Principles for Equity-centered Design of STEAM Learning-through-Making

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INTRODUCTION

Described by Wohlwend, Peppler, Keune and Thompson (2017) as “a range of activities that blend design and technology, including textile crafts, robotics, electronics, digital fabrication, mechanical repair or creation, tinkering with everyday appliances, digital storytelling, arts and crafts—in short, fabricating with new technologies to create almost anything” (p. 445), making can open new possibilities for applied, interdisciplinary learning in science, technology, engineering and mathematics (Martin, 2015), in ways that decenter and democratize access to ideas, and promote the construction of new understandings (Blikstein, 2013). Further, when learners develop a nuanced understanding of the designed dimensions of things, systems, and knowledges, they begin to understand that the objects, ways of operating, and even ideas in their world are constructed, and therefore, changeable (Clapp, Ross, Ryan, & Tishman, 2016). There is power in this understanding, and it is fundamental to contemporary approaches to learning that encourage making as inherently agentive and empowering for learners.

In this Rapid Community Report, we make the case for centering equity in the design of Science, Technology, Engineering, the Arts, and Mathematics (STEAM) learning-through-making. When the foci of design, critical problem-solving, and creation reflects learners’ lived experiences and interests, it is more likely for learners to feel empowered as designers and makers of things that matter to them and their communities, thereby shifting the culture of learning-through-making to be more expansive and responsive to inequities that learners experience in their daily lives.

STRUCTURE OF THIS REPORT

This report begins with two short sections that review principles for equity in the design of STEAM learning spaces and in the design of STEAM learning activities. These sections conclude with a set of key questions that educators, researchers, practitioners, and decision-makers can use to guide their design thinking and actions. A third and final section offers a set of four overarching recommendations for areas of investment and ongoing inquiry coupled with actions that decision-makers, researchers, and educators can take to ensure that STEAM learning-through-making centers equity. Appendix A, following the reference list, includes a list of key terminology and working definitions used in this report.

Designing for Equity in STEAM Learning *Spaces*

> *“Human beings or societies produce space together to structure, open up, and limit activity (Lefebvre, 1991). The spaces that humans inhabit have certain value structures and ideologies because they are constructed by those who live in them with their own values, ideologies, and ways of being in the world.”* ~ Tucker-Raymond & Gravel, 2019, pp. 34-35

The authors of this report view learning to be socially, culturally, and physically situated in systems, contexts, and communities (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). Through that theoretical frame, we offer an overview of design considerations for physical and virtual STEAM learning spaces that center equity.

Educational efforts aimed at equity recognize that learning is a social process fraught with power hierarchies and structure-agency dialectics that actively discriminate against potential learners through the oppressive mechanisms of racism and sexism, among others. Community building and design principles that center equity and inclusion require an explicit disruption of these processes that function to exclude groups long underrepresented in STEAM. Thus, a focus on equity and inclusion is necessary in efforts that seek to welcome all learners into these environments. Further, it is imperative that STEAM learning environments draw in and draw from cultures and practices that are a part of the communities in which they are situated.

As we consider STEAM learning environments that center equity as a core design principle, it is helpful to begin with this fundamental assertion -- that the spaces humans create cannot be dissociated from human ways of being which are shaped by social interactions, human ideologies, cultures, systems, and structures of power. As we consider equity a driving principle for the design of STEAM learning environments, it is important to actively question assumptions about the ways spaces are designed to both open up and limit STEAM learning. What must be asked in relationship to the design of learning environments is which ideologies, cultures, and systems are reflected in, for example, a STEAM learning context within a traditional high school science lab with rows of benches, fixed at a standard height and bolted to the floor, with seating oriented to focus all eyes on the front of the room? For whom, and in what ways, does this infrastructure open opportunity, and for whom does it limit possibilities, and it what ways?

Building on Resnick and Silverman's (2005) ideas, Alper (2013) suggests that spaces, tools and activities in STEAM learning environments, and particularly makerspaces, should literally and metaphorically have *low floors (with ramps)* so that everyone, including novices, younger and older people, and people with diverse cultural identities, learning, social, emotional, linguistic and physical needs can easily enter and participate; *wide walls* that provide ample latitude for multiple pathways of movement and exploration of materials and ideas; *high ceilings* that open possibilities for vertical movement and complexity; and *reinforced corners* at the intersections of the lowest floors, widest walls and highest ceilings so that those at the limits receive necessary supports too. Drawing from an inquiry into diverse makerspaces to support their design of a university-based makerspace, Peppler, Keune, and Whiting (2018) similarly describe design principles for equitable makerspaces, including "(1) *mobility* to arrange workstations according to learning needs, (2) *diversity* of materials to support a broad range of approaches to making, and (3) *openness* of access to materials for youth of all ages" (pp. 1519-1520).

