Using 3D Printing to Enhance Understanding and Engagement with Young Audiences: Lessons from Workshops in a Museum

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Abstract

This paper details findings from a collaborative research project that studied children learning to 3D print in a museum, and provides an overview of the study design to improve related future programs. We assessed young visitors' capacity to grasp the technical specificities of 3D printing, as well as their engagement with the cultural history of shoemaking through the museum's collection. Combining the museum's existing pedagogical resources with hands-on technology experiences designed by Semaphore researchers, this study enabled both researchers and museum education staff to evaluate the use of 3D-driven curriculum and engagement materials designed for children visiting cultural heritage museums. This study raises critical questions regarding the practicality of deploying 3D media to engage young learners in museums, and this paper illuminates the challenges in developing models for children to put historical and contextual information into practice.

Introduction

Children increasingly access museum content through digitally-mediated experiences. While most museums rely on exhibition and engagement strategies that prominently feature visual displays and didactic panels, new approaches that introduce interactive and immersive digital technologies promise to engage new audiences and facilitate novel pedagogical outcomes (Dlodo and Beyers 2009; Eisenberg 2013; Posch and Fitzpatrick 2012). These approaches have, for the most part, been developed across diverse, interdisciplinary research areas ranging from learning sciences to experience and interpretation design. They often rely upon unique or bespoke partnerships with digital manufacturers, content producers, and academic researchers. Despite a growing amount of hyperbole (and critique) around the educational value of 3D technologies in museum contexts (Sportun, 2014; Younan and Treadaway, 2015), the strategies used to engage children with these technologies have received little formal evaluation outside of a handful of early studies in the domain of informal learning (Brahms and Werner, 2013; Wang 2014). Consequently, there is a scarcity of research that addresses how museums can fruitfully engage younger audiences in cultural programming through the use of emerging 3D technologies.

This paper documents a collaboration between the Bata Shoe Museum in Toronto, Canada, and researchers from the Semaphore Research Cluster on Inclusive Design in Mobile and Pervasive Computing, which is part of the Faculty of Information at the University of Toronto [1]. It details findings from research that studied children learning to 3D print in a museum space, and provides an overview of the study design to improve related future programs. The research agenda underlying this collaborative project sought to develop a participatory learning experience based on 3D modeling and printing for children visiting the Bata museum. Through a workshop-based study, we assessed young visitors' capacity to

grasp the technical specificities of 3D printing, as well as their engagement with the cultural history of shoemaking through the museum's collection. Combining the museum's existing pedagogical resources with hands-on technology experiences designed by Semaphore researchers, this study enabled both Semaphore researchers and Bata education staff to evaluate the utility of 3D-driven curriculum and engagement materials designed for children visiting cultural heritage museums. The study raised critical questions regarding the practicality of deploying 3D media to engage young learners in museums. In this paper, we will illuminate various challenges we faced in developing models for children to put historical and contextual information into practice by creating their own 3D printed shoe accessories. Museums use a variety of technologies to engage visitors, and tying museum content to specific interactive technologies from visual media to haptics – is indeed what they, as institutions, do best (Brewster 2001; Feher 1990; Hall and Bannon 2006; Muntean et al., 2015). This short study demonstrated that 3D printing, when used in a directed workshop in concert with dedicated museum pedagogical tools, can support a fruitful learning environment that allows students to connect historical technologies with contemporary ones. This fusion of technical-digital *and* cultural literacies, we suggest, should be an important consideration when designing similar museum-based collaborations. We hope that readers will find the theoretical and practical insights gained from this study useful for their own practices and pedagogies, or possibly find inspiration to develop similar museum-based 3D projects and experiences.

