Learning and Teaching in Library Makerspaces: A Literature Review on Making Literacies

ISAM 2017 Paper No.: 109

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I. Introduction

What literacies or knowledge, skills, and dispositions can people learn in makerspaces or through making activities? How can we tell? How can we design makerspaces and making programs to support learning? What kinds of makerspaces and making programs as well as approaches or pedagogies help facilitate various kinds of learning? Given claims about the potential for makerspaces, fab labs, hackerspaces and making programs (hereafter referred to simply as makerspaces for clarity) to transform innovation and entrepreneurship, creativity, and education (particularly science, technology, math, art and engineering, or STEAM, learning and workforce development),[1], [2] what answers can the current research base provide on these questions?

The literature on the idea of learning through doing or making is often tied to the constructionist educational theories of Seymour Papert (and can be traced even farther back to Jean Piaget's constructivism and earlier thinkers); however, the research on facilitating and measuring learning in makerspaces is much more recent and is still catching up to anecdotal practice and the burgeoning Maker movement.[1], [3]–[5]

The literature on makerspaces in library publications is even more recent, though work on the library as a center for creation and activity programs has a longer genealogy). [6]–[8] Much of the library literature has focused on explanations of makerspaces and how to create them, justifications for their place in libraries and librarianship, operations, case studies, specific equipment or projects, and programming and outreach.[9]–[11] However, relatively little attention has been paid to making literacies, learning and teaching in library makerspaces, its impact and outcomes, and specifically how instruction in making fits within literacy instruction in libraries in general. [4], [6], [8], [11]

This paper selectively reviews the recent literature and will: summarize current theory, research, and practice on making literacies and on teaching and learning in makerspaces; analyze the competencies or knowledge, skills, and dispositions reportedly involved in making; and examine how these might fit within the current Association for College and Research Libraries (ACRL) Framework for Information Literacy for Higher Education[12] and be taught in library makerspaces and/or integrated into existing literacy programs and curricula.

II. Methods

The audiences interested in makerspaces and learning range from education (both formal and informal at all levels, especially in the STEAM, design, and entrepreneurship disciplines); the galleries, libraries, archives, and museums (GLAM) sector (in the case of libraries, particularly school and public, but also higher education more recently); out-of-school time, youth, community, and civic organizations (e.g., job training, entrepreneurship, youth and community development); 21st century skills/literacies initiatives (e.g. Remake Learning, Partnership for 21st Century Learning); policymakers; and, of course, makers and makerspaces, artists' collectives, and other DIY and participatory spaces and traditions. These audiences produce scholarly research literature, substantive grey literature such as conference papers and presentations, reports, white papers, trade and popular literature, websites, blog posts and more in a variety of venues and formats. To compile an initial bibliography, a variety of sources and terms were searched in May-July 2017 and compiled with an earlier general bibliography on makerspaces completed in 2016. Eventually the scope of inquiry was confined largely to a selection of works from 2013-2017 in English representing the range of audiences and contexts previously noted. Given the short space of this review, here I focus only on some seminal and recent works.

III. Results

A. *Current theory on learning and teaching in makerspaces*

Given the heterogeneity of makerspaces--both informal and formal; diverse and standardized; top down and bottom up; digital and physical; dedicated, distributed, mobile or online; student, volunteer, or instructor and staff run; in various organizations and disciplines[13]--current practice is disparate but largely falls into three strands: "understanding making as a set of designed learning activities, studying makerspaces as communities of practice, and exploring makers as identities of participation (Halverson & Sheridan, 2014)."[14] However, the theoretical base is more widely agreed upon, though still diverse.[15]

As noted earlier, the actual research literature on learning in makerspaces is emerging but the field is based on a solid educational theoretical background in learning as process of doing and making, extending from Johann Pestalozzi, Friedrich Froebel, and Maria Montessori to Jean Piaget's constructivism and the work of John Dewey to Seymour Papert's constructionism, widely regarded as the theoretical precursor to the modern maker movement.[16]–[18] Some