Consciously and intentionally applying universal approaches to design (CAST.org; Centre for Excellence in Universal Design, 2019) means that everything in STEAM learning environments, including physical makerspaces as well as digital platforms and networks that facilitate digitally distributed STEAM learning, should be designed to meet everyone where they are, regardless of size, age, (dis)ability, language, social status, gender, or identities. However, doing so requires a commitment to creating opportunities that are accessible to, usable by, and inclusive of everyone (see Burgstahler, & Thompson, 2019) with an eye toward design features that address universal design principles. Key questions for STEAM educators to consider in the design of equitable physical and virtual STEAM learning spaces include:

- Who does this learning environment aim to serve and what are its purposes?
- For whom does this environment open access to STEAM learning, and for whom does it limit access? Why? In what ways, and at what times?
- How can we design spaces to meet the diverse learning needs of those we aim to serve? Further, how might the design of these spaces, from conception to implementation, centrally involve diverse learners--?
- How do spaces reflect, inspire, and nurture the learners we serve?
- Is the environment flexible and dynamic or static and intractable?

- How does our environment align both literally and metaphorically with the idea of low floors, wide walls, high ceilings and reinforced corners? How does it foster mobility, diversity, and openness?

Designing for Equity in STEAM Learning Activities

The design of STEAM learning needs to be refracted through the lens of activity. Making practices and activities align closely with disciplinary practices and dispositions in STEAM disciplines (Honey & Kanter, 2013; Martinez & Stager, 2013). Making activities open opportunities for learners to practice a range of disciplinary literacies that include identifying, organizing, and integrating information across sources; creating representational forms; communicating with others for help and feedback; sharing finished or almost finished objects; and documenting their maker processes and milestones (Tucker-Raymond & Gravel, 2019). However, current conceptions of making as part of scientific inquiry are often situated in dominant, white, male, middle-class cultural values and practices which are "offered" to communities and youth of color as promising interventions (Vossoughi, Hooper, & Escudé, 2016). This approach, both ideologically and in practice, continues to position non-dominant cultural and linguistic communities, including youth of color, as needy, rather than as sources of powerful thinking.

Through a lens of equity, designers must recognize that diverse learners are each grounded in different relationships, purposes, and experiences with tinkering, making, and experimentation. Maker traditions that are centered in North American Indigenous cultures, as well as those that are geographically centered in rural cultures or in urban cultures will each differ in important ways, but when spaces and learning activities are designed to consider the unique perspectives, strengths, and competencies that makers bring from their own culturally situated practices, new connections for disciplinary STEAM learning can be strengthened (Vossoughi et al., 2016). Approaches toward impactful and equitable STEAM learning must therefore attend to the past, present, and future background and contexts for learning and provide possibilities for traditionally marginalized groups.

One example from which to draw inspiration for designing with community relationships in mind is *rasquachismo*, defined as "an everyday practice of innovation and improvisation in working-class Chicano/Latino communities" (Olivares, 2009, pp. 2). While understood in some circles as an aesthetic of the Chicano art movement, *rasquachismo* is the transformational practice of a bicultural stance, "an attitude rooted in resourcefulness and adaptability… presupposing the world view of the have-not [a stance that] has evolved as a bicultural sensibility among Mexican Americans," on the basis of Mexican vernacular traditions (Ybarra-Frausto, 1989, pp. 5). Recognizing the ways that individuals and communities have historically engaged in what the field of STEAM education now refers to as making can unite researchers, educators, and practitioners in the creation of meaningful learning experiences for all.

The design of STEAM learning-through-making must be centered in understanding its socio-historical situatedness, and attendance to present socio-political and economic inequities, all with a vision toward humanistic and promising futures for both community partners and researchers. Key questions for designers, educators, researchers, and community leaders to consider as they conceptualize STEAM learning-through-making therefore include:

- What is considered equitable and consequential making (Calabrese Barton & Tan, 2018) for different communities? And, if we don't know, how can we find out?
- Whose knowledges, practices, and resources are valued in making (Barajas-Lopez & Bang, 2019) and how does the intersection of maker-identities impact such (Tan & Calabrese Barton, 2018)?
- How might this focus on "whose knowledges" or "whose values" significantly inform what gets made, how, and why?
- How do STEAM learning-through-making environments draw in and draw from the making contexts, cultures, languages, and practices that are part of the communities in which they are situated?
- How do learners see, hear, and feel themselves reflected in the design of this STEAM learning-through-making activities and participation in these spaces?

