DECEMBER 2021 FIELD BUILDING COLLABORATIVE WHITEPAPER

TRANSFORMING PUBLIC EDUCATION WITH MAKING AND DIGITAL FABRICATION

ACKNOWLEDGMENTS

The Fab Foundation and the Field Building Collaboration gratefully acknowledge support from the National Science Foundation for this work through the INCLUDES Program Award #2012790.

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How to cite this document:

Blikstein, P., Jones-Davis, D., Pryor-Jones, S., Santoso, S., Cornforth, K., Weisgrau, J. & Lassiter, S. (2021). *Transforming public education with making and digital fabrication*. Field Building Collaborative. https://buildfabmake.org/wp-content/uploads/2022/01/TransformingEducationWithMaking-2021.pdf

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One of the best opportunities we have to offer project-based, culturally relevant, and justice-oriented educational experiences for children and youth can be found in maker and digital fabrication education. It has the potential to be a foundational component of 21st-century education—both in the United States and beyond.

A once-in-a-generation opportunity to transform education

One of the best opportunities we have to offer project-based, culturally relevant, and justice-oriented educational experiences for children and youth at scale can be found in maker and digital fabrication education. More than a passing educational trend, it has the potential to be a foundational component of 21st-century education—both in the United States and beyond.

Maker and digital fabrication education is often associated with putting 3D printers or sophisticated technology into schools. It is, however, much more than that. It is a fundamentally different way to structure the school experience, empower students and teachers, allow for flexibility in curricula, value many ways of knowing, connect with learners' cultures, experiences, and communities, and enable collaboration and sharing. Since making and creativity are a fundamental part of human nature, maker and digital fabrication education should not be limited to a particular space, time, or set of technologies. Rather, it should be incorporated into all areas of formal and informal education.

However, we are at a crossroads. Although thousands of schools have built makerspaces and digital fabrication labs in the last decade, significant obstacles threaten to hinder further growth and expansion in inclusive directions, beyond these spaces into education writ large, for everyone. The past 10 years have taught us that this type of education can be incredibly empowering, but can also exclude many groups, among them immigrants, girls and youth of color. We know that it can enable children to develop deep projects and expertise, but without intention, it can also lead to trivial and oversimplified learning experiences. We have observed that it can be democratized, or can remain concentrated in just a handful of schools or limited to a minority of self-selected students. Therefore, infrastructure, policy, and design decisions need to be made thoughtfully and urgently in order to allow the movement to grow in an equitable and sustainable way.

In this document, we will discuss the aforementioned obstacles, their root causes, and opportunities for solutions. We will also show how this type of education has the potential to be a driving force for the learning institutions of the future, an important component of the preparation for the future of work, a crucial element supporting informed, civically-minded community members—as well as a key element in the design of educational systems that are more just, equitable, and inclusive.

We will also outline the role and vision of the **Field Building Collaborative,** a new partnership formed to address these notable gaps and challenges, and propose a series of recommendations for policy and practice geared towards educational leaders, educators, funders, and policymakers.

Origins, history and growth

The impulse to create is a critical driver of the human experience. From the beginning of time, humans from all cultures and backgrounds have used a variety of materials to solve problems, make tools, invent new technologies, and generate art, music, and other products of creative human expression. We have never stopped creating, learning from our making, and applying our learnings to our daily life.

However, as educational systems grew and became increasingly formalized and mass-produced, these inherently human experiences were in many cases removed from the lives of many children. For at least a century, researchers have been pushing back against this pattern, advocating instead for a more experiential approach to education, where rich materials and toolkits might be used and manipulated to create and explore (Dewey, 1902; Freudenthal, 1973; Fröbel & Hailmann, 1901; Montessori, 1964). Critical pedagogy pioneer Paulo Freire criticized school's "banking education" approach (Freire, 1974)—the mere "deposit" of decontextualized information in children's minds—and proposed that local culture and experiences should inspire educational topics, practices, and approaches. Freire was also an advocate for education as a form of empowerment, claiming that students' learning should be deeply connected to meaningful personal or community problems.

In the decades that followed, many researchers including many from the Global South, started to expand on this idea and conduct deep explorations into mathematics, science, and engineering as practiced by non-dominant communities and countries outside of the US and Europe. These researchers brought to the fore sophisticated and complex ways in which these other nations and communities created and used their own mathematics and engineering and told a new story about their contributions—many having been erased after multiple centuries of European colonialism (e.g., "Ethnomathematics," D'Ambrosio, 1985; Powell & Frankenstein, 1997; "Street Mathematics," Nunes et al., 1993; "Funds of Knowledge," Moll et al., 1993; Ladson-Billings, 1995b; Gutiérrez & Rogoff, 2003).

Meanwhile, scholars such as Seymour Papert (1980), Cynthia Solomon, and Edith Ackermann (2001) shared this enthusiasm for unleashing students' intellectual passions and interests but were particularly interested in the role of new media, materials, and toolkits as powerful construction and expression materials—particularly digital ones. Papert, who worked with developmental psychologist Jean Piaget for many years after having left his native South Africa (where he was an anti-apartheid activist during his university years), pioneered together with Solomon and others the use of "digital construction kits" with children, contending that the computer should not program the child—rather, children should program computers. Their theory of "**Constructionism**" states that learning happens remarkably well when students build, make, and publicly share objects, a theory that—many decades later—would be at the core of what making and digital fabrication mean for education.

Many young researchers in that group—among them Paula Hooper, Mike Eisenberg, José Valente, and Yasmin Kafai—went on to become important leaders in the conceptualization of maker/digital fabrication education. This next wave of scholars focused on advancing the agenda that technology in education should be an emancipatory tool that puts the most powerful "construction materials" in the hands of children, catering to many forms of working, expressing, thinking, and building, which Turkle and Papert (1991) would call "**epistemological pluralism**."

