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Optimizing the Use of Digitization Technologies in Museums

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ABSTRACT

Digital technologies are used mostly for artifact preservation, but they can also be used for educating people about those artifacts in a museum context. This paper investigates the way various age groups react differently to distinct kinds of digitization technology. By using different technologies with certain age groups, adolescents can learn more from the artifacts or objects they are interacting with. This project aims to explore which technologies work with what age group in order to optimize adolescent education and artifact accessibility in museums. Accessibility for this study is defined as a museum making their collections available to a variety of people through digitization, whether online or in an exhibit.

To explore the notion that separate age groups react differently to various digital technologies, I considered adolescents as three distinct age groups: six- to eight-years-old, nine- to eleven-years-old, and twelve- to fourteen-years-old. I then created a digital exhibit comprised of digital scans of four artifacts from the Ancient Mediterranean Cultures and Archaeology (AMCA) Lab of Butler University. This digital exhibit can be used with the three groups in future outreach programming. The primary technology being tested is photogrammetry. A review of 3D printing and virtual reality are also included. The results indicate that all groups can benefit from the use of these technologies, but that certain technologies would have a greater impact on specific age groups over others with varying levels of flexibility. For instance, the oldest age group, 12-14, could learn from looking at a 3D printed scan, but they might engage with a virtual environment better. However, the youngest age group, 6-8, would learn well from a 3D-printed model, but they might struggle in a virtual environment. It is also important to note that these technologies would allow for greater learning among other groups besides adolescents and could help increase any visitor’s experience in a museum.

INTRODUCTION

When most people think of museums, they think of a physical location, filled to the brim with artifacts and people buzzing around them. They might even picture the sprawling halls behind the scenes, where museums keep thousands more artifacts tucked away. However, when thinking of a museum, it is rare for a person to first consider technology or how different types of technology are being used in a museum setting. At first, using excessive technology in a museum was seen as counter-productive, with the explanation that people could not have the same experience through a screen that they might have in person.[1] But in the last twenty years, technology has had a considerable impact on educational experiences, with many studies suggesting that technology can be highly beneficial to an individual's learning experience.[2] As with other educational institutions, museums are becoming increasingly impacted by technology and what it has to offer. Now, instead of dusty halls filled with glass cases, museum visitors will also find computer interactives or other hands-on activities to help draw in the guests. The Indiana State Museum renovated most of their Indiana history galleries to include activities and games that will interest a younger audience, like a chopping wood hands-on activity or a game about how to pack a covered wagon.[3] A study done by Katz and Halpern has shown that interactives such as these allow the guests to engage with the material more, with positive

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[1] Murphy, John W. "There is Nothing Virtual about Virtual Reality." *ETC: A Review of General Semantics*, *53:4,* 458-463. Institute of General Semantics, Winter 1996-1997. https://www.jstor.org/stable/42577769

[2] Mitchell, Linda M. "Using Technology in Reggio Emilia-Inspired Programs." *Theory Into Practice* 46, no. 1 (2007): 32-39. Accessed March 18, 2020. www.jstor.org/stable/40071631.

[3] "Nineteenth State." Indiana State Museum. Indiana State Museum and Historic Sites, September 11, 2020. https://www.indianamuseum.org/galleries/nineteenth-state/.

results.[4] Museums can also use this technology as a learning tool outside of their physical boundaries, making their collections accessible to a wider audience.

A wide array of technology is already used in a museum setting. Collections departments can use technologies like cameras and computer databases to help with the cataloguing and conservation of artifacts.[5] Other forms of technology such as computer interactives, microscopes, and magnifying glasses can all be used for museum interactions and programming, which benefits the overall experience of the guests.[6] Not only do these technologies help with preservation and interaction, but they also increase artifact accessibility. Accessibility in this case refers to a museum's ability to make its collections more available to a wider variety of people. For instance, the Western Museums Association states that only about three to five percent of a museum's collection can be displayed at one time. By making their entire collection available online, museums are able to reach a much wider audience than they ever could by simply putting artifacts on display.[7] This means that people who live all over the world can access material culture and learn from it in a variety of ways.

In the past, photogrammetry has primarily been used by museums for archiving artifacts and increasing online artifact accessibility. I am arguing that these photogrammetric scans can be

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[4] Katz, James E., and Daniel Halpern. "Can Virtual Museums Motivate Students? Toward a Constructivist Learning Approach." *Journal of Science Education and Technology* 24, no. 6 (2015): 776-88. Accessed February 2, 2020. www.jstor.org/stable/43867744.

[5] "Smithsonian 3D." Smithsonian Institution: 3D Digitization. Smithsonian. Accessed February 1, 2021. https://3d.si.edu/.

[6] Page 218. Dragotto, Erin and Christine Minerva and Michelle Nichols. "Is Museum Education 'Rocket Science'?" *The Journal of Museum Education, 31:3,* 215-222. Taylor and Francis, Ltd., Fall 2006. Accessed February 10, 2020. https://www.jstor.org/stable/40479563

[7] Faust, Rachael, and Katie Williams. "Maximizing Collections Access." Western Museums Association. Western Museums Association, May 23, 2012. Accessed March 1, 2020. https://westmuse.org/2012/05/22/maximizing-collections-access.

used in museum education both in the physical museum and outreach programming, and that different age groups will benefit from different photogrammetry interpretation technologies based on a variety of different teaching methods. I believe six- to eight-year-olds will learn better from 3D printed photogrammetric scans, nine- to eleven-year-olds will learn the most from playing with a photogrammetric scan on a tablet or computer, and twelve- to fourteen-year-olds will learn best from a virtual environment where photogrammetric scans have been implemented. To test my hypothesis, I have researched different pedagogies that are used in primary school education today, such as Reggio Emilia, play-based learning, and object-based learning. I have also supplemented this research by creating photogrammetric scans of artifacts from the AMCA Lab's collection at Butler University. Creating these scans helped me understand the reality of using technologies such as these, and if the issues that can arise while using these technologies is outweighed by the benefit they have for museum education. This research combined with these photogrammetric scans can act as a tool for the AMCA lab in future community outreach that will help introduce local children to Ancient Egypt, Ancient Greece, and Ancient Rome through educational programs.