Overarching Recommendations for STEAM Learning-through-Making

In this section, we highlight practical and innovative directions in STEAM learning-through-making that centralize equity, and in our view, offer transformative potential for STEAM disciplines and communities. We offer three overarching recommendations, each of which is supported by a set of research-informed recommendations for action.

Recommendation 1: Support Generative Justice for Community Empowerment

To combat the exclusionary forces of discrimination, we recommend a form of community engagement in STEAM learning environments that shares resources and expands what counts as valued learning and information. *Generative justice* works for the rights of participants and community organizations to create their own forms of value in partnerships with researchers and educators and gives them ownership over how they produce those forms (Eglash, 2016). That is, if researchers, program designers, and educators are to seriously consider the needs of communities and community partners in research projects, community organizations and citizens should be involved in the creation of educational spaces and projects from the beginning. In each case, communities, along with educational institutions and researchers, have a right to distribute resources that meet their project goals. To this end, we offer three actionable recommendations.

R1. Action 1: Prioritize representative and responsive mentorship

In STEAM disciplines in the U.S., the underrepresentation of people of color, women, and persons with disabilities (National Science Foundation, 2019) presents a cultural vacuum for youth with diverse, non-dominant identities and lived experiences (Basile & Lopez, 2015; McGee & Bentley, 2017). It has long been understood that models and mentors who can build meaningful relationships with youth are pivotal in breaking down barriers to STEAM learning and careers (Powers, Schmidt, Sowers, & McCracken, 2015). Persistent underrepresentation of teachers and mentors in makerspaces who reflect diverse lived experiences, however, means that classed, gendered, abled, dominant linguistic perspectives pervade the design of learning; biases may go unquestioned. As a result, children and teens of color, youth with disabilities, girls, and those with non-dominant linguistic and cultural strengths may find the activities and practices inherent in many STEAM learning environments to be alienating because they are framed by dominant assumptions and perspectives that undermine rights to self-determination in learning. We view the presence of diverse mentors in makerspaces and representative mentorship to be baseline considerations for the design of equitable STEAM learning-through-making activities. Importantly, all STEAM learning mentors can develop awarenesses of their intersectional selves, the role of discrimination in the lives of learners historically marginalized in STEAM, and the cultural and professional expectations of communities, learning-through-making spaces, and academic STEAM spaces (Alvares, Blume, Cervantes, & Thomas, 2009). Those in decision making roles, and those who design learning spaces and activities, can advance policies and shape systems that require representative and responsive mentorship. Mentorship, in this way, would incorporate members of the community as mentors, drawing widely from a variety of areas of life, work, and experience with making.

R1. Action 2: In the design of maker pedagogies, draw out relationships around identity

STEAM learning-through-making seems to depend, in part, on how learners understand themselves as makers. When learners know themselves as capable makers of things and ideas, they are more likely to engage and continue in maker behaviors, which in turn supports continued learning (Clapp, Ross, Ryan, & Tishman, 2016). For youth, however, maker identities are multifaceted, dynamic, and relational (Davis & Mason, 2017). For example, when asked to describe herself in relation to STEAM learning and making, Maria, a participant in Davis and Mason's (2017) study of middle-school girls' maker identities, talked about herself and her abilities in relation to her mother, who is an art teacher and a Latina woman (p. 186). Like her mother, Maria understood making with diverse materials and technologies as art (pp. 187-188). Maria also reported that she was excited to share her maker project with her parents, knowing that her work would be met with praise and affirmation. In Maria's example, we see how she positions herself as a maker in relation to her activities, her cultural identity, her values, and skills of her family and community.

Paying attention to identity in making requires learning designers to consider who a maker is (and who can be a maker); what a maker does; for whom a maker makes; why, and in what ways, making happens; why making matters; and who a maker can become in, and through, the act of making (Calabrese Barton, Tan, & Greenberg, 2017). These considerations are nested within hierarchical social relationalities, since identities are contingent on recognition by others in the social environment, including those with more power (e.g., Cuero & Kaylor, 2010; Kirkland, 2011). Such social relationalities are further anchored in how the contexts and relevance of making are defined and shaped. People's participation in historical, cultural, and everyday experiences related to making (versus promoting only a narrow model of making) must be solicited, nurtured, and built-upon to create spaces that attend to maker identities that resonate both with the learner and with others working together in groups and communities. Further, it is important to consider the plurality of makers' salient identities that should be brought to bear on their making endeavors, to "[read] injustices along axes of oppression and [locate] intersectionality" (Tan & Calabrese Barton, 2018, pp. 57). An explicit attention to intersectionality through actively soliciting community data to inform youths' making is productive in supporting youths' justice oriented forms of making. For example, Tan & Calabrse Barton (2018) illustrate how 10-year old Tonya drew from her identity as an African American girl who loves her "beautiful black hair" as well as her identity as a sometimes homeless youth, to design a light-up, decorative beanie hat with a hidden alarm powered by a solar panel for young girls like herself who may find themselves quartered in homeless shelters and concerned for their safety.