The first decade of the 2000s was when designers and researchers started to envision the use of industrial equipment such as 3D printers as educational devices for personal expression (e.g., Eisenberg, 2002). By then, educational robotics kits were present in many schools, but many new, low-cost platforms were being created as open-source hardware (**MIT Cricket**, **Gogo Board**🔗, **Wiring**, **Arduino**🔗, **micro:bit**🔗), making the creation of interactive objects much easier and accessible. Still, a growing sense of lack of gender diversity drove designers to invent more inclusive "construction kits" for the creation of novel types of products such as interactive textiles (e.g., Buechley, 2006; Buechley et al., 2008). There were also many new ideas for the use of recycled materials, particularly in developing countries such as Thailand and Brazil (Sipitakiat et al., 2004; Blikstein, 2008).

The emergence of a special "lab" or a "space" in schools

It was also in the early 2000s that Neil Gershenfeld's team at the **MIT Media Lab**🔗 (and later at the **Center for Bits and Atoms**🔗 at MIT) came up with the idea of packaging much of his lab equipment—including a laser cutter and small milling machine—into a "portable," standardized fabrication lab (Gershenfeld, 2005). These "fab labs" began to be refined, redesigned, and popularized by a creative group of scholars and students from MIT, such as Iranian-American professor Bakhtiar Mitkhak (Mikhak et al., 2002), Yael Maguire, Nitin Sawhney, Saul Griffith, and many others, with the first labs starting with India, Norway, the US, and Costa Rica.

In tandem, in January 2005, the O'Reilly publishing house produced the first issue of **MAKE: Magazine**🔗 under the leadership of Dale Dougherty, reviving the idea of "do-it-yourself" (DIY). The magazine targeted a broader non-academic audience and made use of new tools such as low-cost electronics kits and 3D printers that were more readily available to consumers. In April 2006, the first **Maker Faire**🔗 took place in the San Francisco Bay Area, attracting tens of thousands of people. The "Faires" became immensely popular in the United States and abroad, starting a stream of events, books, user groups, and products that brought the branded "maker movement" to hundreds of thousands of people globally. By 2017, over 220 Maker Faires had taken place around the world, including in Tokyo, Rome, Shenzhen, Berlin, Paris, Detroit, and San Diego.

In 2009, Brazilian scholar Paulo Blikstein and his team at Stanford University, and later at Columbia University, including Marcelo Worsley, created **FabLearn**🔗 (originally FabLab@School)—the first academic project to research maker/digital fabrication education, including the use of multimodal learning analytics methods to capture complex learning. The annual **FabLearn Conferences**🔗 began in 2011, and the **FabLearn Fellows**🔗 program which started in 2013, grew to reach researchers, practitioners, and students in 29 countries by 2021. More than 30 FabLearn conferences (including international spin-offs) in the following decade created a worldwide community of diverse maker educators with a particular focus on infusing research and cultural awareness into these learning environments. In this process, tens of FabLearn Labs were built in schools around the world, the **"Meaningful Making"**🔗 books series was established, and a presidential panel was organized at the American Educational Research Association, birthing a brand new research field that now has hundreds of scholars worldwide.

The first-ever "spaces for making/digital fabrication" in K-12 schools were created independently by MIT's **Center for Bits and Atoms**🔗 and the FabLearn program; the Fab Lab team at MIT opened a lab at the **MC2STEM STEM high school**🔗 in Ohio in 2009, while the first two FabLearn Labs were opened at the **1502 MPEI School**🔗 in Moscow in 2010, and at the **Castilleja School**🔗 in the San Francisco Bay Area in 2011. These three labs would eventually become the blueprints for thousands of labs worldwide, with many other models developed subsequently.

In 2009, the Center for Bits and Atoms at MIT spun off a nonprofit organization, **Fab Foundation**🔗, led by Sherry Lassiter, to support, provide resources and facilitate the growth of these new learning spaces at scale. The Fab Foundation has increased the number of fab labs across the United States that are focused on integrating digital fabrication in K-12 through partnerships with many organizations. There are now more than 2000 fab labs in over 125 countries. In 2017, with the support of the **Fab Lab Network**🔗, the Fab Foundation launched **SCOPES-DF**🔗, a community of practice for educators with an online repository of standards-aligned digital fabrication lessons, led by Sonya Pryor-Jones.

The **Maker Education Initiative** (**Maker Ed**🔗) was established in 2012, by founding Executive Director AnnMarie Thomas, with a mission to integrate making into educational contexts, and published a **Makerspace Playbook**🔗 in 2013. Over the following 9 years, Maker Ed engaged and trained more than 45,000 educators from around the world. With 35 regional hubs nationally, Maker Ed, currently led by Executive Director Kyle Cornforth, supports educators to maintain the pedagogical stance that making can happen anywhere and does not require a physical space, but a disposition to learner agency, hands-on learning, and a commitment to educational equity.

A national spotlight on maker and digital fabrication education

Making and digital fabrication reached the highest office of government within the United States in 2014, when the Obama administration held the first Maker Faire inside the White House and appointed Stephanie Santoso as the first-ever Senior Advisor for Making at the White House Office of Science and Technology Policy. There she worked with a team to launch President Obama's **Nation of Makers**🔗 initiative, focused on broadening participation in STEM through making, fostering entrepreneurship, supporting local and advanced manufacturing, and facilitating community-based problem-solving.

The Nation of Makers initiative sparked many other projects in subsequent years. In 2016, a subset of the organizations and individuals involved in the initiative worked together to launch the independent, national non-profit, **Nation of Makers**🔗, currently led by Executive Director Dorothy-Jones Davis. Nation of Makers supports the thousands of organizations that are engaged with making primarily within the United States (including K-12 institutions and educational service providers) through community building, resource sharing, and advocacy, within the maker movement and beyond.

Also as part of this 2016 initiative, **Maker Ed** and **Digital Promise**🔗, two non-profit organizations committed to accelerating innovation in education, issued a call to action for U.S. school and district leaders to sign the **Maker Promise**🔗—a pledge by schools to dedicate a space for making, designate a champion for making, and display what students make. Within two years of its launch, almost 2000 schools from all 50 states made this commitment. Subsequently, the Maker Promise evolved into a broader campaign and network of support for educators, advocates, and leaders championing the growth of making for youth across the country.