TECHNOLOGIES

Photogrammetry produces a 3D model using a computer software, such as Agisoft Metashape or Meshroom, that can be downloaded to a computer to create 3D copies of an object or location.[8] These photogrammetry programs can even be downloaded onto smartphones or tablets to make the process of photogrammetry easily available. The technician running the

[8] "Photogrammetry." Cultural Heritage Imaging. Cultural Heritage Imaging. Accessed March 20, 2020. http://culturalheritageimaging.org/Technologies/Photogrammetry/.

program takes hundreds of images of the object or location from as many angles as possible in a well-lit and preferably light-controlled space. This process normally requires a high-quality camera, but the increasing quality of phone cameras makes this process easier to accomplish with phone cameras. After taking the photos, the technician then needs to edit the photos, so that the computer program is not confused by the lighting or any extra space surrounding the artifact. This is accomplished by using programs like Adobe Photoshop and Adobe Bridge. That technician then uploads all of those photos into the photogrammetry software. Before rendering the model, it is necessary for the technician to check the quality of the photos as well as the "masks." A mask is a filter that tells the software the areas of the photo that it needs to focus on when creating the photogrammetric scan. When these masks are placed on the photos automatically using a technology like photoshop, they oftentimes have to be edited before running the software and rendering the model. Having a bad mask can result in the software focusing on more than just the object. A bad mask creates extra geometry, which in this context means extra parts to the 3D model that are not part of the actual artifact. After editing the photos, the technician can then run the software, which uses a point system to combine all the photos and align them in order to make the model. After the model is finalized, the technician can go into other programs, such as MeshLab or Blender, to edit the scans and make any necessary changes. These changes can range from erasing excess geometry to filling in holes that could not be filled in during the rendering process. The finalized 3D virtual model can then be posted online, printed by a 3D printer, or used in person for closer study.[9]

[9] Advanced Visualization Lab, "Photogrammetry Workflow Guide." PDF. Indiana University, Bloomington, Fall 2018. Accessed March 2, 2020.

Sketchfab is a website that gives museums and cultural institutions the capability to post virtual scans of their artifacts, which makes these photogrammetric scans more widely available. Some of these scans can also be downloaded, allowing them to be printed by educators and scholars.[10] Some museums use photogrammetry and 3D scanning to help preserve their collection, but they will not post it online because they still fear that fewer people will come to see the collection in person.[11] However, institutions like the Smithsonian are proving these museums wrong. Within the last year the Smithsonian Institution created "Smithsonian OpenAccess," where their entire collection is available online through high-quality 2D or 3D images.[12] If these 3D models are available and can be used in classrooms and education programs, more people will learn about the existence of these artifacts at an earlier age. This could help potentially spark an aspiration to see the artifact in person. Katz and Halpern discuss a study where students participated in virtual tours at various museums, either in 2D or 3D. They found that almost all of the students who participated in 3D virtual tours expressed desire in seeing the museum in person, whereas it was more common for the students who saw the 2D tours to express less interest. Having 2D images available is better than not making the artifact accessible at all but using three dimensional scans is much more effective. [13] The Covid-19 pandemic has demonstrated to museums that they need to strengthen their online presence, which has raised the number of museums that are prioritizing their online presence. For instance, the

[10] Novaky, Meser, Nick Reinhardt, and Silkevd Smissen. "Publish & Find 3D Models Online." Sketchfab. Accessed February 25, 2020. https://sketchfab.com/.

[11] Katz, James E., and Daniel Halpern. "Can Virtual Museums Motivate Students? Toward a Constructivist Learning Approach." *Journal of Science Education and Technology* 24, no. 6 (2015): 776-88. Accessed February 2, 2020. www.jstor.org/stable/43867744.

[12] "Smithsonian Open Access." Smithsonian Institution. Accessed February 1, 2021. https://www.si.edu/openaccess.

[13] Page 778. Katz, James E., and Daniel Halpern

Children's Museum of Indianapolis launched the Museum At Home initiative, in order to provide ideas for museum-related activities for kids and their families while the museum was closed.[14]

3D printing, which can also be referred to as stereolithography or rapid prototyping, can be accomplished in a variety of ways. Some, like stereolithography apparatus (SLA), creates a 3D model by building it from the bottom up. SLA is the most commonly employed method of 3D printing. This method can have problems with accurately copying the resolution of an object, which can make the project expensive. There are also size and material constraints with SLA that can make it challenging and expensive to create an accurate reproduction. If the object is too heavy or large, then a larger SLA machine would be required. The copies are also created out of different types of resin, so chemical composition needs to be checked and considered. Most of these resins are also unnatural colors. Another method of 3D printing is computer numerical control machining (CNC), a machine that cuts a larger piece of material down into a preset shape. This method is much more complicated, and it involves the larger piece of material moving on an x, y, and z plane while being sliced by a laser. The programming for this method better duplicates the object's resolution and its shape, can potentially create larger replicas, and allows a wider range of materials than can be used for SLA. Quality 3D printers are still very expensive, but smaller ones are becoming more accessible with a general cost of around two hundred dollars, hopefully making this technology more available to a wider variety of people.[15]

[14] "Museum at Home." The Children's Museum of Indianapolis. The Children's Museum of Indianapolis, 2020. https://www.childrensmuseum.org/museum-at-home.

[15] Page 155. Wachowiak, Melvin J., and Basiliki Vicky Karas. "3D Scanning and Replication for Museum and Cultural Heritage Applications." *Journal of the American Institute for Conservation* 48, no. 2 (2009): 141-58. Accessed February 1, 2020. www.jstor.org/stable/27784660.

Even though 3D printing is complicated, 3D printing virtual models of artifacts has an abundance of benefits and can be accomplished in a variety of ways.[16] These printed replicas of fragile artifacts can be used to put these artifacts on display, to study fragile artifacts without damaging them, or in a classroom setting to give students more exposure to artifacts, by allowing them to see, feel, and hold a copy of that artifact themselves:

> "Creation of replicas for study is now possible at any scale, and in almost any material. Replicas are valuable from research, exhibit, and restoration perspectives, and they can enhance the general public's appreciation of the museum or heritage site."[17]

By 3D printing virtual models of artifacts, whether they are created by photogrammetry or 3D scanning, people of all ages will be able to better interact with artifacts normally kept in museums. Because of the fragile nature of artifacts, it is impossible for a wide range of individuals to handle them. If educators are able to create 3D replicas of these objects, then students can interact with them on a more personal level, and they can benefit from being able to touch and explore the object itself. For a student who cannot visit certain museums or cultural heritage sites, they can study 3D replicas of the artifacts found there, creating a similar experience.[18]

Virtual reality is a technology that is used to create a simulated environment. This environment can be used to immerse audiences fully into a variety of simulated experiences, that can range from fictional to historical to digital, immersive copies of real-life locations. All of these examples can benefit from using photogrammetric scans of smaller object to make them

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[16] Wachowiak, Melvin J., and Basiliki Vicky Karas. "3D Scanning and Replication for Museum and Cultural Heritage Applications." *Journal of the American Institute for Conservation* 48, no. 2 (2009): 141-58. Accessed February 1, 2020. www.jstor.org/stable/27784660.

[17] Page 144. Wachowiak, Melvin J., and Basiliki Vicky Karas.

