating information. Makers enacted this practice within specific making processes—e.g., designing—with the purpose of sourcing and navigating information related to their chosen problems. The research supports efforts to bridge learning while making with learning in schools by positioning STEM literacies as central practices involved in the processes of designing and making.

Keywords Making · Makerspaces · Making spaces · Design · Literacies · STEM education

Introduction

The promise of making as a rich, multidisciplinary learning activity that has the ability to transform learning spaces in and out of school is gaining significant attention (Halverson and Sheridan 2014; Honey and Kanter 2013; Martin 2015; Peppler et al. 2016). Making in education builds from a rich tradition of technology and design education (Cross 1999;

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Hynes and Hynes 2017; Jones et al. 2013; Wilson and Harris 2003), and from the traditions of constructionism in which educators argue that people learn better when they are able to design and build their own objects and representations to understand problems in the world (Blikstein 2013; Papert and Harel 1991). With a focus on the relationships between designing, constructing in the world, and learning, educators and researchers have described compelling examples of learning environments centered on the practices of making (Gutwill et al. 2015; Martinez and Stager 2013; Sheridan et al. 2014; Wardrip and Brahms 2015). These descriptions build from efforts to characterize the practices of designers (Cross 2011; Lawson 2006) and engineers (Crismond and Adams 2012; Cross and Cross 1998; Dym et al. 2005; Koen 1988; Lewis 2006) by adding dimensions from artistic and crafting practices (Peppler 2010; Halverson 2013; Vossoughi and Bevan 2014). Yet, the majority of research on learning through making comes from out-of-school spaces (see Peppler et al. 2016), and both empirical evidence and theories for connecting making to K-12 curricula are lacking (Nemorin 2016; Wardrip and Brahms 2016). In this paper, to provide a foundation from which to begin establishing connections between the practices of learning while making with the practices students are asked to perform in schools, we use literacies to describe the practices that experienced individuals engaged in while designing and fabricating.

While there is research on making and tinkering practices (Bevan et al. 2015; Gutwill et al. 2015; Wardrip and Brahms 2015), rich descriptions of makers' practices are relatively limited, especially related to how people use literacies as they design and build (Wilson et al. 2014). There is ample literature describing research on technology and design education (see Jones et al. 2013), wherein scholars have long been working to classify approaches to design (Burghardt and Hacker 2004; Christiaans and Venselaar 2005; Cross 2011; Dym et al. 2005; French 1999; Koen 1988; Lewis 2006; Pahl and Beitz 1995). Within those frameworks, designers go about realizing their conceptual designs by producing "design embodiments" (Pahl and Beitz 1995); doing so is akin to making—where the designer fabricates physical artifacts or produces digital embodiments of the concept to assess and make revisions to the design solution. Coupled with these design embodiments are the "conceptual designs" (French 1999), where the ideas, processes, and solutions are formulated. Within that work lies an essential and inseparable relationship between representations and processes for designers and makers. Here, we propose that examinations of the literacy practices of experienced makers and descriptions of how they use representational texts can inform the ways in which educators identify and support young people's literacies in both informal as well as formal—i.e., school—learning spaces.

Representations are central to designing and making activities, and they exist in many modalities and levels of formalization. For example, two makers may produce a sketch on paper while they gesture and talk about a design they are trying to make. Later, they may rely on 2D schematics or 3D designs used to fabricate pieces of that object using digital tools like a 3D printer. The resulting print is then critiqued by the individuals, whereby they draw on the prototype with a marker to imagine revisions or alternative designs. The centrality of representations and ways of using them is apparent in design and making, and literacy practices provide a lens through which we can examine and understand their use. More specifically, we argue that literacy practices can bridge design and making activities and the content and practices of the STEM disciplines that are emphasized in school. We are motivated to explore how making literacies are STEM literacies, in part, because of the relationship these disciplines have to empowerment for historically marginalized groups (Moses and Cobb 2001; Tate 2001). Literacies provide ways to generate an expansive view of what participation in STEM might look like, and who can participate in these historical

exclusive domains. Examples of making in informal settings have shown how students historically blocked from participation in traditional STEM activities not only access but thrive in design and making experiences (Calabrese-Barton et al. 2017), which further motivates our work to establish ways of relating making and schooling.

Theoretical framework

We ground this study in theory and research on literacies as social practices involving representational texts. Building from the literature on literacies, we construct relationships to STEM literacies to articulate a conceptual bridge that links activities in informal STEM spaces and formal STEM settings, like classrooms or in-school making spaces (Gravel et al. 2015; Tucker-Raymond et al. 2017). We propose a developing framework that is neither finalized nor exhaustive, rather it is a tool to guide the present study and future work examining how makers use representations to go about their design and fabrication processes.

