Art Education

ISSN: 0004-3125 (Print) 2325-5161 (Online) Journal homepage: https://www.tandfonline.com/loi/uare20

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To cite this article: Aaron D. Knochel, Wen-Hsia Hsiao & Alyssa Pittenger (2018) Touching to See: Tactile Learning, Assistive Technologies, and 3-D Printing, Art Education, 71:3, 7-13, DOI: 10.1080/00043125.2018.1436320

To link to this article: https://doi.org/10.1080/00043125.2018.1436320

TOUCHING TO SEE:

Tactile Learning, Assistive Technologies, and 3-D Printing

Aaron D. Knochel, Wen-Hsia Hsiao, and Alyssa Pittenger

ART AND DESIGN EDUCATION IS MOST VITAL WHEN REALIZED AS A WORLD REIMAGINED. There is an important opportunity to reimagine our world when embracing the learning styles and abilities of all that participate. We share a set of projects that focus on the transformative potentials for assistive technology (AT) in the form of tactile graphics. According to the Assistive Technology Industry Association (2017), AT is "any item, piece of equipment, software program, or product system that is used to increase, maintain, or improve the functional capabilities of persons with disabilities" (para. 3).

In the following, we present early research in using 3-D printing to develop tactile experiences to improve understanding and enable broader aesthetic participation in arts learning contexts for all learners that would benefit from tactility and in particular those with low vision. Our exploration of 3-D printing to create AT in the arts learning space explores both the opportunities a digital fabrication workflow offers in creating curricular resources and reflects on how our senses comingle in understanding the world around us offering insights in how we touch to see.

Our hope in presenting these early outcomes is to motivate innovations in arts pedagogy, increase capacity within our field to realize daring curricular design through digital fabrication, and increase access to the visual arts curriculum for all learners through tactility.

Accessibility is a right regulated by federal law, but more importantly it is an *a priori* understanding that learning happens in designed environments. If curriculum does not meet the needs of its participants, this is an indictment of the learning design and not the learner. Accessibility, as an issue of design, has been advanced through the concept of universal design (UD).

Coined by architect Ron Mace, UD is "designing all products and the built environment to be aesthetic and usable to the greatest extent possible by everyone, regardless of their age, ability, or status in life" (Center for Universal Design, 2008, para. 3). UD as a framework for designing access made its first real impact in urban planning and architectural designs that emerged in the 1960s for people with physical disabilities (Institute for Human Centered Design, 2016), but the issue of access has been significantly empowered as a civil right most notably through The Americans with Disabilities Act (ADA) of 1990. The ADA, along with the Individuals with Disabilities Education Act (IDEA) of 1990, ensures that all learners, ages 5–21, have free and appropriate public education tailored to the needs of learners.

ADA and IDEA, as federal legislation, assures accessibility is central to the mission of public education in the United States. Internationally, issues of accessibility and the civil rights of people with disabilities have been engaged in the United Nations treaty, The Convention on the Rights of Persons with Disabilities (2006), intended to protect the rights and dignity of persons with disabilities. Unfortunately, the U.S. Congress has yet to ratify this treaty.

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Universal Design for Learning (UDL) is a flexible framework of goals, methods, materials, and assessments that envision curriculum as highly customizable from its very inception making accommodations applied after-the-fact unnecessary. UDL is guided by three core principles to provide multiple means of: (1) representation, (2) action and expression, and (3) engagement (National Center on Universal Design for Learning, 2012). The UDL model is informed by educational research and neuroscience as to how the brain learns, but also by the use of technology to gather data about learning to develop systems that are more accessible through modularity.

The close relationship between AT and UDL can be perceived through one of its leading organizations the Center for Applied Special Technology (CAST). CAST began in 1984 with a focus on how emerging desktop computer technologies such as the Apple Macintosh computer could enhance learning for students with learning disabilities (CAST, n.d.). Learning, cutting edge technology, and accessibility have been interrelated from the very beginning of UDL.