Another result of these initiatives was the **Makers + Mentors Network**🔗, a STEM initiative of **Citizen Schools**🔗, which partners with communities and organizations to uplift STEM mentoring and maker-centered learning as essential tools to build a stronger, more diverse workforce. In 2018, the Makers + Mentors Network launched the **Make For All**🔗 initiative, which expands maker-centered learning through a commitments model that brings together organizations and provides them with the support to create and grow programs. The **Maker Fellows**🔗 program was created a year later to expand access to sustainable maker-centered learning. As AmeriCorps VISTA members, Maker Fellows work with their host sites (community colleges, makerspaces, museums, Historically Black Colleges and Universities, and other historically underserved institutions) to support meaningful, culturally relevant, and community-driven maker-centered learning.

The challenges

The growing recognition of the need for inclusion and equity

As the movement grew, a series of important calls were rightfully made to re-examine some of its cultural and organizational roots. Leah Buechley delivered a breakthrough keynote at the FabLearn 2013 conference calling for a new focus around diversity and inclusion on maker and digital fabrication education (Buechley, 2013). Buechley, who had invented the first platform for e-textiles and was a pioneer in the research into gender and technology, showed that a large majority of projects shown at Maker Faires and on MAKE: Magazine covers revolved around projects by and for upper-middle-class boys, such as cars, robots, and rockets. In fact, a 2012 research study (Make, 2012) looking at the demographics of the popular Bay Area Maker Faire indicated that attendees were overwhelmingly male (66%), college-educated (86%), and affluent. Buechley called for a greater diversity in themes, audiences, and technologies in the movement, pointing to the inclusion of the rich, complex cultural maker practices of Indigenous, Black, and Latino communities, such as low-rider cars, pottery, textiles, costume-making in carnival parades, and many others.

Subsequent years witnessed many other critiques of the movement as it recentered around more inclusive practices. Blikstein & Worsley (2016) called for greater attention to creating learning cultures and sustainable facilitation instead of assuming that maker learners were autodidacts or hackers—an assumption that was harming girls and students of color. Vossoughi, Hooper, and Escude (2016) pointed out issues of culture, power, and inclusiveness of students of color—in particular the shaping of the movement to images of the Silicon Valley—and the need for attention to pedagogy. Researchers and practitioners also attempted to center maker practices and identities in the context of indigenous communities (e.g., Barajas-López & Bang, 2018) and other non-dominant populations (Tan & Calabrese-Barton, 2018; Holbert, Dando & Correa, 2019), considering social justice making that honors cultural histories and techniques from marginalized communities (e.g., Craft Network🔗 led by Dr. Maria C. Olivares of Boston University, and the Social Justice Sewing Academy🔗, led by Sara Trail). Worsley and Bar-El (Worsley & Bar-El, 2020; Bar-El & Worsley, 2021) have developed recent work on "Inclusive Making", developing research and design of environments and activities for people with disabilities. In a national study of makerspaces, Kim et al. (2019) recommended program designers start with culture, inclusive recruitment, and checking for implicit biases in program design and communications.

Terminology: “Maker” and “digital” fabrication

In line with the call to recenter and define the maker movement as more than the domain and interest of a subset of privileged individuals or communities, came a discussion about the marginalization occurring due to the mainstream commodification of the term “maker” by particular brands and entities. While the term promotes a sense of community and identity for some, for others, it could be problematic to narrowly name and define an activity that can empower identity and elicit agency. In particular, many non-dominant communities and individuals (both adults and youth) feel that the term and the related mainstream movement have been limiting, not acknowledging domains such as music, food, or dance as part of the movement. As such, many have actively pushed against the “brand”—and in some cases refuse to identify as “makers.” Debbie Chachra, professor of engineering at Olin College writes that, *“I’m uncomfortable with any culture that encourages you to take on an entire identity, rather than to express a facet of your own identity”* (Chachra, 2015) and Jen Ryan of Project Zero states that *“along with a sense of belonging comes the implicit corollary—not belonging. [...] we run the risk of excluding those who might ordinarily consider themselves makers”* (Ryan, 2015).

Indeed, a concern as we consider broadening participation are the terms we use to describe the grouping of these tools and technologies into a “discipline”, and the boundaries we may inadvertently place on the field. For example, “digital” fabrication may not adequately represent traditional and non-digital tools and skills used to create and innovate. A further effect of narrowing making and digital fabrication to a technique or technology may promote the “keychain phenomenon”—a shallow learning outcome generated by the widespread practice of “too-simple” projects and workshops, such as children 3D printing objects downloaded from the web without ever having designed them, or laser cutting simple designs like keychains and nametags (Blikstein, 2013).

Inversely, the broadening of the term “maker” and its realm to other well-defined areas (such as art or design) may cause some individuals and entities to feel as though their identities are subsumed by the movement. The definition of “making is everything” could cause a reaction in communities that may feel as though they are being forced into an identity that they do not wish to possess. In particular, some communities and professions with rich cultural histories may resent the notion of making as “new”, as they have been making “for ages.” Would artists want to be considered “makers”—or “just” artists? Consequently, the “making is everything” definition might make the definition so generic and diluted that it risks losing all sense of community and uniqueness.

The many faces of maker and digital fabrication

How do we begin to acknowledge the broad scope of "making" in a way that uplifts maker cultures of diverse backgrounds and traditions, without diminishing the individual identities of makers, no matter how they identify? And how do we recognize the accomplishments and potential of what the movement has achieved so far? This is an ongoing conversation in the community that is timely and necessary. As a first step, we recognize that as we broaden our understanding about making and its role in non-White and non-male-dominant culture and communities, it is crucial to highlight the scholarship of a growing cohort of researchers dedicated to this work.