Literacies as social practices in making processes

Literacies are people's facilities with consuming, creating, and manipulating multimodal, representational texts in a variety of languages, registers, and communicative modes (Cope and Kalantzis 2000). For instance, effectively searching for information on the World Wide Web, navigating search terms, determining reliability, and reading and making sense of text, images, and video—sometimes all together—are literacies (Coiro and Dobler 2007). Literacies are also constituted by the purposes, identities, and tools—including means for communicating—valued in the particular place and time they are enacted (Gee 1996; Street 2003). Through literacy practices, people then communicate what knowledge is valued in any given social and cultural setting as they use and create shared repertoires for meaning making and frameworks for interpretation (Dyson and Genishi 2005). Thus, the construct of literacy practices connects particular literacy events, or time- and space-bound interactions around multimodal texts (Heath 1983), with broader social and cultural values about reading, writing, and communicating (Barton and Hamilton 1998) in ways that are mediated by local values and purposes.

How people engage in literacies is entwined with their purposes for doing so; literacies are always part of purposeful activities. As such, literacies offer a theoretical perspective through which the processes of designing and making can be understood, and through which the practices makers' employ can be more richly described. Through these descriptions, we can identify places to support new makers and to potentially broaden notions of what making can look like by focusing on the multiliteracies, often digital, present in these processes. Building from the literature on making and tinkering (see Vossoughi and Bevan 2014), we have identified at least eight goal-driven purposeful processes from our interviews with experienced makers: ideating, designing, tinkering, fabricating, sharing, managing, teaching, and socializing (Tucker-Raymond et al. 2017). We acknowledge the somewhat artificial divide between some of these processes, and we understand that many makers would argue they bounce back and forth between processes with such fluidity that the boundaries are nearly non-existent (e.g., some might argue that making and tinkering are one and the same). And, we invite critique and opportunities to revise this list, as we do not presume it is exhaustive. However, as an analytical tool, it is useful to develop finer-grained descriptions of practice so that we can further articulate

patterns of literacies we see among those proficient in their crafts. Further, these descriptions can be used to design supports for new and emerging makers to develop their literacies in different making activities, and to relate those literacies to school STEM practices and content (Tucker-Raymond et al. 2017). For the purposes of this paper, we select four of these making processes to focus our analysis on processes through which makers' conceptualize and produce artifacts,[1] and we briefly define them below:

Ideating: Captured in moments of inspiration, thinking, writing notes, and doodling. People's experiences and frames of thinking, both disciplinary and everyday, serve as fodder for creativity (John-Steiner 1997).
Designing: "The iterative selection and arrangement of elements to form a whole by which people create artifacts, systems, and tools intended to solve a range of problems, large and small" (Honey and Kanter 2013, p. 4).
Tinkering: "Characterized by a playful, exploratory, interactive style of engaging" (p. 164) with materials, tools, and problems (Resnick and Rosenbaum 2013).
Fabricating: "To build or adapt objects by hand, for the simple pleasure of figuring out how things work," (Honey and Kanter 2013, p. 4) and often driven by one's desire to share a personally meaningful product with others.

STEM literacy practices

We introduce the notion of STEM literacy practices to serve as a complimentary analytic frame to the making processes described above. Our goal is to develop understandings of the ways in which people comprehend, produce, and manipulate representational texts within multidisciplinary science, technology, engineering, and mathematics learning contexts, like making spaces. Furthermore, these literacy practices are goal-oriented (Gee 1996; Street 2003) and mediated by people, tools, and values in particular social contexts (Cole 1998). We argue that particular repertoires of STEM literacy practices are needed to successfully navigate the demands of making. As people engage in making, they participate in a range of valued literacy practices at the forefront of STEM innovation. We developed our initial theory-based framework by reviewing the literature on literacies in STEM fields (Bruna and Gomez 2009; Varelas and Pappas 2013; Wilson et al. 2014), and examining the NGSS cross-cutting themes and practices (NGSS Lead States 2013), and the Common Core State Standards for engagements with representational texts, such as reading technical documents (National Governors Association Center for Best Practices and Council of Chief State School Officers 2010). We suggest the following STEM literacy practices: (a) identifying, organizing, and integrating information across sources, (b) creating representational forms and traversing representational systems and materials, (c) communicating information to different audiences, and d) documenting making processes and/or milestones. As we have stated, this is a developing framework, and an overall goal for this study is to examine and refine this list and the descriptions of these practices (see Tucker-Raymond et al. 2017 for a more detailed description of this framework). For example, we have begun to identify sub-practices of *communicating* that involve seeking help, assistance to complete a task or series of tasks one cannot complete alone, and

[1] We do not include analyses of literacies in the other processes (sharing, managing, teaching, and socializing) because the participants in this study tended to discuss their own practices and the ways representations were used in the four processes we focus on in this paper. Many acknowledged the existence of these other processes when considering their work within making spaces, shops, or other community centers with tools.

providing feedback, or seeking advice, opinion, or consultation while engaged in making processes. To address our explicit goal of empirically examining and revising our framework, here we describe one practice considered across different making processes. Explicating one practice allows us to better understand how youth and adults may move fluidly between ideation, design, tinkering, and fabrication.