3-D Printing as Assistive Technology

In the fall of 2015, Knochel, an assistant professor of Art Education in the Penn State School of Visual Arts, joined a working group comprised of faculty and instructional designers interested in opportunities for 3-D printing as AT. Knochel's (2016) previous work explored participatory design communities and do-it-yourself prosthetics, and he was eager to find further expression to digital design and fabrication that could impact what it means to be an artist, maker, and teacher. Members of the working group began to explore using 3-D printing to make tactile graphics to support learning.

Tactile graphics can be traced back to the origin of braille, one of the earliest AT. Invented by Louis Braille in 1829, braille is a translation of letterforms into embossed dot patterns that can be felt through the fingertips. Use of braille has seen some decline due to technologies such as screen readers and other audio/voice recognition devices, but braille is still an important tactile language system. However, tactile graphics, like all graphics, can show something beyond textual description. Tactile graphics, such as graphics-specific embossers and fusers that utilize a special microcapsule paper that "puffs" up, provide a raised surface employed to communicate images and diagrams. Tactile graphics utilizing embossing printers and microcapsule paper technologies are effective, but the printers themselves are costly and use software that is difficult to maintain and update. There is a great deal of specialization and ingenuity evident in this equipment, but new solutions come to market slowly due to economies of scale problems.

While issues of availability and cost are not automatically solved by introducing 3-D printers, Knochel was intrigued by art curriculum design that is accessible through the very materials that aid in students' apprehension of cultural data. What does it mean for pedagogy and visual arts curricula to question the very centrality of visual transmission in the learning process? As visual arts educators, how could we think about seeing without sight?

As a result, Knochel became involved in several projects exploring tactile graphics and 3-D printing. He involved art education students in developing tactile graphics for online courses, mentored a graduate student exploring the development of tactile graphics for visitors in art museums, and conducted user testing to determine best practices for creating 3-D printed tactiles in relation to cultural data. The following showcases two of these experiences: (1) Art Education graduate student Alyssa Pittenger discusses her development of tactile graphics to accompany a slideshow that would be given in an online linguistics course, and (2) Art Education doctoral candidate Wen-Hsia Hsiao discusses her use of 3-D scanning and printing to augment the experiences of the collection at the Palmer Museum of Art in University Park, PA.

Alyssa Pittenger's Research: Tactile Graphics in Online Environments

In a spring 2016 course focused on integrating technology in art education, students were assigned a slide presentation from an undergraduate online linguistics course and charged with making it accessible to students with visual impairments. In order to achieve this goal, Pittenger translated images from the slideshow into 3-D printed tactile graphics to provide tactile access to learners.

Too often in public school programs for students with disabilities reinforce the inaccessibility, both physically and mentally, of curriculum (Wexler, 2009, 2012). 3-D printed tactiles may provide opportunities to bridge the gap for students with a range of disabilities. "3D printing has really paved the way for assistive design over the last few years by offering complete customization and precision to change the lives of those in need" (para. 2), states Laura Griffiths (2014), assistant editor for *TCT Magazine*, a 3-D printing industry publication. Exploring the boundaries of 3-D printing as AT may improve learning for all students.

Pittenger started by reviewing the images in the slideshow and experimenting with different software approaches to create a stereolithographic (STL) file. STL files capture 3-D data and are used to prepare 3-D prints. Pittenger hit roadblocks translating the visual information not being familiar with common standards or strategies for creating tactile graphics. Tactile graphics are "images that are designed to be touched rather than looked at" and they do not include "color, embellishment, and artistic additions" that are expected by visual readers (Hasty, n.d.). It was also important to note that a student must have experience and knowledge with basic tactual perceptual skills and spatial orientation for any tactile graphic to hold meaning (Hasty, n.d.).

Pittenger found that analyzing an image for generating tactile graphics raises important questions when designing accessible curricula. For example, her assigned slideshow had an image of a corgi. Her first thought was how fun it would be to create a 3-D model of a dog that could aid non-sighted students, but how could she create such a complex object with her novice 3-D modeling skills? Manager of Accessibility Programs at National Federation of the Blind Clara Van Gerven (2015) advises, "don't reinvent the wheel" (para. 4). Van Gerven recommends using sources like Thingiverse or LibraryLyna for searching for existing 3-D models that can be formatted for 3-D printing. However, as Pittenger added braille to a model that she found on Thingiverse (see Figure 1), she began questioning the approach: how was the corgi image adding to the educational impact of the slide? According to the guidelines for tactile graphics developed by the American Printing House for the Blind (1997), if the graphic does not convey essential content it should be omitted. Evaluating content necessity is an important lesson for instructors to consider when adding visual media to instructional material.