When STEAM learning-through-making activities are designed with students' culturally situated or gendered interests and identities at their core, evidence suggests they can open new gateways to exploration, discovery and STEAM problem-solving. In one study by Kafai, Fields and Searle (2014) for example, youth of color learned about electronics and developed advanced coding skills through making with eTextiles. These activities leveraged sewing and material aesthetics that were familiar to many of the girls in the study -- the metaphorical low floor -- but also opened new "clubhouses of computing" (p. 547) as the girls discovered they could learn to do coding, too.

R1. Action 3: Move toward community-centered approaches to learning and research

Community-driven approaches reposition or reframe intervention and research as activities that are defined by communities, led by communities, and informed by the values, goals, needs, purposes, ways of thinking, knowing, building trust, and connecting that are central to communities (e.g., Kovach, 2009). These approaches replace positivist (colonial) epiSTEAMologies in both research and practice in favor of approaches that centralize the rights of communities to self-determine their own learning futures. Researchers and educators in positions of leadership can act on Green's (2017) recommendations for Community Equity Literacy, all of which centralize the role of community in equity-oriented work. According to Green, educational leaders must (a) understand community history (Horsford, 2010; Lyon & Driskell, 2012), (b) work from asset- and structural-based perspectives about community (Gorski, 2013; Kretzmann & McKnight, 1993; Mapp & Hong, 2010), (c) recognize and leverage community assets (Green, 2015, 2016), (d) navigate the community power structure (Lyon & Driskell, 2012), and (e) advocate for community and school equity (Green, 2016) (p. 381). In makerspaces, this will mean tapping into community histories of making; centralizing the inherent power and value of local knowledges, practices, and expertise; taking required actions (i.e., advocacy, fundraising, creating opportunities) to ensure makerspaces are designed by/for/with community and accessible to all.

Recommendation 2: Build Networks

We advocate for the cultivation of multi-institutional networks to generate collective impact approaches toward informing and impacting the STEAM education field. To this end, we recommend that collective networks recruit multiple stakeholders from diverse backgrounds for research advisory boards or other initiatives that involve design and implementation efforts. Collective networks open up new possibilities for constructing collaborative pooling efforts and shared data stores to expand national and localized research efforts of maker-oriented initiatives and coalesce distinct inquiries and approaches toward informing and impacting the STEAM education field. Subgroups and interdisciplinary groups can then cultivate the overarching connectivity of these maker networks to further their local aims. Collaborative research outcomes may inform the development of funding opportunities and achieve broader impacts in STEAM education.

R2. Action 1: Bring together multiple stakeholder groups to plan for and operationalize STEAM learning-through-Making

The development of equitable, accessible STEAM learning spaces, pedagogies, programs, research, and generative networks of innovation is happening through investment by multiple stakeholders that include government funding organizations (e.g., National Science Foundation, 2017), private sector partners (e.g., Ermacora, 2018), institutions of higher education, libraries, museums, community-based non-profit organizations, and K-12 schools (Freeman, Adams Becker, Cummins, Davis, & Hall Giesinger, 2017). The shared insights of multiple stakeholders serve diverse audiences for diverse purposes, and are fundamental to the design and mobilization of dynamic, inclusive, and socially just models of makerspaces that cut across traditional organizational silos. Bringing together community participants encourages generative knowledge building process and practices that benefit from field expertise.

Successful program experts can inform the field by developing norms and shared understandings of STEAM learning-through-making. These networks can build upon collective experience through reflective action such as conducting asset mapping and communicating around landscape analyses from a collective lens (see resources compiled by Burns, Dagmar, Paul, and Paz, 2012).When a wide array of people, groups, and organizations bring their diverse strengths and expertise to the design of spaces and programs, the results can encourage inclusive STEAM learning-through-making iniativites for the learners those spaces seek to serve (Calabrese Barton, Tan, & Greenberg, 2017). Forging research and practice links between and across stakeholder groups, and centering equity at the core, can transform the way the field operationalizes and designs pedagogy and learning in makerspaces.

R2. Action 2: Support networked, interdisciplinary research programs that expand understandings of STEAM learning-through-making

Although this report is concerned with STEAM learning-through-making, we see tremendous potential in interdisciplinary research networks that bring new, innovative, and complementary methodological and theoretical perspectives to advance understandings. As research in the field of STEAM learning emerges, multiple methods of data collection and analyses need to be developed to inform rigorous definitions and theories of learning that reflect uniquely situated nuances of learning-in-practice while also advancing understandings of common principles.