In this section, we have highlighted a group of diverse scholars and practitioners that are paving the way in designing inclusive, equitable, and intergenerational maker experiences. We believe these scholars' work has brought forth a new wave of maker education that respects and acknowledges the rich funds of knowledge and community cultural maker experiences that makers bring with them to the educational space along with acquired maker and digital fabrication knowledge. It is essential to catalog and share their stories and contributions to ensure that the origins of making and its proliferation include a rich range of trajectories, capturing the attention and interest of all students. However, this list is not comprehensive or exhaustive—it is just one first attempt to capture some of the work in this field. We will continue to add new people and research to this report in future revisions.

Isabel Correa

- Doctoral candidate at the **Snow Day Learning Lab**🔗, Teachers College, Columbia University.
- Strategies for success/research focus: Creativity in maker education and biodesign as a space for urban youth to respond to the climate emergency by imagining how we might create with nature, and within our local socioecological communities.

Dr. Kareem Edouard

- Assistant Professor, School of Education and the **Expressive and Creative Interaction Technologies (ExCITe) Center**🔗, Drexel University.
- Strategies for success/research focus: Intersectionality of race and culture and STEM engagement for students of color, with the goal of motivating Black students to pursue STEM learning through culturally-relevant informal STEM programs. His work also examines equity and access in the maker movement for Black student participants.

Blair Evans

- Founder and Director, **Incite Focus**🔗, a lab focused on relationships between Digital Fabrication, Permaculture, Experiential Learning, and Appropriate Technology. African American community activist, technologist, inventor and founder of over half a dozen Fab Labs.
- Strategies for success/research focus: Blair's work empowers youth and community members to create the conditions for change by promoting a greater sense of individual autonomy, as well as developing community resilience through digital fabrication education.

Dr. Nettrice Gaskins🔗

- Digital artist, academic, cultural critic and advocate for STEM.
- Strategies for success/research focus: "Techno-vernacular creativity" and Afrofuturism. By broadening the view of making through mediums like film, music, video games, hip hop, and dance, Dr. Gaskins takes her gift as a practicing artist and her academic expertise in digital media to support students and educators in the exploration of techno-vernacular creativity. This framework is used to personalize the making and learning of youth, often marginalized and engaged in cultural norms and activities that are naturally situated for making.

Elena Durán López

- Ph.D. candidate, Graduate School of Education at the University of California, Berkeley.
- Strategies for success/research focus: Working with a Pomo tribe in California, Elena reconceptualizes how spaces for making should be co-designed between universities and Indigenous communities, proposing a more holistic and historical approach to examine the value of such spaces for nondominant communities. As part of this work, she created a new method to inspect the decision making process and power relationships that underlie this co-design.

Stephanie T. Jones🔗

- Ph.D. candidate, Computer Science and Learning Science, Northwestern University.
- Strategies for success/research focus: Intergenerational connections to making. Jones' research at the **tiilt lab (Technological Innovations for Inclusive Learning and Teaching)**🔗 with Professor Marcelo Worsley include inter-generational learning opportunities, building technologies that are personally relevant, and the relationship between anti-Blackness and computing. Jones' workshop, FamJam, uses traditional and digital fabrication tools to support parents and children in making board games together, providing an environment where parents and children can be co-collaborators and value the experience and cultures of families as a learning tool.

Dr. Breanne K. Litts🔗

- Assistant Professor, Instructional Technology and Learning Sciences, Utah State University. Director of the **Learn Explore Design Lab**🔗.
- Strategies for success/research focus: Making and design in Indigenous communities. In school and out-of-school time collaborations with community organizations, Dr. Litts' and her team examine how youth construct their identities through place and story, and how to use technology to help people collaborate. In partnership with the Northwestern Band of the Shoshone Nation, Litts has worked with tribal youth to share and preserve important cultural and historical stories of the Tribe while developing technological and design skills, which has expanded the notion of making for youth participants and non Indigenous researchers.

Dr. Amon Millner🔗

- Associate Professor of Computing and Innovation at Olin College of Engineering. Director, **EASE (Extending Access to STEM Empowerment) Lab**🔗. Co-inventor, **Scratch**🔗 programming language and co-founder, **South End Technology Center Fab Lab**🔗.
- Strategies for success/research focus: Engineering-based entrepreneurship projects, and pop up maker markets to ignite the interest of often marginalized youth in hands-on community-based making driven by interest and community culture.

Dr. Maria Olivares🔗

- Research Assistant Professor, Wheelock College of Education & Human Development, Boston University. PI, NSF-funded **CRAFT Network**🔗, a national network of researchers who are practicing justice-oriented research in making and committed to under-represented communities in STEM.
- Strategies for success/research focus: Broadening perspectives around making, particularly in BIPOC communities. Examining forms of attunement toward intercultural ways of knowing and being, and re-conceptualizing representation and dissemination of scholarship to include multiple forms of art and humanistic expression. Dr. Olivares works with youth, teachers, and researchers to design formal and informal learning environments that support expansive understandings of STEM.

Dr. Ricarose Roque🔗

- Assistant professor, Computer Science and Education, University of Colorado, Boulder. Director, **Creative Communities**🔗 research group.
- Strategies for success/research focus: Inclusive learning environments that enable young people to become computational creators — able to use computing to create things they care about, develop identities as creators, and imagine the ways they can shape the world. Design-based and ethnographic methods to study the role that social context plays in supporting children's participation in computing; partnerships with youth community based organizations to support intergenerational learning with family units. Families are invited to share their skills, interests and cultural backgrounds, or "funds of knowledge" as drivers for learning.

Sam Thanapornsangsuth🔗

- Lecturer at the Department of Educational Policy, Management, and Leadership, Faculty of Education, Chulalongkorn University, Thailand.
- Strategies for success/research focus: In her work to offer culturally-relevant constructionist education for low-income Thai public schools, Dr. Thanapornsangsuth actively seeks ways to understand and create inclusive maker-centered learning environments for all learners. In order to foster lifelong learning, she gives learners the chance to design, create, and invent projects that are meaningful to them. She also designs environments that promoted learning as a shared experience–working together and developing a community of learners for a lasting impact.