[18] Wachowiak, Melvin J., and Basiliki Vicky Karas

look more life-like and realistic. This means that a virtual environment of a museum, like the Smithsonian, could include multiple photogrammetric scans of artifacts normally on display in that exhibit. This immersive experience can greatly influence how audiences between the ages of twelve and fourteen years old are able to experience the history because the virtual environment allows them to live through that history themselves instead of just hearing about it from third parties:

> "VR allows the user to process information more directly through perception in three dimensions instead of two. Various studies have shown that 3D displays are easier for the mind to process, convey more information more quickly than 2D displays, and facilitate human memory retention and retrieval… the perceptual benefits of 3D are fourfold: a quicker and more accurate grasp of spatial features, an improved appreciation for the scale of physical attributes such as distance and velocity, a decluttering of graphical and textual information overlaid upon a limited display area, and a greater facility for comprehending graphical representations rather than textual."[19]

Virtual reality is becoming less expensive than it was before, making it a stronger educational tool. When educators present these virtual environments to students, the students are able to partake in that historic event or explore a historic location themselves. James J. Sosnoski has worked on a project that focused on creating a virtual Harlem, New York, during the Harlem Renaissance, so that adolescents could experience that time period for themselves firsthand. He asserts that:

> "Virtual Harlem is a learning environment in which participants experience a dramatic, visual history centered in Harlem, New York. By modeling its historical context as a dynamic system of social, cultural, political, and economic relations, Virtual Harlem enables a subject matter like the Harlem Renaissance to be studied in new ways. Unlike a conventional classroom in which the subject matter being studies is available to the students as information in textbooks, on blackboards, or in slides projected on a screen, Virtual Harlem is an experience of the past.

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[19] Pages 5 -6. Haywood, James E. *Improving the Management of an Air Campaign with Virtual Reality*. Report. Air University Press, 1996. 5-13. Accessed April 17, 2020. www.jstor.org/stable/resrep13866.8.

> Students enter a cityscape that can be experienced, albeit virtually, as if they were tourists visiting Harlem via a time machine."[20]

Virtual reality has the educational benefit of virtually bringing students to a location or time period they are learning about, allowing them to "see" and understand the topic themselves. Instead of a teacher just trying to explain it to them, students are able to participate in it actively and learn for themselves.[21]

The Maritime Museum in Amsterdam is an excellent example of the benefits of using virtual reality within a museum setting. While they have beautiful artifacts on display, they also include many technological installations to better help all visitors, not just the younger ones, understand the importance of what they are seeing. Entrance to the museum includes access to a replica of the Dutch East Indiaman ship, "Amsterdam," originally built in 1749. On the ship, guests have the opportunity to partake in a virtual reconstruction of 18th-century Amsterdam, to see it when it was a thriving port city.[22]

In order for virtual reality to be used in education, virtual copies of heritage sites and their components need to become more readily available. Some museums offer 3D tours or 3D copies of their artifacts. Google Tour Creator is a tool that allows both students and teachers to create their own simulated environments, based on Google Earth imaging, or any 360 imaging they have themselves. This kind of application allows educators and their students to take

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[20] Page 141. Sosnoski, James J. "Virtual Reality as a Teaching Tool: Learning by Configuring." In *Small Tech: The Culture of Digital Tools*, edited by HAWK BYRON, RIEDER DAVID M., and OVIEDO OLLIE, 137-49. University of Minnesota Press, 2008. Accessed March 18, 2020. www.jstor.org/stable/10.5749/j.cttttht8.23.

[21] [21] Katz, James E., and Daniel Halpern. "Can Virtual Museums Motivate Students? Toward a Constructivist Learning Approach." *Journal of Science Education and Technology* 24, no. 6 (2015): 776-88. Accessed February 2, 2020. www.jstor.org/stable/43867744.

[22] "East Indiaman Amsterdam." Het Scheepvaartmuseum. Het Scheepvaartmuseum. Accessed March 20, 2020. https://www.hetscheepvaartmuseum.com/whats-on/east-indiaman-amsterdam.

advantage of already existing technology like Google Earth and turn it into a virtual experience that will enhance the students' education. Google Expeditions is an extension of Google Tour Creator, and it is framed as an educational tool that allows for teachers to take students on "virtual fieldtrips." Google Expeditions has over 900 VR sites of different cultural heritage sites and museums, with the ability to zoom in and look at specific architectural features or artifacts. Google Expedition allows for the teacher to lead the virtual environment through their phone or laptop, as well as providing discussion questions and informative reading about what is being seen.[23] I think that students can benefit from these uses of virtual reality because it places them in direct contact with the historical moment or artifact they are learning about, which reduces the distance between the student and the cultural heritage site. That proximity will help expand the students' interest, resulting in them actually learning about the cultural heritage site instead of ignoring what they are taught.[24]

PEDAGOGIES

Studies have shown how these technologies can be used and how they are beneficial, but not how they all benefit different audience groups.[25] In order to understand which of the three age groups would best learn from these different technologies, I researched different pedagogies that are popular in primary education, like object-based learning, play-based learning, and the

[23] "Bring Your Lessons to Life with Expeditions | Google for Education." Google. Google. Accessed March 25, 2021. https://edu.google.com/products/vr-ar/expeditions/.
[24] Katz, James E., and Daniel Halpern. "Can Virtual Museums Motivate Students? Toward a Constructivist Learning Approach." *Journal of Science Education and Technology* 24, no. 6 (2015): 776-88. Accessed February 2, 2020. www.jstor.org/stable/43867744.
[25] Hereniko, Vilsoni. "Virtual Museums and New Directions?" *Curatopia: Museums and the Future of Curatorship,* 327-335. Manchester University Press, 2019. https://www.jstor.org/stable/j.ctvnb7j6j.27

Reggio Emilia approach. My ability to directly interact with these age groups has been severely limited because of the pandemic, so I have not had an opportunity to test this hypothesis on the individual groups. Instead, I have been researching these different teaching methods and how they may apply to different age groups and different technologies, with the intention that the AMCA Lab can use this research while doing community outreach with nearby schools in the future.

The Reggio Emilia approach is a method of teaching from Reggio Emilia, Italy that focuses on preschool and elementary aged children. It uses the adolescents' own exploration and discovery to help them learn and form their own ideas about what they encounter.[26] Linda M. Mitchell discusses the benefits of using technology in a Reggio-Emilia pedagogy:

> "Technology, as a tool, is used for many purposes by young children, including, for example, a) to further inquiry (e.g., Internet searches), b) to help construct new knowledge, especially through ongoing projects (e.g., videotaping and discussing the process); c) for creativity (e.g., producing digital movies), and d) to bring inanimate things to life (e.g., adding battery power)."[27]

This pedagogy is based on the idea that children have the ability to inquire and wonder about the world around them, and that children benefit from making the discoveries themselves. If kids this age are told information outright, instead of leading them to the answer based on what they notice or know about similar object, it is more likely the same interest will not be sparked. This results in them not retaining as much information. Based on the Reggio Emilia education technique, I believe that the six to eight-year-old age group will highly benefit from looking at a

[26] Page 35. Mitchell, Linda M. "Using Technology in Reggio Emilia-Inspired Programs." *Theory Into Practice* 46, no. 1 (2007): 32-39. Accessed March 18, 2020. www.jstor.org/stable/40071631.

[27] Page 33. Mitchell, Linda M.

3D printed model, or something that they can touch.[28] Holding a printed photogrammetric scan would allow for the kids in this age group to experience artifacts in a way that is normally not available to them. 3D printing would allow for children of this age group to understand more about the artifact and how it is used, more so than if they were just looking at it on the other side of a glass barrier.