Setting the Stage: Digital Fabrication in Museums

The research project was informed by current work that a) evaluates the capacity for children to learn abstract concepts using digital fabrication technologies and methodologies employed in studies of child-computer interaction (for example: Bekker et al. 2015; Bilkstein 2013; Eisenberg 2013; Iversen et al. 2015) and b) addresses the role of hands-on participatory technologies in museums (Bearman 2011; Jakobsen 2016; Neely and Langer 2013). The intersection of these fields raises a specific question: does the use of digital fabrication technologies (e.g. 3D printing) enable new modes of engagement with museum content? More specifically, our study was interested in understanding how digital fabrication technologies could also simultaneously contribute to cultural or historical literacy – not just technological or digital literacy. Research questions that informed this project included the following. How might cultural heritage museums and galleries incorporate new technologies like digital modeling and 3D printing through hands-on engagements designed specifically for children in ways that support cultural knowledge building? How can these engagements be used to foster literacy about objects in the museum, as well as the technologies that are used to render them digitally? Does physically constructing an artefact in a museum setting lead to a greater understanding of the object's cultural significance? Can children learn more about objects through design processes, and what measures would museums need to be able to assess this?

The recent proliferation of 3D technologies in museums lends our urgency to our questions, even as accounts of 3D technology in museum environments have focused more directly on questions concerning reproduction, authenticity, and engagement for scholars. Such accounts

span a variety of scholarly fields including: art and design (Su and Pirani 2013; Mongeon, 2015), museology and cultural heritage (Anderson et al. 2002; Cabrera et al. 2005; Grün et al. 2004; Short 2015; Sportun, 2014; Neumüller et al. 2014; Wachowiack and Karas 2013), library sciences (Fernandez 2014), architecture and design (Bearman 2011; Nissen and Bowers 2015), education/learning sciences (Bell et al. 2010; Buehler, Kane and Hurst, 2014; Smith et al. 2015), archaeology (Richter et al. 2013), computer science and interaction (Chu et al. 2015; Eisenberg 2007; Hall and Bannon 2006; Ioannides, 2014), and digital humanities (Turkel, 2011). Artists working with 3D media have recognized a plethora of current and future uses for 3D capture and fabrication that engage with questions around prototyping (Sayers, 2015), re-making (Weidenhammer, 2014), materialization (Ratto and Ree, 2012), and, as one paper has recently claimed, how these technologies can resist hegemonic production as a “destructive practice” (Santoso, 2013). Archaeologists in particular have found 3D scanning useful for producing realistic historical reconstructions of objects and places (Grosman 2016; Di Franco, 2015; Forte 2014). Across many disciplines, much of this work has focused on what might be referred to as the “affordances” of digital fabrication technologies for learning environments (Norman 1999), where the specific qualities and context-specific permutations of these technologies might enable the re-creation of objects in 3D or the visualization of multiple layered settings.

Museums and heritage institutions have also begun interrogating the use of digital fabrication technologies from various perspectives, especially concerning the potential uses of these technologies for informal learning. Importantly, museum staff and museology researchers have made important contributions to this literature as they have sought, through a variety of cases, to create standards for 3D scanning and printing of objects (Metallo and Rossi 2011; Solima and Tani 2016; Jakobsen 2016; Steinbach 2011). Some have argued that 3D capture in the museum context is particularly suitable for objects that may be too sensitive to handle, and are thus unable to be displayed, or in cases where touch-based learning is a paramount concern (Neely and Langer 2013; Wood and Latham 2011). Objects in museums produced through 3D capture and replication can potentially be handled by wider publics, research groups, or originating source communities without harming the original objects (Hollinger et al. 2013; Turner 2015). These considerations are necessary for research conducted about material culture in museums, but they do not necessarily speak to how different publics can engage with museum content through digital fabrication-based design practices.

The development and adoption of consumer-grade 3D technologies has opened new opportunities for the development of technical and cultural literacy. Eisenberg (2013) suggests that digital fabrication tools can be an important component of educational engagement that extends from classrooms to informal learning environments. Posch and Fitzpatrick (2012) studied FabLabs to understand how children interact with digital fabrication technologies in a non-school (informal learning) environment. Through observation, the analysis of objects created by the children, and questionnaires, they argued that FabLabs and makerspaces could provide fruitful learning environments for children, and that digital fabrication technologies had the potential to support a child’s technological literacy better than previous screen-based technologies (2012, 500). Recent research into the

design possibilities and utilities of digital fabrication techniques for children suggests that digital fabrication can provide children with a sustained understanding of technology and an ability to exercise creativity in the production new digital materials (Schelhowe 2013). Further, a recent study by Smith et. al., (2015) suggested that researchers and educators should develop educational environments that support motivation and collaboration when working with digital fabrication (2015, 28). As Iverson et. al. (2015) have recently claimed, digital fabrication technologies should foster curiosity, engagement, and motivation for learning among students of all ages.” (2015, 1). But there remains little empirical evidence about children’s access to, and use of, these tools and technologies in a cultural setting, and it is precisely because of this gap that our research study was initiated.