Dr. Bahiy Watson

- Executive Director and Founder of the **1881 Institute**🔗. **White House Champion for Change**🔗.
- Strategies for success/research focus: Dr. Watson's partnership with the Delgado Community College Fab Lab has been instrumental in transforming high school curriculum into hands on cross disciplinary opportunities for student learning; Bahiy and his collaborators have also used the rich culture of New Orleans Mardi Gras as a vehicle for connecting authentic interest with the tools and capabilities found in digital fabrication laboratories.

Dr. Marcelo Worsley🔗

- Assistant professor, Learning Sciences and Computer Science at Northwestern's School of Education and Social Policy and the McCormick School of Engineering. Founder of the **Technological Innovations for Inclusive Learning and Teaching (tiilt) Lab**🔗.
- Strategies for success/research focus: Improving technologically rich learning environments by creating multimodal interfaces that promote inclusivity and incorporate machine learning and artificial intelligence.

There is also an incredible richness and diversity in the contributions of practitioners working to explore the intersection of maker education, digital fabrication, and educational equity, striving for a more inclusive experience for all young people. Some of these practitioners are listed below—but this is far from an exhaustive list:

- Jerry Valdez (of **Community Science Workshop Network**🔗) working with the migrant farmworker community in California.
- Sara Trail (of **Social Justice Sewing Academy**🔗) working with youth to create quilts that address state-sanctioned violence against Black communities.
- The Navajo Technical University (which hosted the **Diné Maker Faire in 2019 and 2020**🔗).
- The **Let's Talk Code**🔗 program, which engages Navajo students in understanding the cultural origins of coding.
- Dora Medrano Ramos and Linda Le with their **"Learning in the Making: Live!"**🔗 project, which addresses the persistent omission of youth and educators of color from the dominant narratives around maker education.
- Researchers Louise Archer, Kylo Thomas, Jennifer DeWitt, and Esme Freedman, who are engaged in the **Making Spaces Project**🔗 (UCL Institute of Education) which seeks to tackle inequity in STEM by utilizing the rich potential of makerspaces. In collaboration with three community makerspaces, the group is working to generate new research for widening STEM participation in under-resourced communities and marginalized groups.
- Joy Buolamwini (MIT Media Lab) and a **poet of code**🔗 who uses art and research to illuminate the social implications of artificial intelligence. She founded the **Algorithmic Justice League**🔗 to create a world with more equitable and accountable technology.

This acknowledgement of the work of a new wave of scholars and practitioners provides concrete examples of culturally affirming pedagogy. These change makers are working at the intersection of academia and lived experience to broaden the understanding of STEM in both the university and community settings.

SECTION 2

A NEW COLLABORATIVE APPROACH TO BUILDING AN EQUITABLE AND INCLUSIVE MAKER AND DIGITAL FABRICATION FIELD

- *The Field Building Collaborative (FBC): History and purpose*
- *Divergence, intersections and convergence in making and digital fabrication education*
- *Policy and field-building recommendations*
- *Conclusion*

Based on our collective work and experiences, our newly formed Field Building Collaborative has identified three major barriers to the wide implementation of maker and digital fabrication education. We list these barriers and offer recommendations for policy and systemic change.

The Field Building Collaborative (FBC): History and purpose

History of the FBC

In 2019, Sonya Pryor-Jones of the **Fab Foundation** started reaching out to maker-centered learning and digital fabrication nonprofits (**Citizen Schools**🔗, **Digital Promise**🔗, **Fab Foundation**🔗, **FabLearn**🔗, **Maker Ed**🔗, and **Nation of Makers**🔗) to explore how they might collectively think about our work in K-12 education both in the United States and around the world. This collaborative group of partners determined that together they could make a stronger case for an impact on maker and digital fabrication for our youngest learners.

In order to explore this work together with rigor and commitment, the collaborative decided to seek funding and applied for an NSF INCLUDES planning grant, which *"seeks to improve collaborative efforts aimed at enhancing the preparation, increasing the participation, and ensuring the contributions of individuals from groups that have been historically underrepresented and underserved in the STEM enterprise."* The group's specific proposal, *Exploring a Collaborative Model for Broadening Participation in STEM through Digital Fabrication and Making*, was funded in 2020, and the six organizations have since worked together to set the groundwork for a maker and digital fabrication **Field Building Collaborative** (**FBC**). A set of shared priorities and actions, centered in equity, are now leading the FBC towards the use of our respective networks of influence to provide innovative, accessible, inclusive, and equitable high-quality learning environments for all learners through the lens of making and digital fabrication.

FBC purpose, shared vision, and focus

The purpose of the FBC is to explore and address the challenges related to creating inclusive and equitable high-quality STEM learning environments based around making and digital fabrication education. The FBC's shared vision as a "network of networks" is to collaborate with other stakeholders in education to ensure that all voices are represented, and that a holistic approach is designed—one that will empower all student learners through making and digital fabrication. The FBC's constituents believe that it can broaden participation by centering equity in their work at the individual, institutional and cultural levels. The varied collection of approaches offers a wider range of on-ramps for participation in global communities, irrespective of learners' backgrounds, allowing participation along the continuum of making, innovation and digital fabrication learning.

A collaborative focused on maker education and digital fabrication is not a novel concept. What is unique is a collaborative built around the intentional centering and focus of making and digital fabrication on the culture, history and lived experience of the diversity of individuals. For this reason, the Field Building Collaborative seeks to cultivate leadership amongst members, and acknowledge and uplift a diversity of backgrounds within maker-and-digital-fabrication-centered learning, in particular, doing the intentional and important work of elevating the voices, experiences, and contributions of people of color, immigrant scholars and practitioners, and other nondominant communities to the history of digital fabrication and making for STEM.

Divergence, intersections, and convergence in making and digital fabrication education

One of the core ideas behind making and digital fabrication education is the constructionist approach to education, as defined by Papert and collaborators (Papert, 1980) as a pedagogical approach derived from Constructivism and Sociocultural theories of learning. At the heart of constructionism is the idea that learning *"happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity."* In typical Constructionist learning environments, learners are allowed to express their knowledge in diverse ways, build and test prototypes and theories, and collaborate with others. Knowledge-building is not monolithic. This can also be applied to coalition building and collaboration. As the FBC builds our collaborative structure, we regard ourselves as learners who are building new collective knowledge driven by our diverse organizational influences and cultures.