This theory is also supported by the Play-Based Learning pedagogy. The Play-Based Learning pedagogy proposes that playing comes naturally to children, so by combining learning with play, children will be able to learn and retain more information.[29] Play-based learning can be quite effective itself. However, Jahreie, et al. discusses how museums often use a Play-based learning pedagogy. When this is combined with prior preparation from teachers, students have the capability to learn a lot while interacting with exhibits. They outline four steps that could be taken in order to further influence the student's learning experience:

> "First, it is important to orient the students to the physical settings of the museum. Without introduction to the physical organization of the environment, students have difficulties with making choices about what to do and are overwhelmed by the wealth of activities available. Secondly, field trips should be closely integrated with the curriculum. Third, students should be introduced to skills and knowledge about the topic before the visit. Finally, students should be "psychologically" prepared, meaning that they should know that the museum visit is a learning experience."[30]

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[28] Mitchell, Linda M. "Using Technology in Reggio Emilia-Inspired Programs." *Theory Into Practice* 46, no. 1 (2007): 32-39. Accessed March 18, 2020. www.jstor.org/stable/40071631.

[29] Jahreie Cecilie F., Hans Christian Arnseth. Ingeborg Krange, Ole Smørdal, and Anders Kluge. "Designing for Play-Based Learning of Scientific Concepts: Digital Tools for Bridging School and Science Museum Contexts." *Children, Youth and Environments*21, no. 2 (2011): 236-55. Accessed March 20, 2020. www.jstor.org/stable/10.7721/chilyoutenvi.21.2.0236.

[30] Page 241. Jahreie Cecilie F., Hans Christian Arnseth, Ingeborg Krange, Ole Smørdal, and Anders Kluge.

Students will have a better understanding of what they are looking at and why, if they are introduced to the artifact itself, such as what it is, its history, and why it is important.

A photogrammetric scan with an additional activity could help younger visitors learn more about how these objects would have been used. An example of an activity would be a game or program that would help make connections for the students between the artifact they are looking at and its historical context, which could help supplement the digital copy of the artifact. After finishing the activity, an individual could look at a photogrammetric scan, allowing them to interact with it on a more personal level than just looking at it in a glass case. For instance, in the lesson plan mentioned in the Appendix below, students go through a preliminary activity about Ancient Egyptian mummification in order to give them a canopic jar's context. Then, while they are playing with the photogrammetric scan of the canopic jar, they can make observations about the material, shape, and potentially size to understand more about how and why this artifact would have been used. Because it is a form of interaction that requires more instruction, I believe this would be the most beneficial for the middle age group, or nine-to-eleven-year-olds. This way, an educator could go through the information with them in advance or make the photogrammetric scan part of a larger activity, but an adult is still there to guide the children if they have any questions or are confused.

Object-based learning is more popular in institutions like museums, instead of classrooms, because it is less formal.[31] It relies on creating a connection between an object and a person, inspiring the person to want to learn more about the object and its context.[32] This has

[31] Paris, Scott G., and Minda Borun. "Object-Based Learning in Family Groups." In *Perspectives on Object-Centered Learning in Museums*, 245–60. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 2002.

[32] Williams, Patterson. "Object-Oriented Learning in Art Museums." *Roundtable Reports* 7, no. 2 (1982): 12-15. Accessed March 28, 2021. http://www.jstor.org/stable/40479735

become a very popular pedagogy in science and children's museums because it allows for an entire family or group to learn at one time, in a "socially situated" environment. The activity is meant to spark conversation among the group, resulting in adult-facilitated learning. Borun, for example, argues "Direct interaction with objects allows for visual and kinesthetic learning that can be far richer and more complex than text alone."[33] However, the program needs to be accompanied by text, to supply the necessary definitions and contextual information. With the proper activities and accompanying texts, family groups are able to facilitate the activity themselves, but also understand what is happening in the activity and why. An example Borun uses is the "gravity cone." In this activity individuals can push a ball onto a cone-shaped object with a hole at the bottom and roll down the cone in a circular motion. In an ideal museum environment, there would be a sign explaining why this phenomenon happens, so that the families can understand and learn from the experience.[34] Object-based learning is meant to be entertaining, memorable, and something that visitor groups can do together, in order to inspire interaction.[35] It is normally reserved for interacting with the actual artifact or material. However, sometimes this is not possible because of the nature of the artifact. Photogrammetric scans can be used within virtual environments to enhance how a guest can experience an artifact or material heritage site.

Virtual reality or virtual environments are a mix of play-based learning and object-based learning. Because virtual environments require students or museum visitors to immerse themselves in an environment completely in order to interact or explore, they are accomplishing

[33] Paris, Scott G., and Minda Borun. "Object-Based Learning in Family Groups." In *Perspectives on Object-Centered Learning in Museums*, 245–60. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 2002.
[34] Paris, Scott G., and Minda Borun.
[35] Paris, Scott G., and Minda Borun.

object-based learning.[36] Virtual environments can also include games or guided activities to keep users interested in the topic. At the University of California, San Diego's Qualcomm Institute, researchers have created a variety of "immersive" virtual reality machines to help make the archaeological site Khirbat en-Nahas in Jordan more understandable to visitors.[37] Instead of putting on a headset, an individual can step into the StarCAVE, which is five walls and a floor comprised of screens that people can interact with using a remote. When people step into the StarCAVE, they are able to interact with this site as if they were actually there in person. They are able to see a 360-degree view of the site surrounding them, with all of the artifacts and other material culture elements laid out where they were found. By interacting with this site on StarCAVE they can see the context of all of the artifacts and how they were found, as well as click on the individual artifacts to see virtual 3D models of them and the information that has been gathered about that artifact.[38] Knabb, et al. describe one of their researching goals:

> "We aim to use these virtual reality environments as heuristic tools. By visualizing archaeological sites using virtual reality one is able to revisit the site and data again and again without ever going back to the field. In this manner we can investigate the topological and spatial relationship between artifacts, features, and other surface areas of the site and how these changed through time."[39]

While the StarCAVE costs more than what most museums and schools are able to afford, it shows the benefits of producing a fully immersive virtual environment such as this one. Because

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[36] Paris, Scott G., and Minda Borun. "Object-Based Learning in Family Groups." In *Perspectives on Object-Centered Learning in Museums*, 245–60. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 2002.

[37] Knabb Kyle A., Jurgen P. Schulze, Falko Kuester, Thomas A. DeFanti, and Thomas E. Levy. "Scientific Visualization, 3D Immersive Virtual Reality Environments, and Archaeology in Jordan and the Near East." *Near Eastern Archaeology* 77, no. 3 (2014): 228-32. Accessed March 18, 2020. doi:10.5615/neareastarch.77.3.0228.

[38] Knabb Kyle A., Jurgen P. Schulze, Falko Kuester, Thomas A. DeFanti, and Thomas E. Levy.

[39] Page 229. Kyle A. Knabb, Jurgen P. Schulze, Falko Kuester, Thomas A. DeFanti, and Thomas E. Levy.

virtual environments are more independent, I thought this would be best with the twelve- to fourteen-year-olds, or middle school aged visitors. However, because of my research I believe that any age from middle school up would benefit the most from this technology. After the age of twelve, an individual would be able to listen to a coinciding lesson and then participate in the virtual environment by themselves or guided by an educator with high comprehension. On the opposite end, I believe that virtual reality would be overwhelming for students who are younger than middle school age. It would be harder for younger kids to focus and understand what they are seeing, unless the virtual environment was completely mediated by an educator. An activity that is fully led by an educator does not technically qualify as play-based learning, because the students would need time to explore the virtual environment by themselves and choose what they would like to learn about.