also tie making as learning into other theories or frameworks from Lev Vygotsky and Paulo Freire, inquiry and project-based learning (especially STEAM-focused), digital media literacy studies, and other areas, such as Knobel, Lankshear and the New London Group's multiliteracies, James Gee's affinity spaces, Henry Jenkins' work on participatory culture, the MacArthur Foundation Digital Media and Learning Research Hub's connected learning, Jean Lave & Etienne Wenger's communities of practice, and design thinking of various stripes.[1], [18], [19] Many also trace maker learning and teaching practices from communities and movements such as MIT's hacker culture and Fablabs and the DIY movements of the 19th and 20th centuries, as well as the current 21st century maker movement emblematized by *Make*: *Magazine.*[16], [20] Still others are creating their own models or frameworks for a variety of situations, such as the Making and Learning framework for museums and libraries,[4] the uTEC (using, tinkering, experimenting, creating) model for libraries[21], Agency by Design's maker empowerment and thinking practices,[22] and Enactive Cognition,[23] and I^3 (Imitation, Iteration, and Improvisation) for engineering classrooms.[24] What most of these theoretical frameworks and practices share is an emphasis on learner interest-driven, hands-on inquiry and play stemming from real world projects and contexts (often with peer-to-peer support and collaboration and an emphasis on process and iteration) as a path to constructing meaning and learning.

B. *Current research and practice on learning and teaching in makerspaces and on making literacies*

The competencies or knowledge, skills, and abilities reportedly involved in making can have different emphases depending on the purpose of the makerspace, whether it is an informal or formal learning environment, the disciplines involved, the ages of the participants; and other factors.[18] In general, however, these literacies fall into a few (non-mutually exclusive) categories in the literature: disciplinary, digital or technical, and 21st century or soft skills.

Though a great deal of the literature emphasizes the role of 21st century or soft skills in making, the learning of disciplinary content is an important goal. Davee et al. note, "Makerspaces used in formal and informal educational contexts have been found to serve and align well with traditional subject matters and current standards," especially in STEAM and the humanities, and they cite examples of makerspaces as interdisciplinary hubs or ecosystems where makers in various disciplines can come together to share knowledge.[13] Bevan (2015) asserts that, "Science, technology, engineering, and mathematics (STEM)-rich tinkering engages learners in activities centered on the use of scientific and technical tools, processes, and phenomena. Physical phenomena or concepts such as balance, forces and motion, light, electricity and magnetism, resonance, symmetry, and others (depending on the activity design) are core-building blocks for the development and construction of the learner's idea."[25]

Similarly, making can teach digital (e.g. information and communication technologies) and technical literacies (e.g. digital fabrication). Tucker-Raymond et al. note the following literacy practices for making: "a) identifying, organizing, and integrating information across sources, b) posing and solving problems, c) creating and traversing representations, and d) communicating with others, including receiving help or feedback. We do not have the space to define each of these categories, however literacy practices were derived from Common Core State Standards for the English Language Arts (2010), Next Generation Science Standards (Achieve, 2013), and our study data."[26] Makerspaces are natural places to teach technical skills such as modeling and digital fabrication, programming, and other tool-based literacies; Erin Riley identifies various skills, such as machine operation, designing for affordances of machinery, graphics, and the science behind the tools, that can be learned, amongst other skills.[27] In higher education, particularly in engineering, the fab lab model of providing workshops on tool use has been prevalent, though other models are encouraging more small group training and self-directed work,[28] and some have identified the need to go beyond teaching technical skills to higher order and design thinking, such as thinking critically about the behavior and properties of materials and how elements combine holistically.[24] In an interview, Kyle Bowen, director of teaching and learning with technology at Penn State, says succinctly, "When you think about digital literacy and different types of literacies, the very idea of literacy focuses on *what* it is and *how* to attain it. In fluency, we are talking not only about what and how — it's also *when* you apply this kind of thinking, and *why* you apply it."[29]

However, the bulk of the literature deals with 21st century or soft skills--habits of mind, dispositions, affective modes, or learning practices that making can promote--especially in informal learning. For formal higher education, there still isn't a great deal of research literature available. What there is often emerges from the STEM (not STEAM as there's little research-based literature from art education, despite a strong studio education tradition)[30] disciplines, especially engineering and computer science (as evidenced by the number of papers from the American Society of Engineering Education (ASEE) conferences and its *Envisioning the Future of Maker Education* report from 2016). This has often been in response to the call from research and accreditation bodies for a move away from an emphasis on theory and mathematical modeling in engineering education and a return to more hands-on, multidisciplinary design-build experiences to solve real world challenges (e.g. community projects and project-based courses, freshman design through senior capstone experiences, competitions or hack-a-thons, and entrepreneurial ecosystems).[31]–[34] Forest et al. indicate the impact of this type of physical

