INTEGRATING MATHEMATICS AND MAKING: A SHARED GOALS AND VALUES FRAMEWORK (IN PROGRESS)

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Although there is a growing body of research on mathematics in informal learning environments (Pattison, Rubin, & Wright, 2016; Rubin, Garibay, & Pattison, 2016), less has been done to understand how math can be integrated into other informal STEM education settings or topics, and how this integration might engage those who do not already have positive attitudes about math. Over the last decade there has been a proliferation of out-of-school environments that foster building, making, tinkering, and design activities (Bevan, Gutwill, Petrich, & Wilkinson, 2015; Vossoughi, Escudé, Kong, & Hooper, 2013), creating an unprecedented opportunity to engage a wide range of participants in mathematics that is both purposeful and powerful.

The primary activity of *Math in the Making* will be a convening in the spring of 2016 with researchers and practitioners in out-of-school mathematics and making to advance the field's understanding of how to highlight and enhance the mathematics in making experiences, develop tools and resources for informal educators, and foster collaborations for future efforts. This document outlines a framework to guide these conversations and establish shared goals that lead to productive discussions about the integration of mathematics into making and tinkering experiences.

Shared Goals (That Motivate the Authentic Integration of Math in Making)

1) ***Educators from both the math and making/tinkering communities share the broad goal of helping children and adults develop the dispositions, skills, knowledge, and values to be successful and empowered citizens in the modern world and critical consumers of information and resources*.** These dispositions, skills, knowledge, and values will, in turn, allow individuals to contribute to healthy and sustainable communities. Both math and making/tinkering are fundamental realms of knowledge and practice in today's STEM-rich society.

2) ***Mathematics can support rich, authentic making and tinkering.*** Mathematical thinking is essential to the way humans interact with the world, including through making and tinkering experiences. Whether or not they are aware of it, individuals use math skills and concepts, such as proportional thinking or spatial reasoning, whenever they build, create, and explore. Purposefully and authentically integrating math learning into making and tinkering can enrich and deepen the experiences and provide individuals the tools and abilities they need to become lifelong makers.

3) ***Making and tinkering provide compelling, authentic contexts for engaging children and adults with mathematics.*** Mathematics is fundamentally an applied field and a tool for making sense of patterns in the world around us. Unfortunately, math in school is often presented in the abstract, providing students little sense of how to apply math in their everyday lives and little motivation to continue to develop their mathematical thinking and reasoning skills (Martin & Gourley-Delaney, 2014; National Research Council, 2005). Engaging adults and children in mathematics through making and tinkering experiences models math as a powerful tool for solving problems and motivates individuals to recognize and develop their math skills as they build, create, and explore.

Aligned Values (That Guide the Integration of Math in Making)

1). The fundamental characteristics of making and tinkering experiences that motivate adults and children are paramount. In other words, mathematics should be integrated into these experiences without compromising the nature of the making and tinkering experiences. Recognizing that the making and tinkering community is diverse, several educators and scholars have attempted to describe the essence of this movement (Bevan et al., 2015; Brahms & Crowley, 2015; Brahms, Wardrip, & Children's Museum of Pittsburgh, 2014; Vossoughi & Bevan, 2014):

> *"Making is a venerable human practice that has recently taken the educational field by storm due to its perceived potential as a driver of creativity, excitement, and innovation (Honey & Kanter, 2013; Martinez & Stager, 2013). Tinkering is a branch of making that emphasizes creative, improvisational problem solving. It centers on the open-ended design and construction of objects or installations, generally using both high- and low-tech tools (e.g., Arduino microprocessors with pipe cleaners, hot glue guns, and feathers). At the heart of tinkering is the generative process of developing a personally meaningful idea, becoming stuck in some aspects of physically realizing the idea, persisting through the process, and experiencing breakthroughs as one finds solutions to problems (Petrich, Wilkinson, & Bevan, 2013; Vossoughi, Escud´e, Kong, & Hooper, 2013). Problems or challenges are not assigned but are surfaced and pursued by the learner through initial exploratory engagement with the materials, people, practices, and ideas available in the tinkering setting"* (Bevan et al., 2015, p. 99).

> *"Making is characterized by interest-driven engagement in creative production at the crossroads and fringes of disciplines such as science, technology, engineering, art, and math, and has developed into a recognized social, technological and economic movement (Honey & Kanter, 2013; Sheridan et al., in press)"* (Brahms et al., 2014, p. 2).