METHODS

In order to supplement my research on the different pedagogies, I created a digital exhibit using photogrammetry for the AMCA Lab at Butler University. The artifacts from this exhibit can then be 3D printed, used as photogrammetric scans, or implemented into virtual environments in the future. In addition to the digital exhibit, I created a lesson plan to be used among nine- to twelve-year-old students for public outreach to nearby school, which gives the AMCA Lab a template to create other lesson plans in the future.


Figures 1&2: Hercules Statuette from the AMCA Lab, courtesy of the author

I chose to create a scan of the Hercules statuette because Hercules was a larger-than-life mythological figure, who was very famous in Ancient Greece and Rome. I originally believed that this statuette was a votive statuette because of its size. However, Dr. Kvapil, the head of the AMCA Lab, was contacted by a German archaeologist named Norbert Franken, who suggested that this statuette is most likely a chariot fitting for an upper-class Roman chariot based on the eyelet and flat or carved out features in the back. The design of this statuette suggests that it is from a little later in Ancient Rome's history, around the first or second century CE, because it shows Heracles as an older man with both his cloak and club respectively.[40] I found two bronze chariot fittings of Hercules that are from around the first to second century CE.[41] They were sold on the "liveauctioneers" website, and they are busts of Hercules' head and upper body in different positions with different facial expressions. These fittings would have been used on the same chariot. The faces from both of the fittings look similar to the AMCA Lab's statuette, based on the design of the hair and beard. The website claims these fittings are from the first century CE, and that the artifact was owned by an "ex-prominent New York City, NY Gallery."[42] A lot of fittings I saw during my research were secured similar to the Hercules busts, where there was an attachment at the back that would fit around a wood piece projecting from the chariot, or the fitting was hollow so that it could be attached that way. The AMCA Lab's Hercules statuette seems to be too detailed to have either of these kinds of attachments, which might account for the eyelet in the back.

Because Hercules is such a well-known figure, there would be many different opportunities to use this artifact in educational programming. Hercules is also one of the more interesting mythological figures because he contains many contrasts within himself, which has led to an abundance of scholarship.[43] There are also contemporary cultural connections that would allow for younger individuals to recognize the name Hercules, such as the *Percy Jackson*

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[40] Galinsky, Karl. "The Popularity of Hercules in Pre-Roman Central Italy." In *At the Crossroads of Greco-Roman History, Culture, and Religion: Papers in Memory of Carin M. C. Green*, edited by Bell Sinclair W. and Holland Lora L., 191-202. Summertown, Oxford: Archaeopress, 2018. Accessed June 14, 2020. doi:10.2307/j.ctv1228gbp.20.

[41] "Superb Roman Bronze Chariot Fittings of Hercules." LiveAuctioneers. LiveAuctioneers, June 13, 2013. https://www.liveauctioneers.com/item/17800045_superb-roman-bronze-chariot-fittings-of-hercules.

[42] "Superb Roman Bronze Chariot Fittings of Hercules."

[43] Galinsky, Karl.

and the Olympians book series by Rick Riordan or Disney's *Hercules*. The statuette could also be used to teach Roman bronze statuary, chariot decoration, or the complex nature of mythological figures. The only downside to the statuette is that it is nude, like most statuary from the time period. The nudity means that it might be deemed more appropriate for certain student age groups, like high school and above. This particular photogrammetric scan would be hard to 3D print because of the small details like the face, but it would be great to use in a digital environment on a tablet, or in a larger and more immersive virtual environment.

Figure 3: Late Kingdom Canopic Jar from the AMCA Lab, courtesy of the author

The second artifact that I created a photogrammetric scan of was a Late Kingdom Egyptian canopic jar from 664-525 BCE. I chose to work with the canopic jar because I am fascinated by Ancient Egyptian mummification and I knew that Agisoft Metashape would like the material, size, and color of the artifact. It is also a great way to talk about Ancient Egyptian culture and their belief system, as well as a useful tool for introducing children to Ancient

Egyptian mummification. Canopic jars were important features of the Ancient Egyptian burial process for three thousand years. During an Ancient Egyptian burial, the four canopic jars featuring the heads of the Sons of Horus, would have held and "protected" four different organs. The four different organs primarily preserved in these jars were the stomach, liver, intestines, and lungs. Imsety, the human-headed god, protected the liver; Hapy, the baboon-headed god, protected the lungs; Duamutef, the jackal-headed god, protected the stomach; and Qebehsenuef, the falcon-headed god, protected the intestines.[44] When priests were mummifying someone, one of the first steps would have been to remove all of the organs except for the heart. During this stage the stomach, liver, intestines, and lungs would have been placed in their respective jars, and every other organ that had not been left in the body or placed in the jars would be thrown away. Then they did the rest of the steps, like rinsing the body with wine and spices, submerging the body in natron for forty or seventy days, then wrapping the body in linen strips and anointing it with oils and lacquers. The canopic jar I will be working with has the head of Duamutef, so it would have been set aside for protection of the stomach. However, this canopic jar is dated to 664-525 BCE, so it would never have held any organs. During this time the organs were mummified and then placed back inside the mummy's body, and the canopic jars were only used ceremonially.[45]

The photogrammetric scan of this object, paired with an online activity, would allow for students to learn more about Ancient Egyptian mummification in a fun and interesting way. I created a lesson plan that can be used for any future outreach to local schools centered around Ancient Egyptian mummification and the canopic jar, which can be seen in the Appendix. The

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[44] "Canopic Jar." THE MET. The Metropolitan Museum of Art. Accessed June 7, 2020. https://www.metmuseum.org/art/collection/search/559935.

[45] "Canopic Jar."

lesson plan starts with an introduction to archaeology, so that these students understand how archaeologists and Egyptologists learn more about life in Ancient Egypt. This section also looks at the different sources archaeologists and Egyptologists use to figure out the Ancient Egyptian embalming process and the religious beliefs that motivate this ritual. The two main examples discussed are material culture, like canopic jars or the tombs themselves, and literary sources like *The Histories* by Herodotus.[46] Even though contemporary people have to be wary of the lenses Herodotus used when he was writing about other cultures, like the Egyptians, the process he records for mummification only has a few minor differences to what people know today. Two biggest differences are: Herodotus does not mention canopic jars and some parts of the process are out of order. There is also conflicting information concerning how long the body would have been submerged in natron. Some sources, like Herodotus, say seventy days, and others say forty.[47]

An example of an activity that could further allow for students to play while learning is an online game called "Making a Mummy" by the Children's University of Manchester, which can be seen down below.[48] In this game, the user can walk through the steps of mummification and try out the steps themselves. Getting the opportunity to walk through all of the steps, instead of just reading about them, gives students more context and shows them what this process might have look like. After the online activity, the students will then spend fifteen minutes looking at the photogrammetric scan of the canopic jar, and spend time coming together as a group to write

[46] Herodotus, and Robin Waterfield. "Book 2." In *The Histories*, 95–168. Oxford, New York: Oxford University Press, 1998.
[47] Herodotus, and Robin Waterfield.
[48] "Making a Mummy." The Children's University of Manchester. Accessed February 1, 2021. https://www.childrensuniversity.manchester.ac.uk/learning-activities/history/ancient-egypt/making-a-mummy/.

down different observations. Once the students have done this step, then they will participate in a ten-question game to help them retain what they learned.[49] Because it is a form of interaction that requires more instruction, I believe this would be the most beneficial for the middle age group, or nine-to eleven-year-olds. This way, the educator is still there to guide the students if they have any questions or are confused.