Research Design

As informal learning spaces that frequently encourage active engagement with objects, museums draw on diverse pedagogical programs, including constructionism (Papert and Harel 1991) and experiential learning (Kolb 2014), to engage young visitors. Recent research spanning museum informal learning, interaction design, and computer science has focused on the use of new technologies, from tablet computers to augmented reality to mobile apps, as a means to engage young audiences with cultural or historical information (Taylor et al. 2015). Within this critical nexus of research, design, and technology implementation, our research group recognized an opportunity to engage specifically with 3D technologies in the museum environment. The research project described here began as a SSHRC-funded collaboration between a diverse group of researchers at the Semaphore Research Cluster at the University of Toronto. Our initial goal was to address the efficacy of designing 3D representations of artifacts for use in a variety of museum learning contexts.

We narrowed this goal to focus on objects and processes that might be used in the context of cultural heritage learning. This goal was part of a research mandate around investigating the potential of 3D printing experiences to facilitate participatory learning environments for fostering digital and cultural literacy simultaneously. The research project was organized around workshops featuring 3D design and digital fabrication in order to develop insights into the impact such technologies might have in museum-based informal learning spaces. Rather than focusing exclusively on technical skills and digital literacy, workshops were constructed to encourage children to reflect on cultural knowledge associated with artifacts encountered during their museum visit. Our research team was additionally interested in how different user interfaces affect children’s understanding of the 3D design process, a subject that informs ongoing research in the field of human-computer interaction around the viability of 3D printing as a learning tool for children. A series of four workshops entitled “Footwear Futures: What Will You Make?” were designed in collaboration with educators at the Bata Shoe Museum and subsequently run over the course of several weeks in the Spring of 2015. In total, forty-one participants were assessed over four workshops.

The research project was initially formalized following a visit to the Bata Shoe Museum in which Semaphore researchers digitized several objects from the museum’s collection [Figure 1]. Using a Creaform Go!Scan hand-held structured light scanner, we initially captured and

re-created two test models: a pair of 16th century velvet Chopines [Figure 2] and an Indian Paduka sandal [Figure 3] from the Bata Shoe collection. These digitized models would serve as inspiration for digital artifacts that would be created for the workshop experience. Following this digitization visit, teams from the Bata and Semaphore worked to define both the goals and content of the workshops that were to be held. Additional staff at the Bata were consulted in order to draft a plan that would fit in line with the museum's educational mandate and goals, ultimately resulting in workshops centered on the design of shoe buckles – objects that are small and manageable for children, but also important in footwear history. Youth participants were recruited through a joint effort by Semaphore researchers and Bata staff during the museum's annual spring break programming. The research team set up a 3D printing station in the museum, which included live demonstrations in which children and their parents were encouraged to touch, pick up, and play with a variety of different 3D printed models (including small replicas of the artifacts which had previously been digitized).

Footwear Futures: What will you make?

Workshops were designed around two themes: a historical introduction to shoe buckles and footwear; and an introduction to the methods of design used in 3D printing technologies. The first theme was delivered by Bata staff, and was followed by an initial assessment of participants' ability to understand key historical ideas provided during the introduction. The second part of the workshop involved an introduction to the processes of desktop fabrication and small-scale manufacturing, including an overview of 3D design software and the different 3D printing and manufacturing technologies that might be appropriate for museum contexts. Laptop and tablet-based 3D design technologies were introduced to participants with an explanation that these technologies would help them produce 3D printed take-home objects (in this case, small shoe buckles). Following the design and printing stages of the workshops, interview-based assessments were conducted with individual participants, providing them with an extended opportunity to describe their experiences designing 3D-printable objects. At the end, workshop participants engaged informally with members of our research team as we printed the objects they design. The custom design of these workshops allowed our team to focus on a primary research goal: to assess participants' ability to learn from a brief historical introduction and apply this new knowledge to objects they would design.