Another consideration important to designing tactile graphics is understanding what to add or omit when translating an image into a tactile graphic. For example, using both braille and the English alphabet for labeling enables those that read braille and English letterforms. Including both also allows sighted peers to identify and read the words when working collaboratively. As UDL core principles suggest, it is important that teachers provide multiple ways of accessing content in consideration that all learners comprehend content forms differently.

Another consideration for creating tactile graphics is simplification. For example, Pittenger translated the Incipit of the Gospel of Mathew located in the Lindisfarne Gospels from the 8th century into a tactile graphic (Figure 2). Using guidelines for design recommended by the American Printing House for the Blind (1997), she reduced clutter to better distinguish lines and symbols. She omitted details by editing the image in Pixlr, a free online graphics editor, so that the final tactile object would better illustrate the large letterform that dominates the composition of the 8th-century manuscript (Figure 3).

Once she finished erasing, Pittenger enhanced the colors of the image by increasing the contrast values to make design elements more distinct. After converting to SVG[2] (Figure 4), she was able to import the file into Tinkercad, a free, browser-based, 3-D design and modeling tool. She added a platform so that the tactile would be easier to handle (Figure 5).

After 3-D printing the final design, Pittenger felt the tactile graphic was successful in illustrating the dominant design elements of 8th-century script. The more Pittenger explored and worked through designing 3-D prints as tactile graphics, she became a strong believer that such objects could make curriculum more inviting for all learners, in particular those with visual impairments. From designing replicas of artworks for students to see through touch to creating simple shapes or objects that could be used as inspiration for freehand drawing, 3-D printed tactile graphics could enhance student experiences in the art learning space.

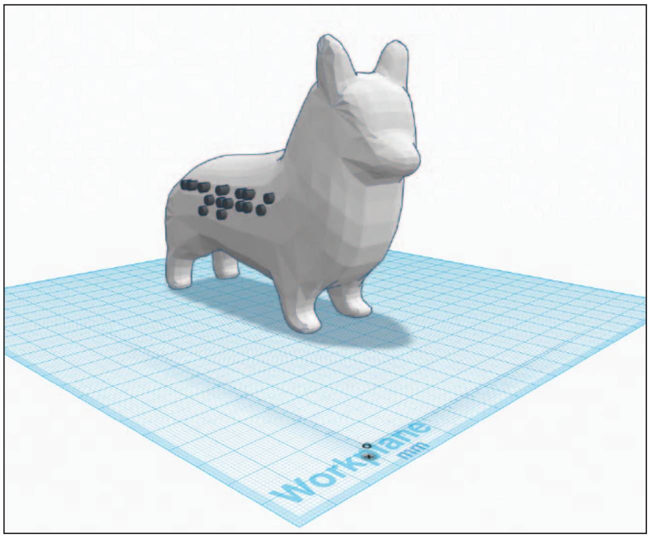

Figure 1. Remix including braille of the 3-D model corgi. Original 3-D model by Isaac Dirksen shared under Creative Commons on Thingiverse.

Figure 2. The Incipit of the Gospel of Matthew in the Lindisfarne Gospels. Original image file is public domain and can be found in the Wikimedia Commons.[1]