modeling and design-build-test education through the positive responses from alumni who used the Georgia Tech Invention Studio on self-reported measures such as design and manufacturing skills, outlook on engineering, safety and teamwork skills, post-college employment and, to some extent, GPA.[35] Georgia Tech was also involved in a multi-institutional study to chart the differences between students who have low and high involvement in makerspaces as well as the effects on their idea generation and design self-efficacy and found that freshmen who were highly involved in the Invention Studio were more inclined to complete design tasks and were less anxious.[36] Similarly, Roberts and Buckley surveyed alumni of University of Delaware's Design Studio and found that it significantly increased students' satisfaction with in-class demonstrations and sophomore through senior design.[37] Academics are increasingly calling for more empirical research into making and learning in higher education contexts, including the possibility of using academic makerspaces as collaborative testbeds or sites for further assessment and research.[38]

In 2014, Vossoughi and Bevan conducted a review of the literature to find "1) what is known about the impact of tinkering and making experiences on school-aged children's learning (interest in, engagement with and understanding of STEM in particular) 2) the emerging design principles and pedagogies that characterize tinkering and making programs and 3) the specific tensions and possibilities within this movement for equity-oriented teaching and learning."[18] They noted that, besides the literature on making as entrepreneurship or community activity or path to STEM learning and workforce development, "making as inquiry-based educative practice" comprises the largest body of peer-reviewed literature, though still not extensive. In their review they found that the definitions of making and tinkering varied, with important differences between assembling things according to instructions, tinkering as a playful, problem solving orientation toward existing objects, making as a more open-ended approach toward constructing a "product," and engineering as a bridge between more formal and informal science-based approaches. In terms of the claims supported by the (largely qualitative) literature, they note that educational making can:

> "(1) Position and support young people to participate in science programs and learning activities, including how making programs support opportunities for belonging and mattering (NRC & IOM, 2002); developing interest and identity (NRC, 2009) and expanding experiences and skills in communication, leadership, and the negotiation of differences (NRC, 2012).
> (2) Structure and implement program activities to support young people's learning and development, including providing opportunities for skill building and connections to community and school experiences (NRC & IOM, 2002), the development of conceptual understanding, STEM skills, scientific ways of knowing, an understanding of how science is practiced in the world (NRC, 2009), and critical thinking, reasoning, and innovation (NRC, 2012).
> (3) Create a supportive community of learners that can leverage the interests and skills of each member of the group towards shared goals, including opportunities to develop supportive relationships and positive social practices (NRC & IOM, 2002) as well as flexibility, initiative, appreciation of diversity, and metacognition (NRC, 2012)."[18]

In terms of pedagogy, they noted the importance of: utilizing hybrid models that blend formal educational structures with more informal "communities of practice" models; encouraging the development of maker identities; facilitating making skills, deeper and more complex engagement, and connection with prior knowledge, including everyday skills and formal curricular knowledge; creating playful, welcoming and exploratory environments with broad definitions of making, learning and intelligence; making skills, materials and tools transparent; and providing opportunities with low barriers to entry and great flexibility (in terms of depth and variety of making). They also cautioned against a narrow focus on: STEM learning to the exclusion of interdisciplinarity; an opposition between formal and informal learning; or emphasis on privileging the tools of making, especially more high tech rather than low tech tools (e.g. 3D printers, microcontrollers, CNC machines). Finally, Vossoughi and Bevan called for more research on age groups beyond middle and high school students, on forms of pedagogy, and on equity issues in making.[18]

Others also speak to the facilitation and facilitation skills needed for deeper learning to take place in makerspaces, (such as the ability to spark interest, sustain participation by following the learner's ideas, and deepen understanding by making connections), recognizing that different strategies may work for different types of learners and objectives. [30], [39], [40]

Harvard's Agency by Design project published a white paper in 2015 and a book, *Maker-Centered Learning*, in 2016 summarizing their research (including a literature review, interviews and site visits with maker educators, and the development of a conceptual framework through action research) on learning and teaching in makerspaces for young people and the affordances that support them.[2], [22] The project found that "developing students' discipline-specific knowledge and skills (e.g., science, technology, engineering, and math [STEM] skills) and more maker-based knowledge and skills (e.g., learning to code or how to use a drill press) were certainly important to the educators we spoke with. But these learning outcomes were always discussed as being secondary or instrumental to the more dispositional