As maker / digital fabrication education developed over the last decade, several organizations were created to study, disseminate, and scale it up (including some of the organizations in this collective). While some focused on policymaking and physical infrastructure, others focused on identifying and supporting hobbyists and grassroots maker communities. Some focused on research and outreach to academia, while others focused on implementation, teacher training, or curricular content. As a result of this branching out, these organizations developed complementary specialties, communities, and strategies.

Just like in any growing movement, there are convergences and divergences that generate healthy conversations, e.g. about the very definition of what "making" and "makerspaces" or "fab labs" are, the differences between "making" and "digital fabrication," the focus on workforce development, the ways to integrate making into the curriculum, and the evolution of technologies to necessitate and extend learning.

The differences in our origin stories can make it difficult to be absolute. However, as six unique organizations that are nationally and internationally respected networks, the FBC has the potential to reach educators and makerspace organizations of all kinds and make change at a strategic scale. Collectively, the FBC organizations are grappling with the design and delivery of approaches and resources that honor our various methods of delivery while addressing inequalities that are contextualized to meet local needs.

While we collectively may never unanimously agree on one way to define a "maker", or which technologies (low or high) are necessary to move the needle on learning, the FBC agrees that:

- **Maker learning experiences are not yet being universally offered to all students, and not with the same level of quality to all students.**
- **The nature of dominant maker activities in most schools does not yet offer a welcoming or culturally relevant environment to nondominant youth.**
- **Making and digital fabrication spaces can provide a unique connection between STEM disciplines, youth activism, creative fabrication, and personal meaning, but that connection is not yet present or fully developed for most youth.**
- **Making and digital fabrication can offer a more equitable entry point to STEM that could broaden participation for all learners.**

Having that in mind, and based on our collective experience, we list below a series of policy recommendations that we deem important to move the movement forward with a renewed concern about equity, inclusion, and social justice.

Policy and field-building recommendations

Based on our collective work and experiences within this space, our Field Building Collaborative has identified three major barriers to the wide implementation of maker and digital fabrication education. We list these barriers below, discuss our strategic actions as a FBC, and offer recommendations for policy and systemic change to move the needle towards widespread adoption of high quality, sustainable maker and digital fabrication education. Districts and school systems should focus on professional development, that, in addition to only supporting maker-centered learning and digital fabrication literacy, focuses on STEM outreach that prioritizes the voices and participation of youth who are BIPOC, womxn, living with disabilities, and/or LGBTQ.

Barrier 1: Lack of knowledge about what making and digital fabrication in education is, and how it aligns with state and local standards

A primary barrier to widespread implementation of maker and digital fabrication education is the lack of understanding of what "maker/digital fabrication education" is, its potential, its differences from other educational approaches, and how it aligns with existing state and local standards.

In our collective advocacy work, we will improve our own communications through research, case studies, and storytelling techniques and practices. FBC members commit to documenting and sharing the progress of districts, schools, educators, and students involved in maker-centered learning. Sharing stories of success around transformative teaching and learning helps provide blueprints for best practices and re-invigorates commitment to equitable participation of all youth.

We recommend that policy and decision makers:

- Increase awareness of making and digital fabrication education and the associated learning outcomes, by launching district-level, state-level or national campaigns for maker-centered and digital fabrication learning that showcases its impact on students, educators and communities. To help policymakers and school leaders to understand the benefits of maker-centered learning and digital fabrication literacy, these campaigns should highlight the learning that happens in those spaces rather than the equipment or the technology. They should also highlight a diversity of projects, ideas and tools, and pay special attention not to reproduce societal biases about who participates in engineering and science.

   - Example: The campaign done by **Girls Who Code**
   - Example: The campaign done by **Black Girls Code**

- Adapt state standards to include making and digital fabrication, thereby providing more detail and granularity to educators looking to implement making into the curriculum and providing justification to district leaders.
   - Example: The **Exploratorium's** **"Adapting an Activity for NGSS"** planning tool for teachers.
   - Example: The **SCOPES-DF** **Fab I Can Statements** which serve as guides for teachers and students.
- Create specific local curricular standards for maker and digital fabrication education that provide some universal best practices, but are flexible enough to be adapted by local communities to make them culturally-responsive and specific to their needs.
   - Example: The **Association of Career and Technical Education** has developed a **Quality CTE Program of Study Framework**, which can be used by local CTE programs.
   - Example: The **IDEIA Science Standards** in the city of Sobral, Brazil, is an example of maker-oriented standards that are deeply integrated with the regular school curricula, and created with theparticipation of teachers.
- Develop national standards and programs that reward innovation in schools rather than enforce compliance with past approaches, and offer guidance for the creation of new types of content and activities to be implemented nationally. In other words, instead of just offering incentives for teachers who comply with published standards, offer recognition and reward teachers that go beyond them or generate creative curricula and units.
   - Example: More general awards and recognitions are the **Presidential Awards for Excellence in Mathematics and Science Teaching** and the **Presidential Innovation Award for Environmental Educators**.

- Example: In the field of maker and digital fabrication education, the **Chevron STEM Education Award** and **Teacher Innovator Award** are offered in partnership with the Fab Foundation.
- Example: The **FabLearn Global Excellence Awards** recognize practitioners and organizations working to advance maker education and constructionist learning, while the **FabLearn Fellows** program gives global visibility to outstanding educators in the field.