Each workshop had 10-11 participants between the ages of 9 and 13. As participants entered the workshop space, parents were debriefed and asked to sign consent forms allowing their children to be interviewed and assessed after the workshop. Participants were given nametags with participant numbers to ensure future anonymity. The room was designed with four separate "stations" arranged according to specific activities: *Design*, *Activity*, *Observation*, and *Assessment*. Design stations were large tables where participants would spend time digitally crafting 3D-printable shoe buckles (using either laptops or tablet devices). Observation stations were designed so that children would have the ability to watch the design and printing processes. Activity stations were designed to occupy participants who had completed tasks, giving them an opportunity to use other applications and design tools to create additional 3D models. Finally, the assessment station was where researchers

interviewed participants about knowledge and skills acquired during the workshop in order to determine whether they a) understood the cultural-historical information provided by the museum and b) whether they understood and used some of the core 3D design concepts that were introduced. Assessments were undertaken in two parts: Assessment A was conducted as a station while other children used, designed, and observed the 3D modeling technologies, and Assessment B was conducted as an exit interview.

As noted, participants were introduced to the history of shoemaking and shoe buckles by the museum's head of education, Sheila Knox [Figure 4]. This presentation focused on a broad survey of shoemaking practices, paying specific attention to how, when, and why shoe buckles were used, as well as to methods for decoration as signs of wealth and power. This enabled the presenter to provide a more detailed object biography of the two artefacts that we had previously digitized. Throughout the presentation, children were invited to touch and play with shoes from the Bata's teaching collection in order to understand the mechanism of shoe buckles.

Following this, a researcher would introduce a large group of participants to a number of core 3D design principles required for rendering printable objects. The first workshop introduced these concepts through a touch screen tablet device interface, while the second workshop used the same design software, but on conventional laptop devices with mouse and keyboard interaction. Participants were then instructed to split into different groups for each of the stations, with four participants at each station.

At the design station, each participant was presented with either a tablet or laptop computer and provided further individual instruction on how to use the 3D modeling system. Each tablet or computer had pre-loaded digital objects available in the 3D design application. A range of possible modification options and additional pre-loaded digital templates were also available [see Figure 5]. Participants were encouraged to use pre-loaded shapes and figures to augment existing objects or create their own unique designs, adhering to digital modeling concepts learned throughout the introduction. Although the objects created were not "true" shoe buckles, given that a functional buckle mechanism would have been too complicated to print in the allotted time, they were designed to be easily affixed to participants' shoes using laces so that they could be worn home [see close up of design, Figure 6]. To be available by the end of each workshop, designs were constrained so that they would be relatively quick to print (in under 20 minutes) on a fleet of Makerbot Replicator printers.

As individual participants designed their own shoe buckles, others engaged with a researcher at the observation station. Here, they were encouraged to note the creativity expressed in designs of shoe buckles created by their peers, to examine 3D printers that were printing already-finished designs, and to examine (and touch) a variety of 3D-printed artifacts provided by the researchers. Additional participants at the activity station were assisted by a researcher to use various 3D capture and design applications (e.g. Autodesk's 123D Catch) that had been pre-installed on tablets.

The last station consisted of an assessment interview that was administered to each child individually. This was a simple A/B recall test where six pairs of images were shown to each participant assessing their understanding of the history of shoe buckles and some of the social context around their design. The first questions assessed participants' ability to recall what they learned in the presentation regarding the use in the past (i.e. what shoe buckles were for) and the past social context (For example, what kinds of individuals might wear them and what kinds of places they might wear them). The second part of the assessment included three pairs of images that assessed whether participants could apply this information to contemporary sartorial contexts using updated examples [Figure 7 and 8].

Finally, all participants were assessed with an exit interview regarding their specific designs and the design principles of 3D printing addressed throughout the experience. The last assessment involved qualitative questioning about the purpose and utility of each participant's design, as well as an A/B assessment using pairs of images of 3D designs where one of the pair exhibited a mistake. For example, in one image a part of the design is "floating" above the object to be printed, a design error that would result in a failed print, while the opposing image depicts a corrected version. Participants were asked which version of the possible print had a mistake (A or B) [Figure 9].