For the purposes of this paper we concentrate on describing and explaining *identifying, organizing, and integrating information across sources* (IOI). IOI is a particularly important literacy practice because the multiliteracies involved, conducting research on- and off-line, are often the most difficult for young people (Quintana et al. 2012), and achievement gaps among students with low socio-economic status and others persist when asked to complete similar research tasks online (Leu et al. 2015). Finding and managing information is central for engineering design (Fosmire and Radcliffe 2013), and we posit that skilled makers, designers, and scientists know how to find information from others, evaluate it, recontextualize it for their own research questions, and figure out what else they need to know. Where to find parts and materials, how to connect electronics to microprocessors, how to construct a particular part using a new or novel technique, these are all activities that require finding and using information, and we hypothesize this is a productive place to begin finding points of connection between experienced makers' practices, youth practices, and the kind of work required of designing, engineering, and making in and out of school. In this study, we look to professional makers who have developed literacies for engaging many forms of media for the purpose of finding and using the information they need to meet their goals.

Our research questions ask: What are makers' sources of information? How do makers source materials and information? How do they integrate that information into ongoing projects?

Methods

This study is part of the Investigating STEM Literacies in Maker Spaces (STEMLiMS) project, which is an ethnographic and design-based research project examining the literacy practices of experienced and new makers, in both formal and informal settings, with the goal of designing literacy supports to encourage participation and to improve equity in making processes. This paper builds on our initial efforts to begin identifying and describing particular literacy practices within particular maker processes (Gravel et al. 2015; Tucker-Raymond et al. 2017; Tucker-Raymond et al. 2016).

We interviewed 14 adults (9 men, 5 women from ages 20 to 57) through an in-depth semi-structured protocol. Interviews ranged from 37 to 90 min. Participants were recruited through reputational case selection within an overall purposive sampling strategy to illuminate the unique contexts of different making processes (Miles et al. 2013). That is, we sought out experts in the field, including our advisory board, and asked them to recommend people to interview. Participants included professional artists, one who made metal sculpture and one who invented musical instruments; engineering students and professors who made things like a kayak and a firefly garden nightlight; and entrepreneurs who made products like an ergonomic keyboard and a bicycle pannier. The interviews asked these makers to talk about their history with making in general, but also asked them to describe one project in detail with particular attention to the ways in which they have used representations in their work (Lee and Fields 2013). All interviews were

fully transcribed. We used a qualitative content analysis approach and began coding with a pre-existing and focused scheme to reduce data and to concentrate our analysis (Lofland and Lofland 1995).

Given that literacies are theorized as social practices, beginning with an interview study might appear to be an inappropriate methodological choice. However, our study began with a theoretically-based frame of making processes and STEM literacy practices, described above, that we first wanted to examine by privileging maker voices to check for confirming or disconfirming evidence. Interviews privilege the voices of participants—i.e., makers—and as a method they assist our efforts to understand makers' own perspectives of their processes and literacy practices, even if we derive them analytically from how they talk about their work with representations in the context of making a particular object. Additionally, interviews provide access to the histories of how participants' processes and practices came to be, which provides more longitudinal data on the use of literacies at different points in one's making trajectory. We are ultimately interested in understanding making across age ranges and settings, with a goal of expanding participation. This, by asking people to share personal narratives (Clandinin and Connelly 2000) of their entries into this domain we are able to examine and construct the boundaries and dimensions of this framework for later use in researching practices in making spaces, which are social, community spaces with tools. First, interviews began with participants' histories and general approaches, then we focused on particular works they have made, and finally we presented them with a way of organizing activity (the a priori framework) for critique, discussion, and revision.

Participants

Capitalizing on the methodological advantages of interviews described above, we sought to enroll a broad range of makers—from many social contexts, and different practices, and different domains—so that our empirical examination of the framework reached across settings (formal/informal), populations (youth/adults), and making domains (e.g., from robotics to jewelry making to woodworking). Table 1 presents an overview of the participants interviewed for this study.

Analysis

Focused content analysis attended to two major aspects of participants' interviews related to our research question: a) making processes and b) STEM literacy practices. The unit of analysis for both processes and practices was the meaning unit—any constellation of words or statements that related to the same central meaning (e.g., the making activity of tinkering or the STEM literacy practice of IOI) (Graneheim and Lundman 2004). Codes from each major category (processes and practices) were then checked for co-occurrence with codes from the other categories using the qualitative analysis software Dedoose (e.g., designing x IOI). Our team of four researchers further coded those categories using thematic content analysis (Carley 1990), comparing emergent themes through reading, discussion, and re-reading of excerpts across three interviews. Two researchers coded each remaining interview independently and then met to discuss codes and resolve discrepancies before moving on to coding the next interview.

