3D Printed Tactile Picture Books as a Pathway into STEM

Introduction/Project Overview

Research Questions: 1) How can informal critical making experiences, focused on the design of 3D printable multimodal books, be organized and implemented in informal library-based learning environments to support diverse students' competencies, motivation and persistence in STEM? 2) What aspects of the Tactile Picture Book Intervention, in informal learning environments, most effectively support students' STEM competencies and dispositions, including: 1) tactile graphicacy, multimodal literacy, and 3D design for diverse learners; (2) fabrication skills; (3) collaboration and innovation; (4) self-efficacy and persistence?

The purpose of this research is to design and evaluate the Tactile Picture Book (TPB) Intervention and further study learning conditions and activities in informal learning environment (libraries in particular) that effectively support students' STEM competencies and dispositions. During formative research (Stangl 2014a; Stangl 2015), my collaborators and I identified that the unique human-centered design task of designing and Making 3D printable tactile pictures is ideal design task for attracting demographically diverse students—with and without visual impairments (VI)— to STEM-focused creative activities, all the while requiring students to develop and integrate a suite of STEM, art and literacy skills and dispositions (including 3D design and fabrication, multimodal composition, agency, persistence, and self-regulation, and collaboration and innovation). This study will involve developing a curriculum through participatory methods with students from the Colorado Center for the Blind, and assessing the design and implementation of the TPB Intervention across four library sites with middle and high school students, and community mentors.

Background/Theoretical Framework/Literature Review

The identification of the TPB intervention occurred while working with people with VI and their caregivers, and subsequently while working with a middle school design and technology teacher and his students. We learned that while the opportunity to read and talk about picture books is essential to all children's reading development, there is dearth of accessible multimodal (i.e., featuring tactile or audio features) materials available for children with VI. Tactile pictures consist of tactile representations that convey different kinds of messages and present information through the sense of touch to further a child's cognitive-affective and relational development (Claudet, P. 2009). We identified that emerging digital fabrication, namely 3D printing, laser cutting, and other maker-focused technologies, provide a valuable opportunity to rapidly expand the sparse supply of accessible learning materials for children with diverse learning needs (Stangl, 2014b), while providing meaningful educational experiences (Stangl, 2015).

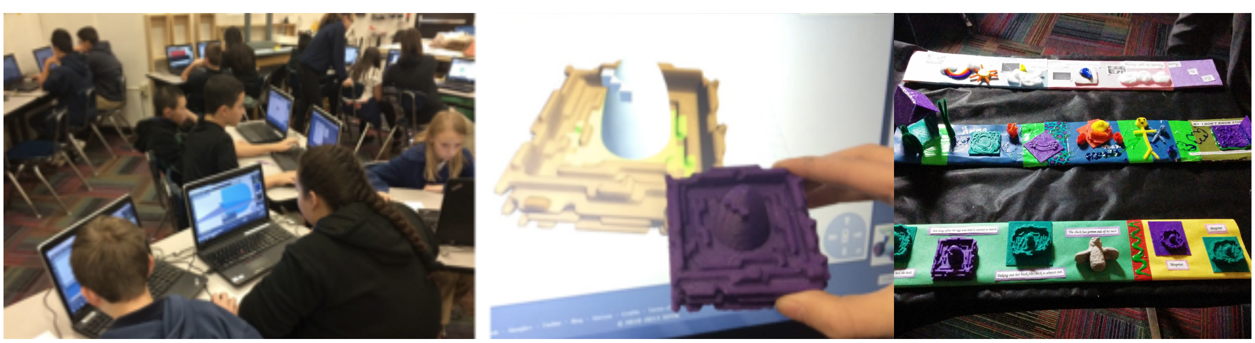

Figure 1. (Left to Right) Students in formative research studies working on 3D tactile pictures after creating clay models; a 3D rendered and printed model of a cracked egg; a collection of completed tactile story boards.