Interdisciplinary networks can leverage diverse and complementary research designs (e.g., survey, ethnography, case study) that include multiple methods of data collection and analyses (e.g., interviews, observation, thematic analysis) to weave complex tapestries of understanding that will inform the future of this emerging field of study. For example, eye-tracking glasses and wearable sensors can provide researchers in makerspaces with detailed data on learners' visual gaze patterns, movement patterns, social interactions, and material uses while they are engaged in STEAM learning activities (Learning Innovation and Technology Lab, 2019). Deeper understanding of activities and their implications for STEAM learning and teaching are possible when analyses and interpretations cut across disciplinary silos.

R3. Action 3: Create networks for those working in K-12 education settings

We advise the creation of a unique network for those working in K-12 education makerspaces. We advocate for the creation of a funded organization that serves as a central organizing body that ties together practitioners from education-focused makerspaces, whether they be teachers, technicians, librarians, or others. As more educational institutions create these spaces, a clear need emerges for continued opportunities for professional development, sustainability, and idea-sharing that draws across K-12 education. While the creation of makerspaces continues to grow in popularity across K-12 school settings, there is a dearth of data on the actual learning occurring in these settings that is needed to assess what is happening, what is missing, and where future efforts should be made.

(a) Priorities should include identifying what teaching competencies are needed for successful student outcomes, and which forms of assessment best meet the needs of learning-through-making environments in K-12 schools.
(b) Priorities should include determining student progress in affective and soft skills that are measured and tracked over a certain time period.

Recommendation 3: Develop Innovative Assessments

In both school- and community-based STEAM learning environments, assessments of learning and impact inform and often drive pedagogical decision-making. Assessments in STEAM learning environments need to focus on capturing the complexities of learning in ways that extend beyond products of learning to also account for learning processes (e.g., methods and dispositions that foster or hinder learning; problem-solving processes) and aspects of learning that are sometimes considered 'intangible' (e.g., emotions about/while learning; engagement; collaboration). Although assessment in STEAM learning-through-making contexts may seem unnecessary, or even contrary to the spirit of learning that is open, dynamic, learner-driven, collaborative and emergent, data gathered at different times and for different purposes can inform instructional design, programmatic revision, and can be re-inserted into cycles of learning in ways that support makers during the formative phases of their work (Black & William, 1998). For researchers, assessment data can inform new understandings of fundamental questions such as what learning looks like during particular projects and with particular tools in STEAM learning environments, what pedagogical moves seem especially supportive of learning, who seems most likely to benefit from STEAM learning-through-making activities, and in what ways (e.g., Herro, Quigley, Andrews, & Delacruz, 2017; Worsley & Blikstein, 2014). What gets assessed and why are two critical considerations for the STEAM learning-through-making community, because often, assessments of learning have been used to justify deficit thinking about particular learners or communities, and to reinforce systematic inequalities (e.g., Ladson-Billings, 2006; Lozenski, 2017).

Assessment data can have policy and funding implications when leveraged by external stakeholders too, which means it is critical for the field to acknowledge the importance of assessment designs that truly reflect a commitment to equity and inclusion in terms of their focus and their methods in STEAM learning-through-making research and practice. Assessment needs to document long-term impact on communities and community members. At the community level, assessments should consider whether, and to what extent, youth return to support the community in mentor capacities. Assessments should also probe the extent to which making spaces enrich communities, community youth, and support communities of practice collectively involved in making. Further, assessments should consider to what extent diverse approaches to making support the development of positive and personally meaningful STEAM identities. Assessments should also take account of artifacts created within making efforts and how those artifacts are taken up by youth, adult community members, and communities.

Thus, we recommend three actions to develop robust, equitable and inclusive assessments of learning in STEAM learning-through-making environments.

R3. Action 1: Design assessments situated in and informed by local cultures, languages, and values, and that centralize learners' perspectives, voices

Culturally relevant and sustaining frameworks for assessment, driven by goals determined in and by the communities in which STEAM learning environments are situated, are essential (Barajas-Lopez & Bang, 2018; Castagno & Brayboy, 2008; Paris, 2012; Vossoughi et al, 2016). The development of inclusive assessments in STEAM learning-through-making programs and spaces should begin with a critical review of the assumptions driving designs. Assessment designers must consider whether particular types of assessment undermine or open new possibilities for the empowerment of those presently underrepresented in STEAM learning and professions (Godhe, Lijha & Selwyn, 2019). Rubrics, for example, can be useful because they provide categories and criteria on which to assess moment-to-moment progress, learners' application of disciplinary concepts in STEAM learning (Leonard et al., 2017) and even complex activities such as collaborative problem solving (Herro et al., 2017). However, when assessment criteria are imposed, or developed, without learners' input, they can limit or shut-down possibilities for STEAM learning. We therefore caution against the development of top-down assessments that measure evidence of disciplinary knowledge or technical competencies without consultation or consideration of the meanings that learners may ascribe to problem solving processes, to collaboration, or to tool use.