> *"Our analysis revealed a set of seven core learning practices associated with recognizable participation in the maker community: explore and question; tinker, test, and iterate; seek out resources; hack and repurpose; combine and complexity; customize; and share"* (Brahms & Crowley, 2015, pp. 3–4).

Mathematics is integral to much, but not all, of making and tinkering but is usually not a motivation or goal for learners in and of itself. In some experiences it is more salient than others—and is probably integral to more making and tinkering contexts than many might at first realize. Finding productive and authentic intersections between the two domains is critical for supporting the goals outlined above. Math can be authentically integrated into making and tinkering experiences such that using or exploring the math is a necessary and valued part of achieving the goals of the experience.

2). Experiences that integrate mathematics with making and tinkering should be culturally responsive and inclusive for diverse communities and learners. Both the fields of mathematics and making/tinkering have struggled to address issues of equity and access (e.g., Apple, 1992; Vossoughi et al., 2013). For this reason, it is critical that the integration of mathematics and making be informed by culturally responsive and asset-based perspectives (e.g., Garibay, Yalowitz, & Guest Editors, 2015; Gutiérrez & Calabrese Barton, 2015; Kirkhart & Hopson, 2010).

***3). Mathematics should be conceived of broadly as it relates to making and tinkering*.** While many people think of math as primarily involving computation and symbol manipulation, mathematics is a much broader field. Mathematicians generally consider the work they do as the "science of patterns" (Jacobs, 1994, p. 19) and "seek patterns wherever they arise" (Steen, National Research Council, & Mathematical Sciences Education Board, 1990, p. 2)—such as in the shapes of trees, in a series of scientific measurements, in a woven fabric, or in the way an animal moves. Jacobs (1994) sees

mathematics as the "language in which the universe is written" and argues that "everything we take for granted in modern technology, a thousand things that would have dumbfounded Isaac Newton, could not have been developed without the creative efforts of mathematicians."

Another common misunderstanding about mathematics is that its goal is getting the "right answer." In fact, the goal of mathematics is understanding and operating in the world. Finding and using patterns allows us to create three-dimensional shapes out of two-dimensional fabric, build houses that fit together exactly, design new drugs, and more. And sometimes doing mathematics is all about asking questions to which there may be more than one answer.

Informal, everyday mathematics is different than school math. In integrating mathematics into making and tinkering experiences, educators should understand and capitalize on the unique characteristics of everyday mathematics, including the role of facilitation and social learning, the importance of non-mathematical goals and values, and the pragmatic use of tools and strategies (Pattison et al., 2016).

Focus Areas (That Bound and Focus the Integration of Math in Making for This Project)

There are a range of settings in which mathematics might be integrated into making and tinkering experiences. As a starting point, ***this project will focus particularly on non-compulsory, free-choice learning experiences in designed learning environments, such as museums, libraries, and maker spaces.***

This project will also focus on several specific domains of mathematics: ***(a) geometric/spatial reasoning*** (including connections between 2-D and 3-D representations) and ***(b) algebraic reasoning/proportional thinking*** (including scaling). These topic areas will provide a concrete starting point for discussing and exploring the integration of mathematics into making and tinkering experiences. Other promising areas of mathematics to explore include: precision, rate of change, and measurement. For this project, measurement and arithmetic were not chosen as initial focus areas because they are so closely connected with stereotypical views of math and may actually limit the perspectives researchers, educators, and learners take on the integration of mathematics and making. During the *Math in the Making* convening, the project team and conference attendees will identify other promising areas of mathematics for future exploration.

Outstanding Questions (That Catalyze Project Discussions)

- How can mathematics be purposely and authentically integrated into making and tinkering experiences?
- How can institutions and educators ensure that this integration supports culturally responsive and inclusive experiences for diverse communities and learners?
- What are promising examples of the integration of mathematics in making and tinkering?
- What strategies and approaches can educators and facilitators use to support the integration of math and making in these settings?
- How explicit should the mathematics be in order to support both rich making and tinkering and the recognition and development of math-related skills, knowledge, dispositions, and values? How important is it for learners to be aware that they are engaging in mathematics?
- How do we deal with "math phobia" inherent in US culture (on the part of learners, facilitators, designers, etc.)? How do we help broaden our collective vision of what math is or could be?
- How does technology relate to the integration of math and making? What should the role of technology be in these experiences?

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