Making activities have potential to engage youth in compelling, creative investigations, develop the STEM workforce by building creative problem-solving skills and positive STEM identities, and broaden participation in STEM fields (Martin & Dixon 2013; Vossoughi & Bevan 2014; Martin 2015). Although publications on making are sparse, there is evidence that making supports students to develop confidence and persistence, demonstrate improved problem solving and creative thinking skills, and develop new ways of viewing themselves and their STEM capacities (Dorph & Cannady 2013; Bowler 2014; Vossoughi & Bevan 2014; Martin 2015).

In order to facilitate TPB-focused learning experiences for young makers we developed a theoretical framework grounded in four key principles from the project-based learning literature: constructionism, critical making, universal design and learning, and studio-based instruction.

Constructionism. Much of the emerging research in "educational fabrication" and "fabrication and learning" is based on the learning theory of constructionism, in which students learn through participation in project-based learning where they make connections between different ideas and areas of knowledge facilitated by coaching rather than by lectures or step-by-step guidance (Papert & Harel 1991). Constructionism holds that learning can happen most effectively when people are active in making tangible objects in the real world.

Critical Making (CM) highlights the use of material forms of engagement with technologies to supplement and extend critical reflection and, in doing so, to reconnect our lived experiences with technologies to social and conceptual critique (Ratto 2011). Critical making includes hands-on productive activities that link digital technologies to society, and serves to bridge the gap between creative physical and conceptual exploration.

Universal Design and Learning (UDL*)* (Rose & Meyer 2002; Dalton & Proctor, 2008) is both a set of values and design principles advocating inclusive design through the provision of multiple means of representation, expression and engagement. UDL focuses on ensuring that materials are accessible.

Studio-Based Instruction/Learning (SBL) organizes activities around a complex, open-ended assignment, in which instructors provide formal and informal critique, impose appropriate design constraints, and guide students to use a variety of design media, and students have opportunities to critique peers' works-in-progress (Kuhn 2001, Schnittka 2012). SBL is reflective, design-centered and fosters learning habits needed to discover, apply and share knowledge (Boyer and Mitgang 1996; Schnittka 2012).

Students make tangible objects (constructionism), collaboratively and with end-user input and a societal impact in mind (critical making), designed for children with VI (universal design and learning) in a library makerspace, where literacy and STEM interests align seamlessly (studio-based learning). In addition to this framework, the TPB design task provides an opportunity to focus on skill development of multimodal literacies and 3D design, and social emotional design skills.

Multimodal Literacy: The integral aesthetic and storytelling components associated with the design task may serve to lower the barrier for participation and attract and retain more diverse participants (Kuchment 2014; Vossoughi & Bevan 2014). Research on multimodal composition suggests the positive impact on students' engagement and identity, as well providing evidence of their complex design of multimodal narratives (Smith, 2014; Dalton 2015). We will leverage research on multimodal composition instruction, and 3D modeling and printing fabrication instruction (Thornburg 2014; Buehler 2015; Stangl 2015), so that students learn to manipulate modal expression to create a unified, engaging story, and make universal design decisions throughout their work. We anticipate that this will enhance their success as designers and motivation to engage in STEM work.

Strategies to encourage students to engage in tactile design include the selection of contextual examples, providing multiple versions of graphics representing similar concepts, prompting students to think of the merits of different formats, and providing opportunities for students to gain their own hands on experience with designing (Aldrich 2000). Another key innovation is our expansion from an emphasis on the mode of touch (e.g., line, shape, position, size, texture) to include a soundscape. The soundscape may include sound effects, music, narration and dialogue that are accessed through micro-processors on the tactile object. Research suggests that children enjoy interacting with sound enhancements, and that comprehension improves when sound reinforces a story's meaning (Zucker 2009) Students also enjoy composing soundscapes, heightening their engagement in expressing their story (Smith 2014, Dalton 2015).