R3. Action 2: Support formative assessments that equip learners to take advantage of distributed expertise and feedback during learning

Learning-through-making creates multiple opportunities for distributing expertise. Distributed expertise refers to (a) the multiplicity of materials and resources available in a space, (b) the knowledge and experience of diverse persons and groups in the space, including peers and facilitators, as well as learners' access to them - and awareness of how to develop the kinds of practices needed to access them for one's own ends, and (c) expertise that is distributed across learners, facilitators, and designers, that can inform iteration. Assessment methods should equip learners to benefit from the collective expertise and resources available in a particular making/learning space. These might include, for example, both the physical tools and combined cultural experiences of each person engaged in the space. Assessment methods should also enable learners to develop and achieve their own learning goals through opportunities, for example to generate their own questions, modify goals, and select alternative tools or strategies as needed to encourage agency, self-regulation, and choice (Deane & Sparks, 2019). Assessment methods should equip learners to benefit from the expertise available within a space, and also expertise that could be brought into the space through digital networks via video conferencing or other forms of synchronous communication. In addition, expertise in the form of physical tools and persons' experiences, can enable learners to develop and achieve their own learning goals. Survey instruments that capture learners' self-reported familiarity with particular tools (e.g., Blikstein et al., 2017) or students' own perceptions of their learning in STEAM learning environments (Galaleldin, Bouchard, Anis, & Lague, 2016) can inform deeper understandings of the knowledges, skills, literacies, and dispositions that learners bring to STEAM learning-through-making activities or feel they gain during their work. Importantly, the collection of, and reflection on, learners' self-report feedback should be ongoing in order to inform the actions of learners and designers alike and include information that can inform concrete recommendations for next steps and opportunities to iterate.

R3. Action 3: Prioritize assessment plans that capture complexities and provide multiple means of engagement and expression for learners over time

In general, assessment plans that include multiple ways for learners to practice skills, and multiple ways for learners to share or demonstrate their learning will be more supportive of more learning for more learners more of the time (CAST, 2018). Given that learning in STEAM learning-through-making environments is often collaborative, networked, and distributed, measurement tools and methods of analysis that require independent data points (e.g., fixed effects models) may not be appropriate. Instead, methods such as narrative inquiry, in-the moment observations curated over time, video analyses, cycles of peer reflection, journaling, cued retrospective think-aloud interviews or design reflections during which learners share new understandings while holding or viewing their creations may offer more open and inclusive approaches. These assessment approaches seek to capture the complexities of how learning happens, why it happens, and for what purposes. Peer assessments, too, can build accountability in participation and establish a culture of shared support and trust. Portfolio assessments that include multiple pieces of work gathered at different moments of a project can provide insight into the unique and divergent learning paths that learners followed. These approaches open up new possibilities for larger, at-scale comparisons. Importantly, these approaches can be used by teachers, facilitators, and researchers alike across different learning-through-making activities and settings.

Recommendation 4: Support Innovative Professional Learning

Although active-learning is not new to education spaces, the introduction and slow democratization of technology has created new opportunities for educators and students to learn critical knowledge sets through engaging and real world applications, while being exposed to the wide variety of STEAM careers available. As more educational institutions create these spaces, continued opportunities for professional development are needed. At the same time, there is a dearth of data on the actual learning occurring in these spaces that is needed to evaluate what is happening, what is missing, and where future efforts should be made.

Professional development models in schools are traditionally ‘top-down,’ meaning that the topics and structures tend to be selected by administrators and delivered to educators in short-term sessions (Guskey & Yoon, 2009). In contrast, models of professional learning in STEAM learning-through-making environments need to reflect the interest-driven, long-term learning fostered in these spaces and pedagogies. Key types of professional learning may include: (1) engaging in science learning in practice (Furtak & Penuel, 2019), (2) a prioritization of a “new ethos” (e.g., participation, collaboration, distributed expertise) in addition to engagement with “new tools” (Lankshear & Knobel, 2007); (3) and positioning educators’ practices as design work (Garcia, 2014).