- Adapt assessment practices to measure new types of learning. Describing student learning in maker environments can be difficult: students will gain proficiency in a wide variety of areas. Assessing the work in makerspaces is possible, but requires a new set of approaches and tools. Instead of a "product culture," in which success is determined by the quality of the product shown at the school science fair, students' learning throughout the process should take precedence. Assessments should measure what matters in makerspaces, and signal to students how they should work, collaborate, and distribute their efforts. Maker portfolios are one mechanism for capturing the learning, skills and experiences that students gain from maker and digital fabrication education. These portfolios are increasingly being included in the application process at post-secondary and higher ed institutions.
  - Example: **Open Portfolios** by Prof. Kylie Peppler
  - Example: **Multimodal Learning Analytics**, a set of computational and sensing techniques designed to capture and research complex, open-ended learning, currently being done in research labs such as the Bertrand Schneider's **LIT Lab** at Harvard University, the Marcelo Worsley's **tiilt lab** at Northwestern University, and the Paulo Blikstein's **TLT Lab** at Columbia University

Barrier 2: A lack of capacity for communities to sustainably design, implement and grow maker and digital fabrication education opportunities for all students

The second barrier to widespread implementation of maker and digital fabrication opportunities is the lack of professional development and staff. Because of the complexity of starting such programs, many educators are daunted by the prospect of implementing maker and digital fabrication education and are unaware of how to get started and how to integrate making into everyday learning experiences.

High-quality implementations of such programs require expertise in multiple fields such as pedagogy, technology, and curricular integration, and there are still a small number of experts and institutions offering professional development in all of those areas.

Our recommendations to policy and decision makers are:

- Districts and school systems should focus on professional development, that, in addition to only supporting maker-centered learning and digital fabrication literacy, focuses on STEM outreach that prioritizes the voices and participation of youth who are BIPOC, womxn, living with disabilities, and/or LGBTQ. We believe that the growing understanding of equity within teacher practices and the integration of Culturally Responsive and Affirming pedagogies, provide platforms and tools for schools to implement activities that ensure safety and support for youth from marginalized communities.
    - Example: Programs such as **Makers in Residence Mexico** 🔗, which serves underserved communities from Mexico City and Guadalajara (Otero, Ornelas et al., 2014). During the program participants created solutions for their community or personal problems. A similar program is **Learning Labs**🔗 run by Nancy Otero at Make:, in this program NEETs from underrepresented communities from Mexico and US created **two team projects**🔗 to solve their community problems using skills they learned in the program such as Biotechnology, AI, and e-Textiles.

- Professional development in this area should not be restricted to the "lab" or science teachers. Whereas they might have more technical training, it is key that all teachers understand the potential of maker and digital fabrication, and are prepared to reimagine their own teaching with these new pedagogies, practices and tools. Thus, funding, programming, and time for comprehensive maker and digital fabrication professional development should be provided for all pre-service and in-service K-12 teachers.
  - Example: Programs such as **UTeach Maker** provide maker micro-credentials to pre-service educators supporting them in bringing making and digital fabrication to their classrooms.
  - Example: Maker Ed's **Making Spaces** program uses a hub and spoke model to support local educational institutions as they integrate making into their learning environments.
  - Example: Makers + Mentors Network's **Maker Fellows** program places AmeriCorps VISTA members at makerspaces, community colleges, Historically Black Colleges and Universities and other minority-serving institutions to support their efforts to expand access to K-12 maker-centered learning.
  - Example: In the city of Sobral, Brazil, a new type of teacher was created: the **Curricular Redesign Teacher**. The municipality hired one per school, and tasked them to redesign the regular curricular units to incorporate maker tools and approaches. This work was done in collaboration with the existing teachers, and is changing how STEM disciplines are taught in a sustainable way (see **IDEIA Project**).
- Incentivize public education systems to systematically incorporate maker-centered learning, offering grants and incentives for states. These resources can be used to hire teachers specialized in making and digital fabrication in full-time positions, cover capital expenditures for making (physical space modification, tools and equipment, consumables), create permanent programs for professional development, and build the infrastructure. A systemic approach is crucial to create programs that integrate seamlessly with the other components of the school system, and survive beyond the initial implementations and grants.

- Example: **Hamilton County Schools🔗** in Tennessee took it upon themselves to actively build out their programs, and now has the largest concentration of school based Fab Labs in a school district, 18 fab labs in middle and high schools across the district, serving approximately 19,500 students.
- Example: The **Ravenswood City School District🔗** in California started their maker program with an external grant, but over the following three years, with its own resources, built out an internal infrastructure with permanent teams for taking care of consumables and infrastructure maintenance, continuous professional development for lab teachers, and curriculum development.

Barrier 3: A lack of community-driven, equity-centered approaches to designing maker-education programming, makerspaces and fab labs

The third key barrier to implementation of equity-centered and community-driven maker and digital fabrication opportunities is the relative lack of true co-design and co-development of opportunities by communities.

Our FBC collective strategic priorities include advocacy work around policy, coalition building, and storytelling. Our desire is to create both understanding and scalable actions for stakeholder-driven participation. Community engagement is focused on supporting stakeholder-specific needs, which acknowledges their range of strengths and limitations. This includes professional development, learning, partnering, and network weaving as a tactic for growth and change.

We recommend that policy and decision makers:

- Support a community-based approach to creating opportunities for maker education within and outside of the classroom.
    - Example: In Providence, RI, the **PVD Young Makers** program provides local youth with free access to digital fabrication tools, studio time, workshops and classes in schools, community centers, and all public libraries.
- Encourage and implement place-based strategies, improving conditions for educators of color and other nondominant communities to advance in the field while including making and/or digital fabrication in their practice.
    - Example: In Cleveland, Ohio **Fab House** was launched to address the persistent disparity and digital divide between majority and minority communities, and is using technology to address social determinants of health.
    - Example: the **Learning in Places** project led by Northwestern University and the Tilth Alliance provides community relevant field-based learning opportunities for students to engage in complex ecological reasoning, through work in learning gardens and other outdoor

spaces, tackling themes such as food sustainability and water usage.

- Encourage and look for opportunities to connect making to culturally-affirming education and social justice.
    - Example: The **North American Indian Center of Boston (NAICOB)**🔗 houses a makerspace within their social service agency and it supports the wide range of social service and justice programs that they lead in education, health & safety, and employment and training.