<u>3D Design for Diverse Learners</u>: To learn to use 3D digital fabrication technologies, participants need to engage in learning from the design process, which includes math and spatial reasoning (e.g., navigating and designing in a 3D environment, scale, ratio, rotating, etc.). They also engage in learning from the fabrication process (e.g., machine operation, slicing a model into smaller parts, designing supports, re-orienting the model for better support), and the science behind the process (additive processes, slicing, G-code). Research on 3D digital fabrication in learning environments has focused on best practices for teaching 3D modeling and printing (Buehler 2015), and how to integrate engineering design principles and fabricated materials into math and science education (Berry 2010; Tillman 2011). Our research is focused on how to integrate learning of digital fabrication through multimodal literacy development and critically thinking about universal design.

<u>Technical and Social Emotional Design Skills:</u> As a fundamental part of his social cognitive theory, Bandura (1986) posited that unless people believe they can produce desired outcomes they have little incentive to act. Individual characteristics and experiences associated with STEM-related activities shape the development of self-efficacy, interests, task values, and long term life goals, which in turn, influence educational and career choices in STEM and non-STEM fields (Eccles 1993) The challenge is to design environments in which learners develop agency. Bandura (2001) highlights the role of agency in the self regulation of learning: "The core features of agency enable people to play a part in their self development, adaptation, and self-renewal with changing times." Students with a strong sense of agency are strategic, self-monitor and problems solve, and persist in the face of challenge. We will observe how students collaborate, gain self-efficacy and persist in their work. We will look for instances where participants make informed choices, set goals, and reflect on personal and collaborative processes.

Study Design and Methods

There are great opportunities to evaluate this theoretical framework and the anticipated skill development in a range of learning environments, albeit for the purposes of this research we intend to work within public library makerspaces. Among informal learning institutions, public libraries play a unique and important role in expanding access to information, services and technology. Public libraries, founded on principles of equity, access, opportunity, openness and participation, have historically been public centers supporting social transformation (Wong 2013; Garmer 2014). Over the past decade, new technologies have sparked a profound shift in the services they provide: physical centers that once mainly circulated books have evolved into dynamic community hubs, expanding access to information and technology, and providing a path to economic opportunity, particularly for disadvantaged populations (Hartman 2011; Garmer 2014). Libraries continue to transform as they redefine their role as a trusted community resource with the potential to support learning, creativity and innovation (IMLS 2009; Garmer 2014).

Participant Recruitment and Selection: We have identified four potential partner high schools (Colorado Center for the Blind, Centaurus, Northglenn, and Boulder High Schools) and their students with advanced technical skills to be mentors during the TPBP programs. We selected high school partners based on: presence of a STEM/Engineering/Technology program, potential to impact underrepresented students (including students with VI, girls, Hispanic and African American students, and socioeconomically disadvantaged students), and proximity to one of our library partners. Furthermore, we have identified four potential partner libraries (Anythink Libraries, Mamie Doud Eisenhower, Lafayette, and Boulder), to include a diversity of Makerspace facilities and formats, varying levels of experience in facilitating STEM activities, potential to reach underserved audiences, and existing connections to local Maker communities. All sites are located within 45 minutes of Boulder, to facilitate frequent in-person interactions.

Preliminary Participatory Curriculum Design: To develop the TPBP curriculum, we will conduct participatory design sessions at the Colorado Center for the Blind (CCB) with students with VI and artist Ann Cunningham. Students who participate in the design sessions will receive training to enhance their tactile literacy, create tactile pictures, help develop activities for the curriculum and provide feedback about the workshop structure. They will also gain experience in 3D modeling and emerging technologies. Analysis of the data will result in the development of a framework for evaluating multimodal experiences involving tactile pictures and sound, as well as a refining the curriculum that will be used at four library sites.