Findings presented here focus on the co-occurrences of processes (i.e., ideating, designing, tinkering, making) and one particular literacy practice, identifying, organizing,

Table 1 Interviewee profession and central object chosen by interviewee to represent their work as a maker

Interviewee profession	Object discussed by interviewee
Professor of engineering education	Stage for recording stop motion animation movies
Professor of engineering/physical computing software start-up CTO	Pizza box skee ball game
Professor of materials engineering	Zine
Out of school time engineering program teacher	Firefly nightlight garden
Engineering graduate student	Kayak
Engineering undergraduate	Daft Punk/Tron helmet
University crafts house student director	Metal and glass table
Community makerspace organizer	Software program for representing physical movement in 3D
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

and integrating information (IOI).[2] We selected representative excerpts of themes that emerged within the co-occurrences for IOI in each of four processes. These excerpts are not intended to represent the makers' values, intentions, or approaches to making writ large. Nor are these data representative of all makers. Rather, they are illustrations of the ways in which makers engage these literacy practices in each of the processes of making we identified. Once the data were analyzed and the findings described, we distributed the written results to each participant as a form of member checking (Lincoln and Guba 1985). From conversations with the participants we were able to revise and clarify the ways in which the themes are presented. The illustrations provide for richer descriptions of the literacy practices as to present opportunities for supporting the cultivation and development of these literacies in new makers. We bold sections of these illustrations to call particular attention to the literacy practices within statements about making processes and practices. We present the themes related to IOI across the activities of making at the conclusion of the findings and discuss their implications for future research on making and learning.

Findings

We use these findings to assert three central claims: (1) literacy practices are a useful conceptual framework for structuring the ways we can develop and refine descriptions of how experienced makers engage with representational texts in complex, multimodal, multiactivity, transdiciplinary domains; (2) specifically, the practice of identifying, organizing, and integrating information exists as a tool to support navigating landscapes of

[2] For an elaborated description of the co-occurrences for all making processes and literacy practices, please see Tucker-Raymond et al. 2017.

tools, materials, and techniques and sourcing objects and knowledge from various communities as makers practice their crafts; and finally, (3) STEM literacies like IOI present opportunities for connecting practices from the curricular standards (e.g., NGSS) (NGSS Lead States 2013) to maker processes.

Across the interviews with 14 experienced makers, we identified the practice of IOI 32 times during the process of ideating (most common practice seen in that activity), 39 times while designing, just 7 times while tinkering, and 79 times while fabricating. We did not find IOI in sharing, teaching, managing, and socializing more than a few times, so we have omitted that in our analysis. We include analysis of IOI in tinkering because, while infrequent, themes emerged that helped us to understand IOI as a coherent practice across many processes. Further, a goal of our work is to eventually develop supports for new makers, and tinkering has been shown to be a point of entry for new makers (Petrich et al. 2013; Resnick and Rosenbaum 2013).

Sources of information used by makers

Before describing the nature of IOI within each of the processes, we present a list of the sources of information reported by our interview participants as a means for answering the first of our research questions. Sources of information across the activities of making included:

- The Internet: blogs, forums, web-pages, articles, Google Scholar, image searches, Wikipedia
- Popular culture: movies, music, popular artwork
- Web tutorials such as Instructables.com
- How-to videos (on YouTube and other sites)
- Product specifications sheets and product brochures
- 2-D and 3D Diagrams, digital or analog (e.g., CAD, circuit diagrams, STL files)
- Text books
- Lecture notes
- Patents and research papers
- Social media
- Books, magazines, and catalogs (e.g., McMaster-Carr)
- Designed objects—where information about decisions and particular assemblages of components can be scrutinized by examining the object itself
- One's own prior works: sketches, physical artifact, chunks of computer code
- Conversations with near-peers, fellow makers, and experts—in person and online

This list of sources of information is diverse and comprehensive, and we found that experienced makers have a worldview that information is available anywhere and in nearly any form: digital media, interpersonal communications, and even in objects themselves. The list illustrates a stance that experienced makers took toward their work: that each problem, task, or challenge was an opportunity to engage different representational "texts" to gather new information that could help them meet their goals. Viewing the world as a source of information can be considered an aspect of how making is framed as a learning activity (Halverson and Sheridan 2014).

IOI in each making process

While the list of sources illuminates a potential stance toward information in the world, it is also rather ambiguous, and we could argue this is a list of sources of information for any task or domain. It is within the particular making processes that we can understand how these sources of information are identified, organized, and integrated into ongoing projects. Thus, we present the ways in which IOI was used in conjunction with these sources of information within each of the four processes described above: ideating, designing, tinkering, fabricating.