Figure 4: "Making a Mummy" Activity, Children's University of Manchester[50]

[49] An example of a lesson plan like this one and the questions that would be asked is in the appendix.

[50] "Making a Mummy." The Children's University of Manchester. Accessed February 1, 2021. https://www.childrensuniversity.manchester.ac.uk/learning-activities/history/ancient-egypt/making-a-mummy/.

Figure 5: Black-figure chimney lekythos from the AMCA Lab, courtesy of the author

The next artifact I started working on is a black-figure lekythos. This lekythos would be a great way to teach students about the differences in Ancient Greek pottery design, how pottery would have been created, and the many different uses pottery had in Ancient Greece. The lekythos was a type of Ancient Greek vessel that would have been used for pouring oil especially in a funerary or religious context. Funerary rituals were incredibly important in Ancient Greece, and these vessels would have had a vital role in anointing the bodies of the deceased.

This lekythos is a great example of black-figure pottery, which is created using a fired clay slip. Black-figure pottery was the earliest form of pottery decorating in Greece, starting in the 7th century BCE. Red-figure pottery was created a little later on and has created a great contrast in the two artistic styles.[51] Pottery was a very big part of Ancient Greek life, which is

[51] McKeown, H., & Debby Sneed, D. 2006.25.T, Attic Black-Figure Lekythos. The University of Colorado, Boulder, May 10, 2018. Accessed June 30, 2020, from https://www.colorado.edu/classics/2018/05/10/200625t-attic-black-figure-lekythos

reflected in the number of different vessels that existed and the specific uses that each type of vessel had. Not only was pottery used in every-day life, but it was also used for different religious rituals and also funerary rituals, like the lekythos. The lekythos would have been used for storing oil, but it also could be used in burial rites. The lekythos belonging to the AMCA Lab would have most likely been used in a funerary context because of its size. It is only five inches tall, and its diameter is one and a half inches. I also believe that this lekythos is from the later part of the Late Archaic period, or 500 BCE to 480 BCE, based on two other lekythoi I found as comparanda that are from this time period. The first lekythos is part of the collection at the University of Colorado, Boulder[52] and the second artifact is from the Metropolitan Museum of Art.[53] Both of these artifacts are similar in size and design – the decorations around the top of the lekythoi are very similar. This lekythos also was made in the chimney design, where the neck of the vase is longer than the necks of other lekythos designs. The chimney design would have been from later in the archaic period, as I mentioned above.[54] The design on the AMCA Lab's lekythos was hard to identify, but it seems to be a chariot with two charioteers. This is based off of two other lekythoi I found as comparanda, that both show two similar chariot designs. The first is from the Princeton University Art Museum, and it shows a charioteer standing in a similar stance. The chariot and horses also look similar to the design on the AMCA Lab's lekythos.[55]

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[52] McKeown, H., & Debby Sneed, D. 2006.25.T, Attic Black-Figure Lekythos. The University of Colorado, Boulder, May 10, 2018. Accessed June 30, 2020, from https://www.colorado.edu/classics/2018/05/10/200625t-attic-black-figure-lekythos

[53] "Lekythos" THE MET. The Metropolitan Museum of Art. Accessed April 20, 2021. https://www.metmuseum.org/art/collection/search/254397.

[54] Folsom, Robert Slade. "Characteristic Shapes." Essay. In *Attic Black-Figured Pottery*, 16–39. Park Ridge, NJ: Noyes Press, 1975.

[55] "Black-Figure Lekythos: Chariot Race (y1962-176)." Princeton University. The Trustees of Princeton University. Accessed April 20, 2021. https://artmuseum.princeton.edu/collections/objects/29095.

The other is from the J. Paul Getty Museum, and it shows horses that look similar to the design on the AMCA Lab's lekythos.[56] Both of these lekythoi are from the late archaic period and are the same design. The photogrammetric scan of this artifact could also be used in a lesson discussing funerary rituals and pottery design in Ancient Greece.

The contrasting color, precise design, and size of the lekythos means that this would not be ideal for 3D printing, especially if educators wanted to center their lesson around the different design methods of Ancient Greek pottery. However, this would be a great artifact for a 3D digitized scan that could be accessed on a tablet or computer, through a website like Sketchfab mentioned above. A photogrammetric scan of an artifact like this one is also a great example of how these photogrammetric scans can be implemented into a 3D virtual environment, like the StarCAVE mentioned on page 14. Having the photogrammetric scan of this artifact, or something similar, in a virtual environment could show how funerary artifacts like this one are normally found and how they would have been used by individuals in antiquity. This kind of hands-on learning would allow for students to better understand the circumstances of Ancient Greek burial, how pottery played a big role in Ancient Greek ritual, and how archaeologists are able to learn from Ancient Greek pottery today. If students were able to interact with a variety of photogrammetric scans with different pottery designs, it would help students recognize the differences themselves and how pottery in Greece changed over time.

[56] "Attic Black-Figure Lekythos." The J. Paul Getty in Los Angeles. J Paul Getty Trust. Accessed April 20, 2021. http://www.getty.edu/art/collection/objects/7190/haimon-group-attic-black-figure-lekythos-greek-attic-about-480-bc/.

Figure 6: Bes Amulet from the AMCA Lab, courtesy of the author

The final artifact I created a photogrammetric scan of was an Ancient Egyptian amulet of the god Bes that is made using faience. Bes amulets would have been used throughout all of Ancient Egypt, but amulets did not commonly depict deities until after the New Kingdom (ca. 1550-1070 BCE). The design and material of Bes amulets changed very little throughout time, which makes it hard to give them a more exact date.[57] Artifacts made of faience are made of earthenware and fired with a specific glaze. In Ancient Egypt, this glaze is normally comprised

[57] Stünkel, Isabel. "Ancient Egyptian Amulets." THE MET. The Metropolitan Museum of Art, February 2019. https://www.metmuseum.org/toah/hd/egam/hd_egam.htm.

of alkaline salts and quartz.[58] Amulets were a very important part of life in Ancient Egypt, which is why I chose this artifact. Many different kinds of amulets existed, made of a plethora of different materials that all had a specific purpose. Amulets would have been more personal and would have been carried by or buried with a specific person. More expensive amulets actually claimed to do a better job merging the amulet and the individual buying it.[59] Bes was a very popular household god in Ancient Egypt.[60] It is easy to identify Bes because he was normally depicted as a dwarf-like man with a headdress or hat. The face is normally in a grumpy expression and the elbows and knees will stick out to the side, like Bes is crouching. Bes was mostly associated with protecting women and children, but Bes amulets are much more common in child burials.[61]

Understanding amulets and why they were important is a big part of understanding Ancient Egyptian religion and their beliefs. However, my time in museum education has showed me how difficult it can be for children to understand what amulets were used for in Ancient Egypt and why they were important. Younger children in particular have a harder time grasping this concept because it is hard for them to think of a modern comparison. Providing students with a photogrammetric scan of an amulet online or on a tablet would allow for them to see the details

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[58] Riccardelli, Carolyn. “Egyptian Faience: Technology and Production.” THE MET. The Metropolitan Museum of Art, December 2017. https://www.metmuseum.org/toah/hd/egfc/hd_egfc.htm.