R4. Action 1: Engage educators in *science learning in practice*

STEAM education has historically involved a focus on teaching scientific constructs and ideas. However, a recent “practice turn” (Ford & Forman, 2006) has drawn from studies of how scientists actually work (e.g., Latour & Woolgar, 1986) to identify and teach practices scientists use for developing and critiquing knowledge about the natural world (e.g., posing questions, conducting investigations; see Furtak & Penuel, 2019). Some success has been documented with educators themselves engaging in this kind of learning in practice. For the teachers involved, “participation in such activities transforms the ways [they] imagine themselves and expands their possibilities for action” (Penuel, 2016, p. 89). Educators’ engagements with science learning in/through practice must also challenge stabilized ideas about how knowledge is constructed and who has expertise, for example by deepening understandings of how indigenous knowledges have, and continue to be, marginalized in mainstream disciplinary practices (e.g., Bang, Warren, Rosebery, & Medin, 2012). It is particularly important for community-embedded professional learning to be situated in local knowledges and practices.

R4. Action 2: Cultivate a “new ethos” towards learning

STEAM learning-through-making environments often offer opportunities for engagements with high-tech tools (e.g., 3D printers, digital fabrication equipment, media-making tools). Long-term engagement in professional learning in technology-rich makerspaces increases teachers’ confidence in their technology proficiency levels (Miller, Christensen, & Knezek, 2017). However, we believe that it is not the use of the tools themselves that is most important; rather, it is the values and dispositions that engagements with such tools can foster, particularly when educators are able to engage in collaborative learning with one another. As Hobbs (2010) describes, “simply buying computers for schools does not necessarily lead to digital and media literacy education” (Hobbs, 2010, pp. 25 –26). Lankshear and Knobel (2007) describe this distinction by identifying two constituent aspects of today's new digital media landscape--both new "technical stuff" (i.e., digital technologies and applications) and new "ethos stuff" (i.e., a mindset viewing today' s world as significantly different than the physical world of the past). The ethos stuff, they claim, values collective intelligence, open and fluid space, and participation-focused production that uses tools for mediating and relating. Indeed, successful professional learning in innovative STEAM learning environments often explicitly engages educators in play (Peterson & Scharber, 2017) and collaboration (Frank et al., 2011).

R4. Action 3: Support understandings of teaching as design

The author team argues that "the new teacher...(a) is a purposeful learning designer, rather than (just) a curriculum implementer...(b) is comfortable working with learners in new, multimodal, online social media spaces...(c) engages their learners' identities and harnesses lateral knowledge-making energies amongst learners...(d) manages a multifaceted learning environment in which learners may be engaged in a variety of different activities simultaneously...[and] (e) is a practitioner-researcher, building and interpreting the evidence base of pedagogical inputs in relation to learner outcomes..." (Kalantizis & Cope, 2010, p. 205). These five features represent a teaching-as-design orientation. Educators who adopt a teaching-as-design orientation are committed to problem solving, iteration, and considerations of space, materials, relationships, and power. When centering learning and building *with* students, teachers-as-designers must begin with both personal empathy towards their students, considering their needs, interests, knowledges, and practices, as well as global empathy, considering issues of power and privilege in their social interactions (see Mirra, 2018).

CONCLUSION

The recommendations in this report address the design of dynamic, inclusive, and socially-just models of STEAM learning-through-making. In service to the cyberlearning learning community, the authors recognize that digital applications, tools, and pedagogies have the potential to support knowledge-sharing; engagement with robust activities that span time frames and geographical distances; and the fluid distribution of outcomes, expertise, opportunities, and collaboration. This requires thinking that cuts across traditional organizational silos and also requires critical thinking around the role of technologies in STEAM learning-through-making environments.

Within STEAM, technology is often perceived as synonymous with innovation, and educational efforts that prioritize information retrieval, creation and visualization, and communication. In contrast, thinking of technology as relational considers questions regarding the politics of the design, purpose, societal imperatives, and access that are in line with thoughts of equity and inclusion. Because technologies are designed, their conception, manufacture, and uses are never neutral (Hoffman, 2019; O'Neil, 2016). Socio-technical systems, too, reflect the dynamics of human interests and power. The equipment, materials, tools, educational programming, workflows, organization, movement of people in educational spaces—all of these elements include decisions normed to specific values that have implications for accessibility and inclusion, who can participate, who will benefit and who will not. Awareness of intended and unintended biases are important design considerations. By centering equity at the core, this report provides guidance to multiple stakeholder groups who seek to design for change, responsivity, and transformation in STEAM education.