IDEATING: While ideating, makers discussed ways in which they navigated various sources of information across a range of representational modalities to generate ideas. These included Google image searching, looking at videos of projects within a particular topics or genres, and examining existing physical objects (which could be considered hacking). Some illustrative examples are presented here:

> "I'll start looking up **videos of ways of how to build a boat**… um, cheaply, so I was Googling like different types of boats… after a week, I decided to make some sort of floating vessel for the Charles River,"—PHIL

> "… the core, the core of the search is usually **an image search** and it's, you know, a gut level reaction… of, you know, which of these images is resonating with sort of… intuitive sense of the direction I want to go."—CAT

> "Let's make a new product, let's look at everything that's out there, um, **we buy it**. **You know we take it apart,** and we say why are these decisions made, **why was it built this way and not that way**. And then find the compromise between completely reinventing the wheel and leveraging the ones that exist."—SEB

Phil spoke about how his office overlooked a river, and how his interest in getting closer to—in a visceral sense—that body of water developed. He employed IOI to seek inspiration and examples of ways to build boats using videos on the Internet, which supported his efforts to refine ideas about a "floating vessel for the Charles River." Cat is an artist who produces large welded copper sculptures, among other objects. She spoke of having general ideas about pieces she wanted to construct, and she employed IOI to navigate collections of images on the web organized around particular search terms like "Chinese dragon" to help her define and focus her ideating. The examples offered by Phil and Cat illustrate a practice familiar to many domains: using large collections of representations—photographs, videos, and information—as sources of inspiration. However, Seb and his partner, Z, exhibited a different approach: using physical objects for ideation by "hacking" them (a revered maker practice, Wardrip and Brahms 2015) to understand a range of possible designs. They conducted this interrogation of physical devices with the particular purpose of examining decisions made by the original designers to ask "why was it built this way and not that way?" Seb and his partner, who are making an affordable DNA replicator, identified information about their chosen problem space that was embedded within designed objects. The objects served as representations of decisions made and processes used made by other makers who worked within a similar domain. This is a process similar to one noted in the engineering design literature where experienced designers use existing products to "get up to speed" on the problem space(s) in question (Cross and Cross 1998, p. 144).

The three examples presented illustrate how makers navigate images, videos, and designed objects to identify information that brings the space of possibilities for their

chosen work into focus. Their motivation for engaging IOI in this way appears to be for inspiration or possibly finding a catalyst for their emerging project idea. Inherent in these approaches is a starting place, or a domain of interest to anchor the quest for information. Cat knew she wanted to do something with dragons, and Seb and his partner knew they wanted to build a small, portable DNA replicator. The anchors served different purposes, from using a search term in Google to find examples and visualize an artistic piece, to learning about the technical decisions others made while working on a similar problem. But across the experienced makers we interviewed, navigating a breadth of representational "texts" (e.g., video, images, physical objects), in service of scoping, refining, and conceptualizing ideas about what to make was literacy consistently applied during ideation.

DESIGNING: In our study, makers spoke about designing as a process similar to ideating, but with focused attention on a chosen project or problem. Like we found with ideating, IOI while designing involves similar anchor points used by makers to further scope their work. We present three excerpts that illustrate how makers utilize key search terms to focus and inform their designs:

> "I spent a bunch of time pulling **old patents** and **old research papers**, a lot of old research papers about historical keyboard designs. Um some of them describe you know angle—you know the angles that work well, the angles that don't work well."—JESSE

> "I invest a regular amount of time just reading stuff … to **be familiar enough with the contours of the territory** so that when I do need to understand something I do know where to go and what the words are."—ALEC

> "…you get that sort of daisy chain of this leads to this, and then this person's website points to this cool thing…. it often has **words and knowledge associated** with it, um, so **that's my path**."—KATHRYN

Designing involves continued navigation of the landscape of tools, materials, and techniques, but with a honed focus on the particular project space the maker has selected. Jesse, who builds computer keyboards, describes a practice of scouring "old research papers" and "old patents" to review the history of keyboard designs as means for specifying the dimensions of the problem, such as appropriate "angles" to consider in the design. Alec, who is designing a spherical projection system to program Logo turtles in 3 dimensions, cites the example of using written texts to understand "the contours of the territory" where his work resides. His example is similar to Kathryn's, where both share a goal of identifying key terminology in that "territory" to serve as waypoints for further navigation and design. Kathryn describes her "path," in this example, where she arrives at "words and knowledge" associated with her area of interest for that project; in this case, Kathryn was designing an Arduino controlled firefly nightlight garden. These excerpts illustrate examples of experienced makers engaging text, pictures, keywords, and historical documents as sources of information for identifying critical features of the terrain in which they work. This practice involves navigating the space, similar to how we describe IOI within ideating. However, in designing, the navigation is guided by more focused goals and intentions, as compared with ideating, where navigating and learning from information provided by others serves to stimulate and define the directions in which makers choose to focus their work.