[59] Martínez, Isabel Canzobre. "Magical Amulets User’s Guide: Preparation, Utilization and Knowledge Transmission in the PGM." In *Magikè Téchne: Formación Y Consideración Social Del Mago En El Mundo Antiguo*, edited by Suárez Emilio, Blanco Miriam, Chronopoulou Eleni, and Canzobre Isabel, 177-92. Madrid: Dykinson, S.L., 2017. Accessed June 30, 2020. doi:10.2307/j.ctt22p7gz1.13.

[60] Donnelly, Paul. "Egyptian Faience Amulets in the Museum of Applied Arts and Sciences (Powerhouse Museum) in Sydney." *Mediterranean Archaeology* 12 (1999): 75-88. Accessed June 30, 2020. www.jstor.org/stable/24667850.

[61] Donnelly, Paul

of the amulet up close and potentially study the figure. Looking at a variety of photogrammetric scans of a variety of amulets could help students identify the different attributes associated with different amulets and why these attributes were important. Printing this artifact could be a great hands-on educational tool for students, particularly young ones, because it could help show them how transportable amulets were and that these amulets were meant to be kept close by the person who owned it. Getting to hold the amulet and study it up close could not only lead them to the same discoveries that could be made by looking at a photogrammetric scan, but it could also show them the context of how an amulet would have been used in antiquity.

Before creating any photogrammetric scans myself, I had to familiarize myself with the technology. This involved researching photogrammetry and its different applications, as well as understanding how the computer programs render the model. Understanding the technology was crucial whenever anything went wrong. It allowed for me to comprehend the problem and attempt to fix it. In order to learn more about photogrammetry, I did some of my own research, but I also participated in a course on Canvas that walked people through the different steps of creating a photogrammetric scan on Agisoft Metashape and Meshroom. This Canvas course was put together by the Center for Academic Technology (CAT) at Butler University, who I partnered with in order to create the photogrammetric scans.

Once I had a firm understanding of how to create a photogrammetric model or a 3D model using photogrammetry, I started using the technology. I began working in the lab in late January of 2021, and the first few times consisted of me trying out the camera and other equipment. It was challenging getting used to all of the equipment. Most of the equipment is expensive, and I was worried about accidentally breaking something. After practicing with the technology for around a week, I started working on the Hercules statuette.

The Hercules statuette was a challenging artifact to run through the photogrammetry software. The statuette is small and made of bronze, which made it difficult for the cameras to pick up specific details or proper color. This happens because the bronze is reflective, and anything that is reflective is going to pick up extra information from the area around the artifact and also have an incorrect color.[62] When photographing the statuette, I captured Hercules laying on his front and back and then propped up facing towards and facing away from the camera, all at the angles of -45, 0, and 45, as pictured in figures seven through nine below. The resulting photoset was about five hundred photos. Part of the preparation process is putting the photoset through Adobe Photoshop and having it assign masks automatically to the photos. This normally works really well and does not need to be drastically edited, but the Hercules statuette required lots of edits because of the gaps and holes in the statuette. These gaps confused the automated masking process, so I had to go in and fix almost every single photo manually. Manually editing the masks for this photoset took about three hours total.

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[62] Nicolae, C., E. Nocerino, F. Menna, and F. Remondino. "Photogrammetry Applied to Problematic Artefacts." *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-5 (2014): 451–56. https://doi.org/10.5194/isprsarchives-xl-5-451-2014.

Figure 7: Photo set up at -45, courtesy of the author

Figure 8: Photo set up at 0, courtesy of the author

Figure 9: Photo set up at 45 above, courtesy of the author

After I finished masking, I tried to build the mesh of the scan and kept getting an error message. Building the mesh comes after aligning the photos and it is the first step in having a complete photogrammetric scan. Once all of the photos are masked, then the photos must be aligned, which results in a point cloud of all of the photos put together. Examples of a point cloud can be seen below in figure seventeen or twenty. The mesh is based off of the aligned point cloud, and this is the first step where any problems, like holes or discoloration are normally visible. When the mesh of the Hercules statuette refused to render, the solution was to delete the entire project and restart. This meant I lost all of my work up to that point. I decided to forego working on the masks again and just try to reprocess the artifact because I was short on time. Once the artifact finally rendered, this caused extra geometry between the legs. This appeared as little random spots between the legs that could not be removed because the software believed it was part of the model. This can be seen below in the finalized version of the first Hercules model. I was also having a problem with Agisoft using photos from the photoset. The software did not align most of the photos that I took of the artifact laying down, which meant that there was a big hole on the base of the statue. Again, this could be edited after post-processing in a software like MeshLab, but I needed the scan for a presentation and did not have time to fix it. Another problem occurred when I color corrected the model before blending the texture. The bottom of the legs and the feet turned bright blue, which can be seen in the photos below. This was caused by the reflection of the lights on the bronze. I was able to fix it by editing the white balance, but the scan still came out super dark and very discolored. I uploaded this scan to Sketchfab, but it took a long time to calibrate all of the different software settings to make the scan look decent. The scan was very shadowy, which made it hard to see certain angles and details.

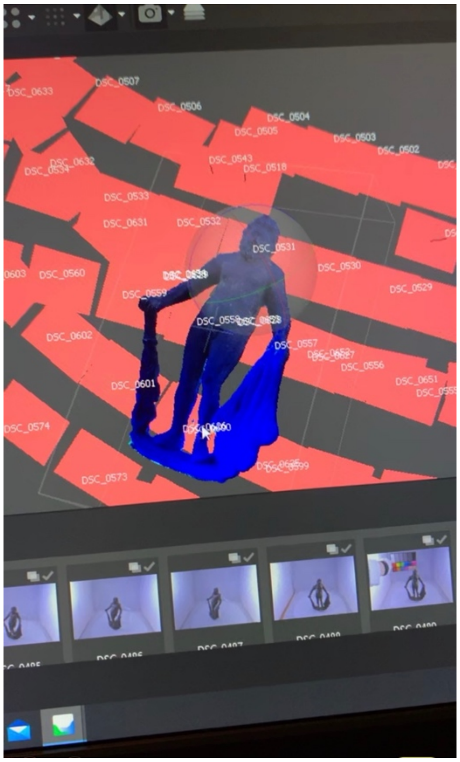
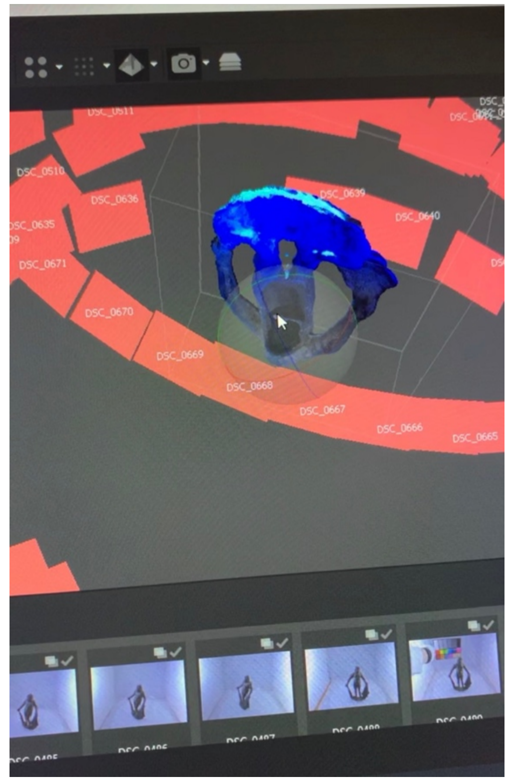
Figures 10&11: Blue Hercules, courtesy of the author