outcomes of developing agency and building character."[22] They divided agency into the ability to find opportunities to make things as well as connect that making with communities, and separated character building into individual development of competence and confidence as a maker and cultivation of "thinking dispositions" or practices, also known as soft or 21st century skills. Relatedly, they developed the concept of "maker empowerment: A sensitivity to the designed dimension of objects and systems, along with the inclination and capacity to shape one's world through building, tinkering, re/designing, or hacking" and found that the capacities of "looking closely, exploring complexity, and finding opportunity" were central to this. They noted other oft-mentioned soft skills that cut across disciplinary boundaries and that aren't tied to particular tools or materials--curiosity, playfulness, resourcefulness, responsibility, sharing, optimism, resilience or grit--as well as "general thinking dispositions associated with stuff making, such as risk taking, persistence, learning from failure, and craftsmanship, and also general thinking dispositions more associated with community making, such as perspective taking and empathy."[22]

Organizations such as Remake Learning, a network of Pittsburgh people and institutions investigating the future of teaching and learning, have also developed their own competencies for design and making through a convening of educators and makers. Remake Learning's include: understanding the design process, identifying paths for personal growth, questioning, following makerspace rules and procedures, selecting materials, systems thinking, assessing and planning, communicating, reflecting, empathizing, being open minded, persevering, playing and valuing process.[41] Also, through a content analysis of *Make: Magazine*, Brahms and Crowley identified the following "set of seven core learning practices associated with recognizable participation in the maker community: explore and question; tinker, test, and iterate; seek out resources; hack and repurpose; combine and complexify; customize; and share."[15]

C. Learning and teaching making literacies in library makerspaces and relation to existing literacy programs

Similar models and making literacies exist in libraries and museums. The Institute of Museum and Library Services (IMLS) and Children's Museum of Pittsburgh collaborated on a grant project investigating the conditions and practices for supporting learning in libraries and museums, and developed a framework, emphasizing a makerspace's purpose, people (most important), and pieces and parts.[4] This framework builds on research from museums and science centers, such as the Children's Museum of Pittsburgh's Makeshop Learning Practices of Making (inquire, tinker, seek and share resources, hack and repurpose, express intention, develop fluency, simplify to complexify),[42] the Dimensions of Learning from the Exploratorium's Tinkering Studio (including engagement, initiative and intentionality, social scaffolding and development of understanding),[25], [40] and the Activation Measures from the Activation Lab at the Lawrence Hall of Science (including dispositions, practices and knowledge such as fascination with STEM, valuing STEM for personal or social goals, scientific sensemaking and beliefs about STEM competency).[43]

The bulk of the literature on makerspaces in libraries comes from school and public libraries and largely tends to be practitioner-focused. Divisions of the American Library Association for public, youth, children's, and school librarians regularly publish trade articles and other how-to materials on the makerspace phenomenon, such as the Young Adult Library Services Association (YALSA) Making in the Library Toolkit.[44] There are issues around terminology and the definition of making literacy in the library literature (for example, the book *Maker Literacy* simply details instructions for some children's maker programming rather than dealing with the competencies taught by making), and Willett reviews the tensions surrounding the library discourse about informal learning in makerspaces, including the perhaps overly positive contrast of informal with formal, in-school learning and over-simplification of narratives around the two.[20] School librarians are also concerned with the application of makerspaces to learning, particularly the Common Core State Standards; they are using makerspaces to promote self-directed learning, writing through documentation and reflective process logs, and collaboration.[45], [46] Graves details how to implement challenge based learning in school libraries by balancing direct instruction and self-directed making and teaching skills, safety, and design thinking at the elementary and secondary levels.[47] Loertscher, Preddy and Derry theorized that teacher librarians can recognize and help scaffold students through the developmental levels of creativity from using to tinkering to experimenting to creating independently (uTEC model).[21] Librarians working with young people are also starting to investigate their information literacy practices in makerspaces; for example, Li and Todd have investigated young people's information practices in a public library makerspace and found that they have a range of information needs and may be more inclined to ask questions based on their own trial and error in the more informal environment of a makerspace than they might in other settings. [48]