Conclusion

Every few decades, new skills, ideas, tools, and activities become crucial for work and civic participation—democratizing tasks previously only accessible to experts. Digital fabrication and making could be a new and major chapter in the process of bringing powerful ideas, literacies, and expressive tools to children and youth. The tools and ways of learning made popular through the maker/digital fabrication movements have been proven to enable student design, create, and build unimaginable objects and inventions, and to cater to many forms of working, expressing, and building (Martinez and Stager, 2013). This adaptivity permits the acknowledgement and embracing of different ways of learning, engendering environments in which learners can develop intense personal engagement. It is exactly that type of deep engagement that is sorely missing from traditional education and that we need to foster.

The next challenge for the maker movement will, thus, be that of liberatory democratization and emancipation: how do we bring such experiences to the children with the greatest disadvantages, to make the movement an equalizing force, rather than another type of technology that widens the gap between private and public schools, affluent and low-income communities? This time, it seems that we have all the elements needed to formulate an answer and to realize, at last, the promise and the potential of maker and digital fabrication education.

SECTION 3

APPENDIX

Links

Section I

Origins, history, and growth

www.gogoboard.org

www.arduino.cc

The emergence of a special “lab” or a “space” in schools

www.media.mit.edu

cba.mit.edu

www.makezine.com

www.makerfaire.com

www.fablearn.org

www.fablearn.org/conferences

www.fablearn.org/fellows

www.fablearn.org/fellows/meaningful-making-book

www.mc2stemhighschool.org

www.fablabs.io/labs/FabLabschool

www.castilleja.org/learning/experiential-learning/maker-spaces

www.fabfoundation.org

www.fabfoundation.org/global-community

www.scopesdf.org

www.makered.org

www.makered.org/wp-content/uploads/2014/09/Makerspace-Playbook-Feb-2013.pdf

A national spotlight on maker and digital fabrication education

obamawhitehouse.archives.gov/nation-of-makers

www.nationofmakers.us

www.digitalpromise.org

www.makerpromise.org

www.makersandmentors.org

www.citizenschools.org

www.makersandmentors.org/makeforall

www.makersandmentors.org/makerfellows

The growing recognition of the need for inclusion and equity

- www.craft-network.org
- www.sjsacademy.org

Changing the face of maker and digital fabrication

- www.snowdaylearninglab.org
- www.drexel.edu/excite
- www.incite-focus.org
- www.nettricegaskins.com
- www.stephanietjones.com
- tiilt.northwestern.edu
- cehs.usu.edu/itls/people/breanne-litts
- www.learnexploredesign.org
- ease.olin.edu/amonmillner
- web.media.mit.edu/~millner/easelab
- scratch.mit.edu
- southendtechcenter.org/fab-lab
- www.mcolivares.com
- www.craft-network.org
- www.ricarose.com
- www.creativecommunities.group
- www.the1881institute.org
- obamawhitehouse.archives.gov/champions
- www.marceloworsley.com
- tiilt.northwestern.edu
- www.sawaros.com
- www.cswnetwork.org
- www.sjsacademy.org
- makezine.com/2020/05/15/dine-maker-faire-on-the-navajo-nation
- prezi.com/i/_id1idjrsldf/make-for-all-commitments-catalog-2021
- www.makered.org/learning-in-the-making
- www.instituteofmaking.org.uk/research/making-spaces-project
- www.poetofcode.com/press
- www.ajlunited.org

Section II

History of the FBC

www.citizenschools.org

www.digitalpromise.org

www.fabfoundation.org

www.fablearn.org

www.makered.org

www.nationofmakers.us

Barrier 1: Lack of knowledge about what making and digital fabrication in education is, and how it aligns with state and local standards

girlswhocode.com/get-involved/campaign

blackgirls-code.medium.com/black-girls-code-presents-futuretechboss-series-49deca05708a

www.exploratorium.edu

www.exploratorium.edu/sites/default/files/pdfs/snack-adapting-activities-to-NGSS-planning-tool_v4-2.pdf

www.scopesdf.org

www.scopesdf.org/fab-i-can-statements

www.acteonline.org

www.acteonline.org/wp-content/uploads/2019/01/HighQualityCTEFramework2018.pdf

www.curriculoideia.org

www.paemst.org

www.epa.gov/education/presidential-innovation-award-environmental-educators

www.scopesdf.org/chevron-stem-education-award

www.fabfoundation.org/teacherinnovator

www.fablearn.org/awards

www.fablearn.org/fellows

www.makered.org/wp-content/uploads/2015/03/Open-Portfolio-Project-Research-Brief-Series_FULL_final-small.pdf

lit.gse.harvard.edu/kinected-makerspaces

tiilt.northwestern.edu/projects/blinc

tltlab.org/multimodal-learning-analytics

Barrier 2: A lack of capacity for communities to sustainably design, implement and grow maker and digital fabrication education opportunities for all students

www.fablearn.eu/2014/wp-content/uploads/sites/2/2018/10/fablearn14_submission_18.pdf

learn.make.co/program-application

learn.make.co/final-projects

www.curriculoideia.org

www.hcde.org

www.ravenswoodschools.org

Barrier 3: A lack of community-driven, equity-centered approaches to designing maker-education programming, makerspaces and Fab Labs

www.pvdyoungmakers.com

www.myfab.house

www.learninginplaces.org

www.naicob.org

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The Field Building Collaborative, formed by Fab Foundation, Maker Ed, Digital Promise, Nation of Makers, Citizen Schools and FabLearn aims to explore the challenges related to creating inclusive and equitable high-quality STEM learning environments through maker and digital fabrication education. In creating a shared vision and strategic actions in collaboration with other stakeholders in K-12 education, to ensure that all voices are represented and all students have access, the Collaborative is developing a series of freely available, equity-centered materials and resources focused on engaging communities in maker and digital fabrication education with support from NSF INCLUDES.

CITIZEN SCHOOLS

FABLEARN

MAKER ED

Digital Promise®
Accelerating Innovation in Education

fabfoundation

NATION OF MAKERS