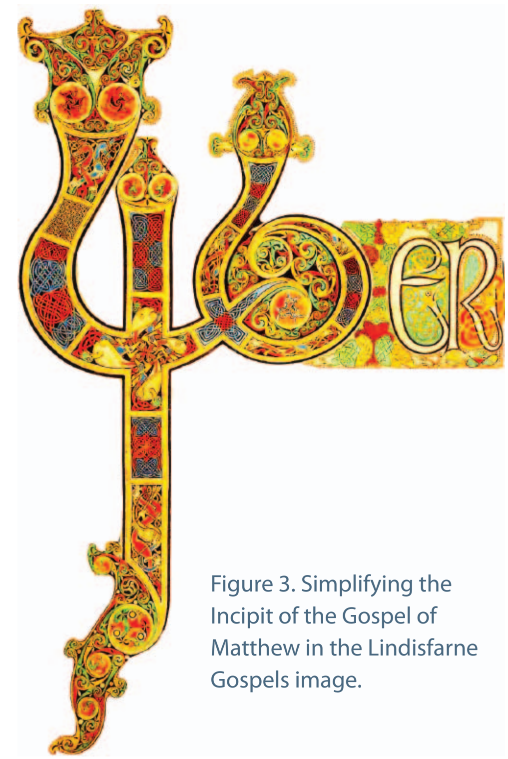

Figure 3. Simplifying the Incipit of the Gospel of Matthew in the Lindisfarne Gospels image.

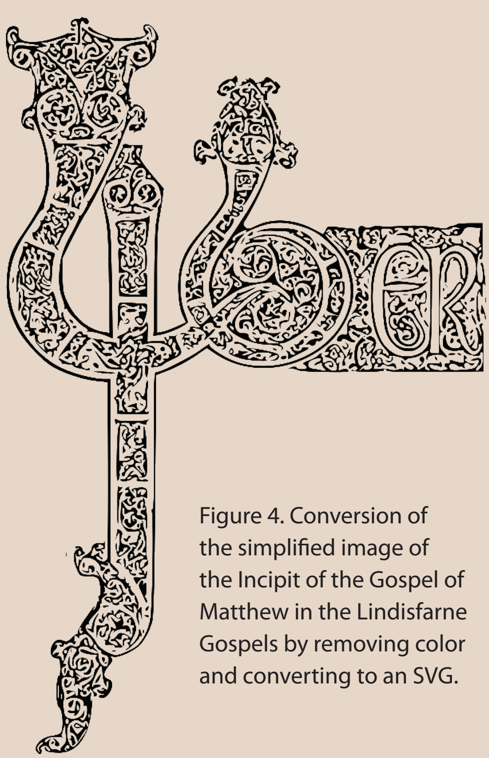

Figure 4. Conversion of the simplified image of the Incipit of the Gospel of Matthew in the Lindisfarne Gospels by removing color and converting to an SVG.

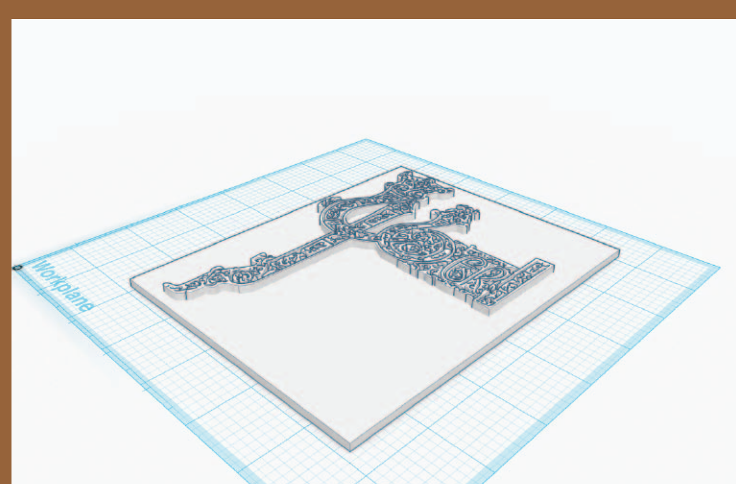

Figure 5. Image of the Incipit of the Gospel of Matthew in the Lindisfarne Gospels as 3-D model designed in Tinkercad.

Wen-Hsia Hsiao's Research: Tactile Learning in the Art Museum

Wen-Hsia Hsiao is a PhD candidate in Art Education with an interest in art museum education. She had prior experience interning at an art museum, where she helped install exhibitions of works by artists with disabilities and assisted persons with disabilities to participate in educational programs through interactive gallery tours and artmaking activities. These experiences caused her to question how art museums respond to the needs of learners with disabilities and how to enhance accessibility in art museums.