TINKERING: Working within the boundaries of a particular kind of project (e.g., Jesse making a computer keyboard) makers embark on quests to discover best practices (either on the web, or by talking with knowledgeable others), to examine the documented mistakes

that others have made to prevent their own failures, and they experiment with different parts and materials to begin addressing particular needs of their projects. We selected three excerpts that highlight the use of IOI within tinkering, as an activity:

> "Very often some of the best tutorials I find are not from experts who've been doing this for 30 years, but from **people who are one step ahead of me**. People who are going to make the same mistakes that I have made, um, or help to let me avoid some of them…. it's a lot of **web tutorials from forums, books**, um, sometimes a weird intuitive leap and just kind of trying it over and over and over again until I get it right."—JESSE

> "I spend a lot of time looking at **best practice videos** on table saws or other things. Particularly like learning a new technique and every so often I'll be able to find someone who's really good at the particular thing that I want to do and then I **practice and work with them**."—WALTER

> "I think there were just different manufacturers who made a similar product, um so they had different varieties. And so **I set up all these experiments** of…**what things do I care about?** What matters?"—KATHRYN

Jesse and Walter offer examples of using "near-peers," those individuals who do similar kinds of work, as sources of information to support their work. These individuals, whether they are those with more experience, slightly higher levels of skill, or domain experts, possess valuable information about a specific problem space. They engage with these near-peers through digital forms like web-tutorials and forums and through interpersonal communications that allow these humans to be rich and adaptive sources of information. Originally a DJ, Walter creates musical instruments that include record turntables that can be played in tandem with or that pick up sounds from other stringed instruments such as a harp or cello. He then performs music he has composed. By examining "web tutorials from forums, books," and "practicing and working with others," these makers are able to play with ideas guided by a larger community of shared ideas, successes, and failures. From the examples offered by Jesse and Walter, the gathered information is used to do something; for example, Jesse engages in repeated trial and error—in a prototypical sense of tinkering with an idea, tool, or material (Resnick and Rosenbaum 2013; Wardrip and Brahms 2015). Similarly, Kathryn offers a possible motivation for tinkering as an activity in which to employ IOI when she says "I set up all these experiments of … what things do I care about?" In this sense, her practice involves information from other makers as well as her own tinkering practices as means for vetting materials and tools for her own making purposes. This playful, yet intentional, experimentation is ultimately a process of identifying, organizing, and integrating information to further her design goals.

These excerpts highlight an intersection between doing—working with materials, manipulating components, attempting new techniques—and a variety of sources of information that enable and support those activities. IOI as a practice for engaging a variety of representational texts—forums, videos, web-tutorials—in tinkering involves interactions with the actual objects and approaches that might be used to make a particular design. This coupling of information seeking, organizing, and integrating with the physical manipulation of an object exemplifies the notion of a practice enacted within a task or context. In other words, information is gathered, elaborated, or refined through the doing of some

hands-on design and tinkering work, where manipulating physical objects is an integral part of identifying, organizing, and integrating information that matters to these experienced makers.

FABRICATING: Finally, in the process of fabricating—where by far the most occurrences of the literacy practice IOI appeared in our coding—IOI was engaged as a sourcing tool for both materials and techniques but also for additional information from knowledge communities.

> "We had to find you know **the right suppliers**, and **the right parts** and custom make some parts and um, eventually we got there."—SEB
> "Almost always the first step for me is to **identify the community** that is good at it… figuring out which one of those it is, is **a mix of what community is [responsible].**"—ALEC

> "Did [this new component] just solve my problems and I can just stick it into my project [to improve it] or do I have to figure out how [the new component works to change its configuration to work with my parts]? Alright, so I take sort of a **people to people approach**, or a **related project search** to start exploring what other projects have parts that might be useful."—AMON

> "Here's what I have, and **I know what is in my inventory, and I know where [new components] can connect**, and one might have a wireless means of connecting to my creation, and others might use Ethernet, or a new type of cable and/or connector. I have to determine whether my new and existing components speak the same voltage… if not, I have to figure out whether it is worth acquiring or making an interface that can connect old and new parts?"—AMON

Mapping and traversing the vast terrain of parts, materials, and tools is an essential skill for experienced makers, one that involves careful vetting of the available options relative to an individual's goals. We argue that IOI is a practice used to navigate the chosen project space in service of sourcing the parts—knowledge and materials—needed to make something. At the level of components, sourcing of the "right parts" and "right suppliers" as Sebastian said, involves finding the parts that can be integrated with existing components in a maker's repertoire. In addition to the objects needed to make something, Alec and Amon spoke about the importance of other makers in sourcing the information needed in support of their creative design and making. Alec finds the "community that is good at it," which is similar to Amon's idea of a "related project search." Amon further elaborates this practice of IOI in making, "I know what my inventory is…I know where [new components] can connect." When makers identify options for completing tasks—often gathered from the community "that is good at it"—they are also often aware of what components are in stock and how the assembled options either do or do not work with one's inventory. These examples suggest a compilation of information from people, from objects, and from tools and materials that is masterfully assembled and used in service of making something. Within this making, we see IOI enacted in different ways to source the required objects, information, and approaches to assist the maker's creative pursuit.