Though there is not a great deal in the library literature on learning and teaching in academic makerspaces, much of what exists deals with cross-cutting goals like fostering creativity and innovation, self-efficacy, collaboration, entrepreneurship, resilience, and experimentation, amongst other skills.[49]–[52] The literature also covers pedagogy and teaching and learning that can fit within typical library instruction avenues--for example, provision of tutorials, workshops and outreach events (by librarians, students,

community members and volunteers, the latter of which is more common in public and school but can be introduced more widely to academic libraries), peer consultations, and collaboration with faculty on assignments in credit courses.[25], [53]–[58] Watson and Kuglitsch suggest that libraries can also promote informal learning by doing the following: "build spaces that are comfortable for all students & users, regardless of background; provide spaces for social experiences; promote discovery and browsing; and inspire imagination and drawing new connections across disciplines."[59]

The last few years have also seen an increase in work on making literacies in academic libraries. Wallace and Chivers at the University of Texas at Arlington Libraries are working on integrating making into the curriculum more generally and investigating making literacies. The beta maker literacy competencies they have preliminarily identified include: identifying a making need and purpose, applying design praxis, managing time, assembling teams, employing effective knowledge management practices, assessing available tools, demonstrating an understanding of digital fabrication and the ethical, legal and socioeconomic issues around making, employing safety precautions, and transferring knowledge to real world situations and sharing with others. They have also recently received an IMLS grant to collaborate with the University of Nevada Reno Libraries and others to further investigate the literacies involved in library makerspaces when integrating into the curriculum.[56], [60]–[62]

The Association of College and Research Libraries (ACRL) recently instituted the Framework for Information Literacy in Higher Education, rescinding its previous Information Literacy Competency Standards for Higher Education in favor of this updated, flexible framework. The frames, as they are called, are: Authority Is Constructed and Contextual; Information Creation as a Process; Information Has Value; Research as Inquiry; Scholarship as Conversation; Searching as Strategic Exploration).[12] Jenny Wong-Welch, STEM Librarian at San Diego State University, has connected 3D printing skills to the ACRL Framework for Information Literacy. She notes that open source 3D model repositories can be a good way of operationalizing the concept of authority as constructed and contextual and the myriad approaches found to projects shows that searching is a form of strategic exploration; modeling is an example of information creation as process; and the peer-to-peer model of learning in makerspaces shows that information has value. For those who delve more deeply into the workings of printers, research is a form of inquiry, and collaborative and peer-to-peer work on projects models scholarship as conversation.[63]

Williams and Folkman note the need for librarians also to develop competencies as makers and the lack of formal curriculum in making and pedagogy, having identified only a handful of library and information science (LIS) courses dealing with makerspaces in any aspect.[64] Bowler describes a project to introduce library and information science students to meaningful making through an extracurricular challenge.[65] Hsu et al. also identified the availability of some courses and MOOCS outside formal LIS education, and the recent IMLS Making + Learning project debuted a MOOC for those developing or running makerspaces in libraries and museums.[66] Oliver highlights ways that school librarians can develop professional competencies to integrate making activities into the curriculum in their libraries, including the formation of communities of practice.[67], [68] Based on interviews and a large scale survey, Koh and Abbas identified the following competencies for librarians involved in learning labs and makerspaces: ability to learn, adapt to changing situations, collaborate, advocate, and serve a diverse clientele; management; program development; fundraising and grant writing; technological literacy; and learning facilitation skills.[11]

In terms of assessment in libraries, the IMLS Making + Learning framework notes, "On the one hand, there are established methods for monitoring success, such as tracking the number of participants engaging in an exhibit or program or the duration of the engagement. At the same time, these do not fully capture the richness and uniqueness of the programs themselves, nor the innovation and creativity of the learners' constructive activities."[4] More in-depth ways to measure evidence of learning include observational notes, interviews, focus groups, examination of artifacts, videos/photographs, surveys or written responses, rubrics, and portfolios, as well as emerging instruments for technological assessment, such as Blikstein's. [4], [69]–[71]

IV. Discussion and Conclusion

The emerging research base points to not only a set of literacies but also different approaches or practices that can support teaching and learning in makerspaces. However, there are still a number of issues and questions for further research, including on: learning in academic library makerspaces; validation of the above identified competencies (disciplinary, intellectual, technical, social, emotional, dispositional, affective, etc.); and what academic library makerspaces are and aren't suited to accomplish, according to type and pedagogies. Given their interdisciplinary, democratic nature and place at the intersection of both informal and formal learning, academic libraries would seem to be well-placed to connect and expand making education beyond traditional disciplines; to explore the bridging of curricular, co-curricular and informal learning; to heed the call for collaboration with professors and assessment units in higher education to further the evidence-based literature on learning in academic makerspaces; and to study information literacy practices throughout the process of making.

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