Many collections in art museums are two-dimensional artifacts (e.g., paintings, graphics, and photography) or are placed in glass cases for safety, security, and conservation purposes. These strategies are necessary but create barriers making it difficult for learners with visual impairments to experience collections. Museums have started to explore 3-D printing and scanning technologies to help provide a more meaningful experience with collections, such as the Smithsonian Institution, the Metropolitan Museum of Art, and the British Museum, among others (Hancock, 2015). Hsiao is interested in how art museums can improve the experiences of learners with visual impairments through tactile experiences by providing reproductions, touching objects, and tactile books.

As 3-D printing technology evolves, it creates new opportunities for teaching and learning and may support learning in art museums (Lipson & Kurman, 2013). In view of this new frontier, Hsiao began exploring 3-D scanning and printing as tactile learning for museum visitors with visual impairments at the Palmer Museum of Art in University Park, PA. Her investigation explores potential strategies for providing greater access to and in-depth sensory experiences of museum collections.

When learning, tactile information is essential for those with visual impairments (Downing & Chen, 2003), but often learning in museums depends on visual and verbal descriptions with limited hands-on experiences. Using 3-D scanning and printing may provide an option for people with visual impairments to hold a 3-D printed replica in their hands, helping them to have an experience with the work of art. In *A Natural History of the Senses*,

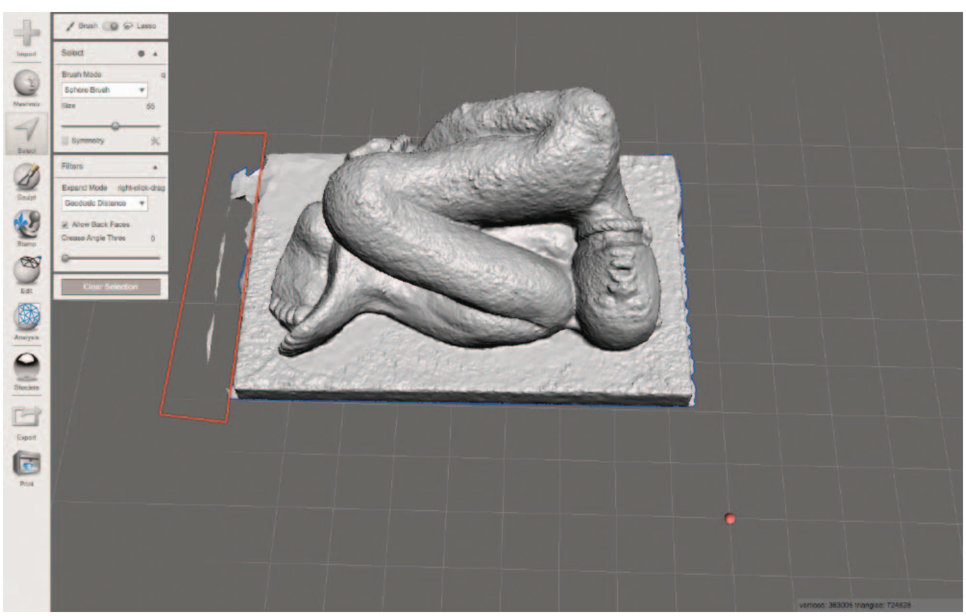

Figure 6. Using Meshmixer to remove unnecessary parts captured in the original photogrammetric scan.

Figure 7. Comparison of the sculpture and the 3-D print: (L-R) Seymour Lipton's sculpture *Lynched* (14 × 24 × 17 in.). 3-D print of sculpture (2.4 × 1.5 × 1.2 in.).

Provocations to a discipline organized around sight requires us to consider the non-sighted learner.

Ackerman (1991) argues that the enrichment of touch offers people a way to visualize the physicality of objects. Based on our remembered experience of touch, Ackerman asserts that what we see is processed in terms of the sense of touch. Seeing evokes our experience of touch. Given that seeing, and thereby touch, is so important to understand art, 3-D scanning and printing may offer an opportunity to capture the form of artworks, although with limitations related to texture and scale.