While the line between making and tinkering is blurry, there appears to be different goals in the two activities that we can understand by looking at the ways makers talk about IOI. When making, this literacy practice facilitates getting the work done—completing the project—whereas during tinkering, the literacy practice occupies a space of learning about possibilities at the intersection of action and idea, where the information is understood and realized through playing with ideas and objects. Fabricating is described as the process

where the fruits of applying IOI at other phases of the process—ideating, designing, and tinkering—are realized through the production of some artifact.

Discussion

Literacies are social practices that enable individuals to engage with various communities and the representations they produce. In this study we found that experienced makers report frequent and varied engagements with numerous forms of representations produced within many different communities and domains. Identifying, organizing, and integrating information from texts enables makers to interact with different communities, motivated by a purpose: making something they find personally interesting and meaningful. Grounded in this well-established phenomenon that making things engages people in motivating and important work (Papert and Harel 1991) and research showing students can learn from these activities (Peppler et al. 2016; Vossoughi and Bevan 2014), we set out to explore the ways in which experienced makers interact with representations while they are engaged in the processes of making, specifically, ideating, designing, tinkering, and fabricating. How people interact with representations—the literacy practices they use—presents us with links to literacies in school curricula and other literacies that can be fostered and supported through maker-based educational activities.

We summarize the themes of identifying, organizing, and integrating information that emerged in the data within each of four processes in Table 2. These themes support the claim that IOI is a practice used to navigate landscapes of possible ideas, tools, materials, and techniques. Further, IOI is a useful practice for sourcing information, including material objects and ideas, in the processes of making. As such, IOI is a crucial literacy for learning in making.

The themes we identified of how IOI is practiced within different maker processes, while distinct in some ways, are presented as components of a relatively coherent social practice employed by makers to get their work done. While separating the makers' work into distinct processes is analytically advantageous for studying how literacy practices are enacted, taken as a whole, IOI is a widely-used practice that appears at all points in a maker's work; therefore, we would argue that this is a coherent practice enacted within purposeful activity. Contained within the practice of IOI are particular component practices or sub-tasks. For example, the identification of words, images, and objects to serve as anchor-points for focusing design decisions emerged as a theme. Here, identification can be considered a sub-task that contributes to educators' understanding of how experienced makers navigate the landscapes of possibility in their work. As such, we argue it is useful to begin articulating differences between identifying, organizing, and integrating within the themes identified in our interviews.

Identifying occurs through the scouring of different troves of information contained within conversations, images, textbooks, videos, patent documents, and conversations with others. Makers are continually engaging the different discourses of the domains in which they work, learning to identify information relevant to their particular task at hand. Identifying features of a problem space by exploring other people's examples stored in digital databases, for example through image searches on the web, shows how the sub-task of identification takes form in ideating. As another example, makers reported identifying key search terms when they were designing. It appears that the task of identifying information is conditioned by the goals of the processes in which the maker is engaging at a

Table 2 Emergent themes for IOI in four different activities of making

Activity	Themes of IOI
Ideating	Navigating the land of possibility at domain level (e.g., robotics)—what am I going to make and what are some potential directions I could go?; identifying information and gathering inspiration from multimodal texts
Designing	Using various texts to narrow and scope the problem and solution; finding anchors (often in the form of keywords) in the texts that focus the design; waypoints for further navigation
Tinkering	Information is gathered and understood through manipulation of objects and techniques; integrated into what the maker knows about the solution
Fabricating	Sourcing objects, information, and knowledge communities that facilitate/enable the completion of the project—a tool to support going from designed idea to constructed object

point in time. How a maker chooses what to identify may differ from process to process within the overall activity of making something, and the skill at seeing things as useful and relevant to the problem at hand is something that likely develops over time.

The sub-task of organizing involves situating newly discovered information within the overall scheme of what the maker knows relative to the chosen problem space. As Alec discussed, understanding the "contours of a terrain" helps him in organizing his design activity by creating a sort of road map of the project space. There is a physical aspect to this organization, literally filing and storing information in organized ways to support continued information seeking, for example, using website tagging or note taking software. But, we might also consider organizing from an ontological perspective, the process of making something new could involve reorganizing how one thinks about tools, materials, and domains as new information becomes available.