Results

The initial seed of our research grew out of two intertwining questions: Does the construction of an artefact lead to a greater understanding of the artefact's historical and contemporary existence? And can children draw connections to the material history of an artefact through digital design processes? Throughout this research, several additional questions emerged. First, based on the relatively low-cost workshop model, were basic principles of 3D printing and design understood in a way that might be scaleable to other museum contexts? Second, were participants able to replicate principles of historical shoemaking practice within their designs? We were also interested in whether this kind of learning environment (e.g. a digital/3D modeling and fabrication workshop) would be a suitable complement existing museum educational content. Would children be able to connect content from traditional museum didactics (e.g. the historical lecture that preceded the workshops) with novel content created using 3D digital fabrication technologies? Would they, without direct suggestion or encouragement, replicate or reproduce ideas discussed or introduced through the cultural-historical component? This is a crucial question for museums interested in using digital fabrication for educational engagement, and presents a new method of engagement with historical subject matter and object-based learning. Finally, are small workshops like these effective for attracting children and their parents into museum spaces? In other words, can they be leveraged to demonstrate a commitment on the part of the museum toward the use of new technologies for the purpose of audience engagement?

Assessing Museum Learning

All the above questions (save the last) were addressed through the two assessments (noted in the previous section). A total of 32 children were tested through both assessments. To begin, we asked participants to identify if they had seen a 3D printer before, or if they were familiar

with 3D printing technology. Twelve children noted that they were completely new to 3D printing - that they had never used or seen a 3D printer in action. A little more than half of the participants, fifteen children, responded that they had never used a 3D printer, but had seen either pictures or videos of them, or had seen them being used in real life situations. Only four participants had previously used 3D printers, and three of the four children had both designed and printed the objects. These participants had used 3D printers through school field trips or through extracurricular informal learning programs.

Participants were asked a series of eight questions about their knowledge and understanding of the historical introduction to shoe buckles as part of the first assessment. This took place after the children were given a historical overview, but before they had designed and printed their own objects. To encourage a wide range of responses, they were asked broad questions, including: “Why did people wear shoe buckles?” and “Where would they wear them?” A range of answers were recorded, but most fell into three categories: functional (for example, to keep one's shoes on), fashionable (e.g. to be used as fashion accessories), or both. Participants also noted that “rich countries” and “Europe” were most likely the places that individuals would have worn the specific buckles they were introduced to. To the first question, many participants (12) responded with a “functional” answer. When addressing the “fashionable” aspect of shoe buckles, most participants noted that they were simply considered “fashionable” or “stylish” or “fancy”. Some participants, however, could connect the important social aspect of accessorizing with shoe buckles that had been highlighted in the earlier presentation. One participant linked this to the concept of wealth:

*I think it was because maybe it was something that proved that you were a certain level ...like if you didn't really have the proper shoe buckle. Like if it was just leather, you'd be considered poor and if it was diamond then you would be considered rich.
[Maia, 11]*

When presented with two images of historical figures (a farmer and a king) students were asked to identify what person would have most likely worn a pair of jeweled buckles. Participants were here given an opportunity to articulated their understanding of how social status and wealth were connected. For example, one participant explained that the king was “like a hero”:

Because... he thought he was like a hero and he would wanna wear shoe buckles and B, he's just a farmer and he wouldn't have shoe buckles that nice. [Nathaniel, 9]

When asked about what kinds of social situations one might “adorn” themselves with such accessories, participants all identified that a “fancy ball” would be the appropriate venue to wear the shoe buckles:

Well I think “A” Because it looks like they have some pretty expensive jewels on them right? And that daily on the streets like in picture “B”. You would wear a shoe buckle but you wouldn't wear something that expensive like they would get stolen or

something. You'd wear them to like a fancy party to show all your fancy friends how much fancier you were than them. [Zara, 11]

As expected, most participants correctly identified the ways in which shoe buckles were worn in the past. Participants were equally successful in understanding the functionality of the shoe buckles - how they were used on shoes in the place of laces. When shown a pair of images of shoes that were missing shoe buckles, most children correctly identified the pair that needed shoe buckles. Effectively, children were quite capable of discerning the difference between a historical shoe that did not have buckles but needed them for functional purposes (an open flap for example), and shoes that did not have shoe buckles but did not need them. Answers to this particular assessment ranged:

Because here it looks like it's a little flappy so it might fall off. You need a buckle to put it on, to keep it tight. [Charity, 11]

Because they have the straps and they are not being buckled and those ones have buttons so they already have something. [Jonathan, 13]

Some of the responses here were also conflated with the previous lesson on wealth and status. As two participants noted in response to the “buckle, no buckle” question “Which pair is missing a buckle, A or B?”:

A already has those buttons and it's on leather and I just personally think that leather with buckles looks bad. But B has like two crosses on there and I think a buckle would look really nice there. [Rebecca, 11]

Because B it doesn't have any way at all to like - it's only slipping in and like there's a little place where there would be buckles and in A they have buttons. And also in B there's more elegant for the match of the buckles. [Addison, 8]

In order to assess if participants truly understood the historical subject matter (the functional and fashionable qualities of shoe buckles), we also included two assessments to see if participants could apply this knowledge in a modern situation. We showed similar images to the first assessment, but used contemporary images and asked participants to identify what type of environment people would wear shoe buckles in if we wore them today, as well as what sort of person might wear them. In the first case, participants noted that the higher status buckled shoes would be “ruined” at a park, but be suitable for a fancy party because you would want to “show them off.” As a few participants noted:

Because we're even though we're in like, it's more advanced now, but like it's still [...] pretty fancy and maybe more expensive and they wouldn't wear them to a park where they could get ruined. And they would wear them to a party where it's more civilized. [Laurel, 12]

“B” because people would probably wear them to parties and like where they meet with friends and stuff. And not in like places where you could lose them and get them dirty. [Bianca, 10]

We also assessed whether or not participants could apply the knowledge provided in the historical lecture to contemporary people. For this assessment, we asked participants if they could identify which contemporary person might wear the buckles presented. The choice was between a non-recognizable person and a recognizable celebrity - in this case, Taylor Swift. Participants did connect the idea of “celebrity” with a higher status, and were able to identify why someone of this status might use fashion as a status symbol.

“B” because she’s a celebrity...Taylor Swift is a higher status person so you’ll probably see her with jewels and jeweled buckles if we still wear buckles. [Heather, 12]

“B” because she looks really rich and she’s a celebrity and she has lots of money so she can buy fancy buckles. [Charity, 11]

Well I think that “B” would because she’s obviously famous and someone that famous again like I said with the king one, if they don’t keep up their standard people might stop thinking they are the best because they don’t have all the newest things. But “A” wouldn’t probably need to because she’s not as like famous obviously. [Zara, 11]

In this assessment, the authors perhaps underestimated the popularity and specificity with which participants would recognize or understand the celebrity. Answers here did reflect the use of fashion pieces as status symbols for individuals, but some of the answers from participants reflect an understanding of the particular individual’s celebrity status. For example,

As a person who’s a big fan of Taylor Swift I wanna say A but I know that she likes everything glimmery even if it’s painful so probably B. [Alex, 12]

I don’t know. I think “B”. Because like she’s obviously like rich. I don’t even know this person but obviously Taylor Swift has more than this person, has a lot of money, and she’s like really famous and red’s her favourite colour so. [Laurel, 12]

The authors also wanted to see if participants could identify the functional qualities of shoe buckles in a contemporary situation, which participants regularly identified. Again, as noted by the participants:

“B” because it has the fabric fold over again and if the fabric wasn’t shut the shoe would probably fall off. [Grace, 12]

This one I think, B. Because there's this little flap thing that doesn't have a buckle and it probably like flaps around. And then this one, they look like shoes that you just slip on and even if you put a buckle there, the buckle wouldn't have any use. [Bailey, 12]

Although the results are more suggestive than definitive, they strongly indicate that participants were able to recall and apply the historical content provided in the Bata educator's earlier presentation to their knowledge about shoemaking, shoes in society, and shoe buckles in particular.