Library Workshop Facilitation: We will implement and research the curriculum delivered in two formats at local libraries: (1) a multi-week class, structured around studio-based instruction. Students will be guided through introductory hands-on activities that help them explore designing for tactile and auditory experiences, story transcription (decoding, abstraction, alliterations of narrative and image), 3D-modeling and prototyping (model refinement and test printing) and final fabrication and testing (at the Anythink and Mamie Doud Makerspaces); (2) a series of modular workshops based on the same themes as the multi-week class but delivered in a more flexible, stand-alone format (suitable for drop-in Makerspaces). In both of these formats, we will introduce students to the belief that designing for diversity benefits society as a whole, not just individuals. Students with and without VI will work together to learn about multimodal story design and fabrication while experimenting with multiple forms of expression in their own work. As students transcribe and compose stories, experiment with 3D modeling, and design with sound, they will consider the user's potential affective and cognitive engagement with the book (e.g., how will the story appeal to children at this age? Will they understand a particular shape?). Students will consider how various modes of touch, color/contrast, and sound work together in a multimodal ensemble to express a story (plot, character, setting, theme), iterate upon their work, share design challenges and solutions, and reflect on how they are pursuing their vision through their design.

Data Collection: We will use a variety of methods to observe and analyze participants' learning during each of the workshops, according to the research questions and anticipated areas of learning. Observations will be made using field notes and analytical memos for post analysis. Throughout the course of each implementation, video will be recorded and analyzed for how the curriculum task structure is amended, including: how participants respond to the studio-based activities designed to support their critical making (human-centered design approach, appreciation for diversity, and systems thinking); their engagement in multimodal design and digital fabrication activities; how participants use and adapt the space and equipment. We will collect observations about how participants, facilitators, and high school and professional mentors participate in activities and the roles and responsibilities they take on, and their discursive practices. After each workshop we will identify patterns and themes, the participant structures and the associated discourse. To collect data about the variation of the TPB

Intervention at each library site, we will meet with library directors, High School Mentors and mentors to make adjustments to the instructional model based on each site's requirements, including hours of operation and program structure, spatial qualities, equipment available, the number of and accommodations needed, participant enrollment, personnel involved in the facilitation, and other emergent factors.

Data Analysis: To understand the outcomes of the proposed intervention on the variation of the intervention at the different sites and participants learning, we use a design-based research implementation plan (DBIR). Using the DBIR approach will allow us to actively refine and iterate the curriculum based on incremental observations about participants' learning and engagement, and identify the variation required for implementing the intervention in differing informal library Makerspaces. At the end of each design TPBP workshop and series, we will analyze the observations to make and account for adjustments. In advance of data collection, we will obtain IRB consent and collect parental assent forms (in English or Spanish). Demographic data (gender, free/reduced lunch, race/ethnicity, parental education levels) will be collected as part of the application survey.

Timeline

	June-Aug. 2016	Sept.-Dec. 2016	Jan.-March 2017	April-May 2017
File IRB Amendment	X			
Curriculum Design	X			
Data Collection Design (Pre/Post Surveys)	X	X		
Conduct PD Workshop for Libraries		X		
Analysis of PD Workshops		X	X	
TPB Making at 4 Libraries			X	
Analysis TPB Making at 4 Libraries			X	
Reporting			X	X

Outcomes

This research aims to advance the STEM education field with new knowledge about the factors influencing the efficacy of critical making in informal learning environments and strategies for broadening participation in STEM, particularly among students with VI. The foreseen impact of this work rests in the development and dissemination of a scaffolded maker curriculum that attends to students' design and technical skills and social emotional skills that are especially important in STEM (e.g., collaboration, agency, persistence, and appreciation for diversity). The iterative curriculum design process will produce an effective, adaptable model for conducting critical making activities in library Makerspaces and beyond. Based on our prior work, we anticipate that the TPB Intervention will attract and engage a diverse group of learners, including students with VI, girls, and other underrepresented minorities. We predict that the nature of the design task will sustain students' interest, resulting in repeat attendance at TPB workshops and multiple iterations of 3D printed products. Furthermore, the findings will lay the foundation for establishing the infrastructure necessary to distribute high-quality, validated 3D designs of accessible tactile pictures for cost-effective fabrication of 3D printed multimodal books for diverse learners.

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