To begin her exploration, Hsiao produced small-scale replicas of sculptures using two kinds of 3-D modeling software: Autodesk 123D Catch (hereafter 123D Catch) and Meshmixer. 123D Catch is a digital photogrammetric software that uses multiple photographs of an object to produce a 3-D model that can be processed into a 3-D print. Meshmixer is a 3-D modeling software used for manipulating triangular meshes that construct the 3-D surface of the digital modeled form. Hsiao first downloaded 123D Catch, a free smartphone app, to take photos to produce a 3-D model. Hsiao took about 20 to 40 photos, each from different angles, of each sculpture. The sculptures were selected due to their availability in the galleries without a glass encasement and freestanding so that photos could be taken from multiple angles. The photogrammetric process was time consuming, and not all of the selections could be processed successfully. In total, Hsiao completed five different 3-D printed models of existing pieces: Seymour Lipton's sculpture *Lynched* (1933) and *Argosy* (1946-48), John Flannagan's sculpture *Mother and Son I* (1926), Henry Dexter's sculpture *Henry Wadsworth Longfellow* (1868), and the lion paw in the front of the museum by sculptor Paul Bowden.

After scanning, Hsiao edited and repaired these 3-D scans using Meshmixer. Through Meshmixer, she deleted backgrounds surrounding the sculptures and repaired some parts of them (see Figure 6). Then, she adjusted the size for each object so that they could be held in the patrons' hands (Figure 7).

Hsiao's creation of 3-D printed replicas of sculptures such as Lipton's, involved technical problem solving, but also attempted to create workflows educators can use to meet the needs of all learners

Figure 8. Comparison of a painting and 3-D print. Left: Jerome Paul Witkin's painting *Jeff Davies* (78 × 48 in.). Right: 3-D print of painting (3.3 × 2.2 in.).

through tactility. These workflows present certain constraints such as the quality of 3-D printed replicas, the interpretive implications of presenting the works at a different scale and material, and the possibility of copyright infringement because current copyright laws do not account for the capabilities of 3-D printing.

To further explore the possibilities of these 3-D printed scale models as tactile learning tools, Hsiao chose a 2-D painting to translate into 3-D print. She selected Jerome Witkin's painting *Jeff Davies* (1980) (Figure 8). Paintings, as flat objects, are difficult to translate as tactiles and so its impact is unclear. Certainly, there are opportunities to learn about composition through the tactile graphic, but the qualities of light, illusions of spatial depth, and even perceived textures in the painting are lost.

3-D printing as AT can play an important role in supporting teaching and learning sculptural objects through 3-D scanning by providing new options for people with visual impairments to experience museum collections. 3-D printed replicas can be printed and shared, which provides a promising strategy for museum engagement.

There are still problems with this alternative strategy: the resulting printed replicas often lack surface qualities similar to the original and are highly dependent on the quality of the scan. Despite these problems, the widely available software and scanning tools used to produce these models do enable a broader array of museum educators to explore how these technologies impact access. Museum educators exploring tactile learning using 3-D printing and scanning in the context of their own collections may increase pathways to engage a wider array of museum visitors.

Conclusion

We have presented the early stages of our exploration of 3-D printing as AT in arts learning to showcase how educators and curriculum designers may augment UDL practices with 3-D printing. Although our work is still in development, we offer these examples as provocations for art educators to question their curricular and pedagogical practices for the ways that these methods create or hinder accessibility in arts learning spaces. We recommend for consideration UDL's three core principles (National Center on Universal Design for Learning, 2012) as guidelines to positively impact all learners. Additionally, technology, from braille to 3-D printing, can introduce UDL and AT in art education by asking new questions.

Questions concerning the centrality of visual transmission in pedagogy and visual arts curricula may provide important opportunities to reflect on our field and our own assumptions about all learners in art education. Provocations to a discipline organized around sight requires us to consider the non-sighted learner and explore what it means to prepare a future art teacher. The increasing availability of 3-D printing creates a broader set of resources available to the curriculum designer. UDL and AT create a radical project of inclusion that should encompass the power of the visual arts, and further research is needed to explore the use of tactile graphics in art education to reimagine our curricula and learning spaces. ■

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Endnotes

[1] https://commons.wikimedia.org/wiki/File:LindisfarneFol27r IncipitMatt.jpg

[2] Using the website http://picsvg.com.