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APPENDIX A. KEY TERMS

Design: Design has been a key focus in education, particularly in the discipline of learning sciences. In an increasingly connected world, educators are sometimes positioned as "environmental designers: we craft the educational ecosystems in which we mutually learn and build with students" (Garcia, 2014, p. 7). These ecosystems are complex, and involve the design of physical and virtual space, pedagogies, and assessments. In an increasingly connected world, educators are "environmental designers: We craft the educational ecosystems in which we mutually learn and build with students" (Garcia, 2014, p. 7). For example, the Stanford d.school K12 Lab supports educators to engage in a design thinking process, engaging them in the creative problem-solving of real-world problems through learning-by-doing (Hasso Plattner Institute of Design at Stanford University, 2019). Core values of the model include a bias towards action, a culture of iteration and rapid prototyping, "show, don't tell," and radical collaboration.

Digitally distributed: Learners connect to STEAM learning through a combination of virtual and face-to-face interactions, some of which involve digital networking and information and communication technologies. Digital applications, tools, and pedagogies that are used in STEM learning have the potential to support knowledge-sharing; engagement with robust activities that span time frames and geographical distances; and the fluid distribution of outcomes, expertise, opportunities, and collaboration.

Equity: Equity refers to educational opportunities and paths in STEAM will no longer be foreclosed on the basis of one's racial, ethnic, and otherwise underrepresented group affiliation. Equity processes require that STEAM educators and practitioners be conscientious of not only the intent but also, and just as importantly, the ways in which they go about achieving equity outcomes. These processes are rooted in a commitment to understand and build on the practices, values, and expertise of the communities marginalized by STEAM education and practitioner fields. Equity includes providing opportunities for high quality learning experiences across the lifespan and in multiple spaces in one's life. A lens of equity actively positions learners as knowledgeable and creative individuals who come together in community within intergenerational spaces for learning that foster both independent learning and interdependent relationships among learners by employing and training people from underrepresented communities in STEAM fields, STEAM education research, and STEAM learning spaces (Olivares, Tucker-Raymond, , Gravel, 2019).

Inclusion: To be fully inclusive, addressing who a maker is, what a maker makes, why a maker makes, what kinds of access a maker has to tools and opportunities to keep making, and how making has historically featured in different cultures is all a part of inclusion. Careful thinking, planning, design, and assessment are necessary to build a culture of access, equity, and inclusion that is responsive to the needs of diverse learners and the communities in which STEM learning-through-making environments are situated.

Makerspaces: Makerspaces go by a variety of names including hackerspaces, hack-spaces, co-working spaces, innovation labs, fab-labs and several other monikers. Makerspace is used as an umbrella term to include different interpretations of learning spaces that involve collaborative, interest-driven, and problem-solving principles and pedagogies (Vossoughi, Hooper, & Escudé, 2016). These spaces center learning around inquiries that span multiple disciplines through activities such as digital media production and sometimes involve rapid prototyping of physical artifacts. In the process, learners engage in creative problem solving, evidence-based decision making, iteration, and collaborative design processes. Communities quickly took up calling the learning in open-studio environments "making" in 2005 with the founding of Make magazine (Martin, 2015). This label persisted despite existing and long-standing ways of referencing these types of learning practices and activities in communities underrepresented in STEAM. Despite an ostensible focus on open and inclusive learning, makerspaces have a history grounded in exclusive disciplines and for-profit corporate cultures (e.g., Silicon Valley).

Making: Making includes two parts: (1) the construction of some kind of artifact, whether it be digital or physical, and (2) the sharing of the process of making and/or the product created with a community of makers (Vossoughi and Bevan, 2014). Making is informed by personal interactions, interactions through time and space, interactions with larger social structures, and purposes. Learning-through-making can be a particularly fruitful space because it fosters critical creative inquiry: interest-driven, collective, and community-oriented learning in making for social and community change. Making contexts use learners' creation of objects to not only explore the world in general and STEAM fields in particular, but also to change them through attention to power dynamics. Making values creativity and ingenuity, distributed expertise, open access to information, cooperation, multimodality, and transdisciplinarity.

STEAM learning environments: These environments represent the intersection between spaces, tools and technologies, and people that operate at the intersection of **S**cience, **T**echnology, **E**ngineering, **A**rts, and **M**athematics as well as associated implications for learning inside STEAM learning environment. STEAM learning in these environments is shaped by access to people and networks, diverse materials, and tools, including digital tools.

Studio-Based learning environments: Studio-based learning environments are highly interactive and collaborative environments that encourage interaction with people, tools, and iterative creation processes. Practices that are employed involve processes of feedback and critique. These environments have a long history in formal education and connect multiple disciplines (e.g., architecture, art and design) and tend to feature apprenticeships with experts or masters, and/or opportunities to tinker and play.