Assessing Children's Designs

The second assessment was designed to do two things: 1) obtain qualitative and descriptive answers from the participants about their unique objects and the specific design choices they made in creating them and b) to assess whether or not they understood some basic principles of 3D fabrication. These assessments took place *after* the children had designed their shoe buckles. The first questions were oriented towards children's previous experiences with 3D printing, and they were prompted with the question: "What did you make?" Further questions were designed to elicit responses about the general affordances of 3D printers and the design process, such as "What can 3D printers make?" and "What Can't they make?" Participants were also asked what kinds of things they might print if they had a 3D printer at home. Finally, (as noted above) A/B recall tests were used a second time as a means to assess whether participants could "find the mistakes" in several 3D designs. These "mistakes" all reflected specific 3D design and fabrication principles: disconnected objects, obscured holes and gaps (which, together with disconnected objects, are referred to as *non-manifold* objects in the 3D printing world), and objects that would require additional material to support overhanging features.

In these assessments, participants were able to identify mistakes nearly 100% of the time. In rare (two) cases, participants refrained from answering. In three cases, participants were unable to correctly identify the mistake within the image, although they were not all able to identify *why*. In one example, when asked which design had a "mistake" (a part of the shoe buckle is over-hanging or "floating" making it impossible to print), a participant responded: "'A'. Because the 'D' is lifted up" (Jamie, 11). Another responded: "'A'. Because you can't print that" (Taylor, 11).

Despite some answers that were not explained in sufficient detail, the majority of participants were able to identify which possible prints had mistakes. As a result, we posit that a basic understanding of how 3D printing and design functions was achieved within the context of the workshops. When asked what 3D printers could or could not make, answers were often situated in prior knowledge of 3D printing as either a technology device or a manufacturing process. For example, one participant noted that they had "*Read about them making food*" (Tyler, 13), whereas another participant noted that they knew "*from watching the news once they can make prosthetic limbs*" (Grace, 12). Other responses included: "*A lot of things. I heard that they can make a house out of like bricks. I've heard on the internet that they've*

been making doors for airplanes” (Owen, 13). Generally (22 of 35), participants answered that they can make “*almost everything.*” When asked what 3D printers couldn’t make, answers were creative and drew more attention to specific materials. 3D printers are not good at making “anything other than plastic” was a common refrain. Examples of things 3D printers cannot make include; “*things that are sturdy, things that need electricity*” (Tyler, 13); “*Maybe like one of these big screens because like it’s made out of fabric or glass*”; “*They can make like animals but not living ones*” (Owen, 13); “*Well they can’t make liquids*” (Zara, 11). Large objects (like buildings and towers) were seen to be difficult for 3D printers due to current size constraints: “*Like, this building. Unless if they’re going to be really big in the future*” (Dorian, 8) and “*well if you want to build like a castle then you just need like a huge 3D printer. Technically you could do it*” (Russel, 9), and “*Well since the printers are only basically, not very big, you can’t make like a giant sculpture*” (Skye, 13).

When asked what they would make with a 3D printer, if given the opportunity, in many cases participants identified toys, models, and other household or personal things. As one participant noted, they would “*Make a binder. The cover of a binder. You could make a lot of things that you wouldn’t have to go and buy*” (Jonathan, 13). In one example, a participant noted that they would “*try and make all sorts of inventions. Because the main reason people don’t make inventions a lot is because they don’t have all the materials, it costs too much [...] I would work on graphene technology*” (Arthur, 9).

As noted, participants also fully designed and printed their own individual models, relying on the principles demonstrated earlier in the workshop. Participants were given a number of template shapes and designs to customize their shoe accessories with, and many of the participants used textual symbols, often choosing to stamp objects with their initials. When asked to describe their models, participants noted that they wanted unique or personalized examples. For example, responses include: “*Well my initials because I wanted to personalize my buckle and the moon because sailor moon is amazing.*” (Alex, 12); “*Well I didn’t really know what else to do and sometimes somebody else and they didn’t put their name so you can’t really tell them apart. So I just wanted to make mine unique.*” (Owen, 13)

Other participants simply liked the design (see Figure 10):

I put a “T” because that’s what my name starts with. And I put a cloud, a moon, and stars because I thought it looked like really neat like kind of like the sky and I put a heart just cause I thought it would look nice on it and I put an exclamation mark.
(Bianca, 10)

In general, the buckles reflected varying degrees of personalization. However, not all participants were unable to finish the design due to issues with their prints (for example, see Figure 11), even if they correctly answered the questions regarding design issues with the 3D design. This shows that despite having knowledge and understanding of the printing process, the technologies used can provide difficult usability and are best crafted under the supervision of an expert or educator.