And finally, integrating appears to involve a process of taking new information and putting it to work within a particular activity. Kathryn talked about tinkering as a way to evaluate new products on the market and to determine whether she needs to care about that option within her chosen problem space. Once the new information was identified and organized, through the activity of tinkering, she decided how, if at all, that information would be integrated into her making process. While it may not be used immediately, it seems plausible that the experience of tinkering with this new thing, or idea, and the sub-task of making a determination about where to integrate it could support her future making when a need arises that might fit this temporarily discarded tool or material. For example, Kathryn spoke about exploring different kinds of Nitinol shape-memory alloy for her butterfly nightlight project. She eventually made a decision about what thickness and form to use, but in her tinkering with other options she gained some sense of the range of possibilities for the material. When a project requires something similar in the future, or if her first choice were to fail, there is other information integrated into what she knows about Nitinol's properties, gathered through tinkering, that she can call upon. Her tinkering may have led her to learn about that materials, its behaviors, and how it might be useful in the future. Amon describes a practice, one of many he and the others employ, where he can literally integrate information while making as he determines whether certain parts he is sourcing will work with the parts he already has in his toolkit. In both of these examples of integrating information during a specific activity, it appears that information is put to work to help achieve some task or goal. And while we can say that it is likely true about all the sub-tasks of this literacy practice, integrating may be the closest thing to evaluating or

incorporating these new ideas and information into ways of understanding the problem and the world.

In sum, describing the components of each sub-task of IOI may be useful in designing specific supports for new makers. IOI as a literacy practice, enacted in different processes, presents a way to understand how makers use different representations to go about their work. The descriptions we present, supported by excerpts from interviews with experienced makers, are an attempt to further and more precisely describe the practices of interacting with these representations with the explicit goal of supporting new makers, in school and out of school, in the same kinds of creative processes as these experienced individuals. In schools, current trends in curriculum reform driven by the testing culture emphasize small skills—e.g., identifying the thesis statement, mastering standard algorithms—which are discretized tasks taught in isolation, and that are rarely contextualized with some overarching purpose. Our data show literacy practices that include the 21st century skills that schools ask students to learn, and, for one reason or another, that they have trouble teaching in equitable ways—identifying relevant information, using keywords as anchors, comparing new ideas to existing understandings—captured in experienced makers' descriptions of their work in different processes. As such, literacy practices as a framework for studying makers can lead us to better understandings of their practice in forms and conceptualizations that provide links to the school curriculum.

Implications

In our study, we propose the use of STEM literacy practices as a framework for understanding the work of experienced makers. The outcomes of this research are cultivated descriptions of practices that we can then identify and support in maker-based educational programming for new makers. Furthermore, these practices are described in close relation to those identified within the Common Core State Standards (CCSS) and Next Generation Science Standards (NGSS) frameworks documents. Our goals with this work are to create bridges between the activities of making and the activities that teachers and students perform in schools. We do this through literacies, specifically, how representations function in this kind of work. The particular literacy practice described here, *Identifying, Organizing, and Integrating Information* is enacted within particular making processes. We imagine that as a model for how teachers could design curricular activities for students so that as they are making, they are developing the practices that NGSS and CCSS recommend. For example, Common Core writing standards say this about researching and building arguments: *Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas.* (CCSS.ELA-LITERACY.WHST.9-10.8; CCSS 2010). Similarly, the NGSS Science and Engineering Practice #1, asking questions and defining problems, quotes an NRC report to say: *Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution* (NGSS Lead States 2013). In both of these examples, we argue that IOI, defined as a STEM literacy practice present in making processes, addresses the needs set forth by these frameworks documents. The

descriptions we offer provide grounding for the design of particular STEM literacy supports for youth makers. For example, experienced makers can scan related projects and identify materials, tools, and approaches that could be useful in their own designs. We could imagine a web interface that allows users to identify related projects (through image searches, on forums and blogs, etcetera) and to organize them by materials, tools, and approaches in a way to facilitate the integration of this information into their own designs. The findings of this study—which pull from experiences of adults in informal learning environments—can be used to support new makers in their quests to navigate the landscapes of possibility within purposeful maker processes. These supports can encourage the kinds of literacy practices described here, which connect maker activities to the curricular requirements of, for example, NGSS, to provide pathways for schools seeking to incorporate more making into their curricula. We believe this is of particular interest and importance for technology and design educators, where the new excitement around STEM and making provides opportunities to frame technology and design as central to how making unfolds in schools, and the frameworks needed to design meaningful learning experiences for all students in these spaces. Our future research in this project includes observing, designing, tinkering with, and sharing literacy supports for out of school and in school making space learning sites.

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