Discussion

Neely and Langer (2013) argue that creative engagement can be facilitated in museums by asking visitors to directly manufacture museum content, for example by replicating objects that are unavailable to touch. Building on this, Jakobsen (2016) has similarly argued that the 3D printer, used in a museum context, is a “fascinating technology” that engages visitors and allows them to interpret objects in novel ways (2016, 133). Following these arguments, our research suggests that children can be engaged with objects by materializing cultural-historic information through a 3D-driven design process.

Our original goals and primary research questions were simple. Upon reviewing literature that addresses the topic of children’s learning via new technology interactions in museum spaces, we discovered a dearth of attention directed toward 3D fabrication, even as these technologies are experiencing a seemingly exaggerated cycle of “hype” directed toward their use in museums. From this basis, we asked: How can cultural heritage museums and galleries incorporate technologies like digital modeling and 3D printing through hands-on engagements designed specifically for children? Additionally, how can these engagements be used to foster literacy about objects in the museum as well as the technologies that are used to render them digitally? Through an interdisciplinary and inter-institutional (museum-academic) collaboration, we organized workshops that would assess the capacity for children to learn cultural-historic information apply it to a creative design process.

Using a variety of assessment measures to account for participants’ level of understanding of historical content provided by the institution and their level of understanding about 3D printing and design, our workshops successfully provided new insights to our research questions. Simply, children were able to understand and repeat knowledge they learned both about the history of shoe buckles and the 3D design process simultaneously. Further, when asked about objects they created, participants noted that they chose designs and letters to personalize their objects, indicating a propensity to use 3D technologies for creative, rather than merely instrumental, purposes. This also potentially showed that children were taking lessons learned from the historical introduction about the use and purpose of shoe buckles – as indicators of personal fashion and style. This has a direct bearing on how 3D printing technologies might be deployed in similar museum contexts for creative engagement. Finally, throughout the workshops, participants were both engaged and excited about both museum content and digital technologies. Not only did they leave with a better understanding of complex themes related to specific museum objects and content (social hierarchy and the construction of shoe buckles, for example), they also demonstrated an increased understanding of basic principles required to use common software 3D design software interfaces and metaphors.

The limits of this study deserve to be mentioned. It was small in size, and focused specifically on one idiosyncratic museum and a subset of knowledge related to the institution’s larger subject matter. In the first assessment, participants did not directly apply language about the fashionable or functional qualities of their own personalized shoe accessories as we had

hoped. However, the second assessment demonstrated that they did understand basic functionalities of shoe buckle examples, as they were able to distinguish between “functional” and “printable” designs; though we did not individually assess students prior to the lecture on this topic. Lastly, the relationship between the different design technologies used, the tablets and the laptops, and children’s learning will be investigated in future publications, and we have yet to examine how the different pre-loaded designs changed or affected the children’s designs, and are publishing this aspect of the research soon.

Technology-supported and culturally-informed workshops such as these could complement conventional museum engagement strategies. However, further research is necessary, as digital fabrication technologies are not ready-made “engagement devices” and require a significant amount of instruction and contextualization to be deployed in a museum setting. In the design of our study, we envisioned printing larger objects - life-size shoes that children could walk around in, for example - but these did not fit within the time or cost frames of our study. Our research suggests that engagements which de-center technology, whether an augmented reality application or a 3D printer, and, instead, equally weight digital-technological and cultural-historical literacies at the same time are both feasible and crucial to the successful deployment of new technology interactions by museums. Framing these in the context of “hands-on” digital interaction promises a wide range of creative modes of engagement, enabling museums to build on existing pedagogical resources and curricular tools that have been developed. Whether or not most museums embrace the contemporary move toward digitally-mediated content, further research that attends cultural and technological issues that arise from the incorporation of these emergent technologies will continue to be necessary.

Footnotes

1. For more on the project and other publication results see:

<http://semaphore.utoronto.ca/imadethis>

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