Figure 12: First completed model of Hercules, can see the extra geometry between the legs and also weird coloring, courtesy of the author

Between the extra geometry and the color of the original Hercules statuette scan, I knew I wanted to try working with this artifact again. When I retook the photoset of the Hercules statuette, I found a stand that allowed for me to take photos of the statuette upside down. I hoped taking pictures of the statuette upside down would help fix the hole in the bottom of the original photogrammetric scan. This ended up not working. There was still a hole in the base, but this time I took the extra time to go into MeshLab after the scan was done and edit the scan there. Editing the scan in MeshLab allowed for me to close the hole and blend it into the rest of the base, so that it is barely noticeable. The coloring of the statuette was much better this time as well, even though it was not perfect. The completed scan had feet and a base that were more gold than bronze, which stemmed from some of the patina that is on the bottom and back of the statuette. The change in color confused the software, so it placed the patina color over the entire bottom of the statue. I then uploaded this scan of the Hercules statuette to Sketchfab in place of the original. I still had to calibrate a lot of the settings, but it was much easier and required less work than the original. The finalized scan has a decent some discoloration but has no holes and shows detail clearly.

Figure 13: Finalized Hercules photogrammetric scan, courtesy of the author

When I began working on the canopic jar, my original intention was to generate three separate scans: one of the entire artifact, one of the lid, and one of the body of the jar. The full scan would serve as a way for the AMCA lab to make the artifact available digitally, while the two other scans could be 3D printed and used as one cohesive jar that the students could take apart. Because of this, I originally took a photoset of over 700 photos. The jar's stability allowed for me to easily take photos of the artifact in multiple positions, without having to worry about it breaking or falling over. At every position I took photos at the -45-, 0-, and 45-degree angles, which can be seen in the photos above.

The first time I ran the photos through Agisoft Metashape, I decided to use the entire photoset and see what happened, instead of trying to divide them up. I figured the software would react negatively to this in some way, but I wanted to see where the jar might need more information. The jar ended up rendering really well, but there was a weird gap between the lid and the jar. This is where the software had read information of the inside of the jar and the bottom of the lid, causing the information to conflict. The software understood that there was a base to the canopic jar's lid and that the jar was empty, but it then tried to merge them into one photogrammetric scan. On the resulting scan, between the gap you could see where the technology had tried to put in the bottom of the lid and the inside of the jar. Because of this, I had to figure out how to remove that conflicting information without compromising the quality of the rest of the model. After talking it through with Olivia MacIsaac in the digital lab, we decided to try and create two chunks. It was also decided at this point that I should just do one scan of the entire artifact and not worry about creating two separate scans of the lid and jar because it was unlikely that the AMCA Lab would ever attempt to 3D print this artifact. When a person creates chunks on Agisoft Metashape, they are basically creating two different scans, that they then merge together to form one whole scan. For the canopic jar, my plan was to create a chunk focusing on the top of the jar, and then a chunk focusing on the bottom. My hope was that after these were merged together, I would not have a weird gap where the lid and jar meet and would also be able to have the bottom be included as part of the scan. However, Agisoft Metashape would not allow for the two-point clouds to merge together, so this technique was not a possibility. When this became an issue, I decided to just create one large chunk of photos again, but this time disable the photos that showed the bottom of the lid or too much of the top of the jar and its inside. This process took a couple of hours, because I had to redo all of the masking and go through each photo to make sure the angle would not confuse the computer program. This strategy worked, and after getting an agreeable photoset the model rendered easily.

Even though there was confusion on camera angles and which photos to use in the overall model, creating this photogrammetric scan was relatively straightforward. The camera easily captured high-quality images because of the artifacts size, and the achromatic color of the jar meant that the software had few problems rendering the model. The gapping problem that happened the first time I tried to render the artifact was caused by my error and miscalculation rather than the software. This shows that it can definitely take the user awhile to understand which angles the software will respond best to and how to optimize the photoset. Adding the model to Sketchfab was also very simple, and the scan needed little editing once it was uploaded to the website. The final scan is very clear and there is no discoloration.

Figure 14: Finalized canopic jar photogrammetric scan, courtesy of the author

The lekythos was the most fragile of the artifacts that I worked with, which made procuring a sufficient photoset challenging. The stem, lip, and handle of the vessel all looked very fragile, and the lip of the vessel was uneven. The fragility and the instability meant that I was unable to take photos of this vessel from all of the desired positions, and I was worried this would impact the software's ability to fully capture the entirety of the lekythos, mainly the bottom. The artifact's fragility meant that most of the photos I captured had the artifact laying on its side. This concerned me because I had also captured photos of the Hercules statuette laying down, and the software had rejected most of them. This is because the artifact was too flat and did not have enough information for the technology to use. I decided to take photos of the jar standing up, and then lying flat on its side, all from the -45-, 0-, and 45-degree angles that were pictured above. This left me with a photoset of around 150 photos, which is normally very small for photogrammetry. Masking the photos was very time consuming because I wanted to make sure that the masks were not picking up any excess geometry that could confuse the software. The small size of my photoset meant that I needed all of my photos to be accepted by the software and aligned properly. Once I meshed the model, most of the lekythos looked perfect, except there was a weird flap over one part of the lip where the geometry had not fused together, which can be seen in figure 15 below. In order to fix this problem, I decided to try and take more photos of the lekythos and add them into the software to see if that would help. After repeating the steps of editing and masking, the bottom of the vessel in this model had multiple holes. I added more photos focusing on the bottom half of the vessel and repeated the steps, again taking extra care with the masks. Adding more photos to the photoset fixed my problem and the lekythos rendered beautifully on the third try. Completing the post-processing had minimal problems that were all easily fixed. This resulted in a well-lit, clear model that captured lots of detail. Uploading the model to Sketchfab was a little tricky because some of the detail was lost in the transition but changing some of the settings helped fix the problem.

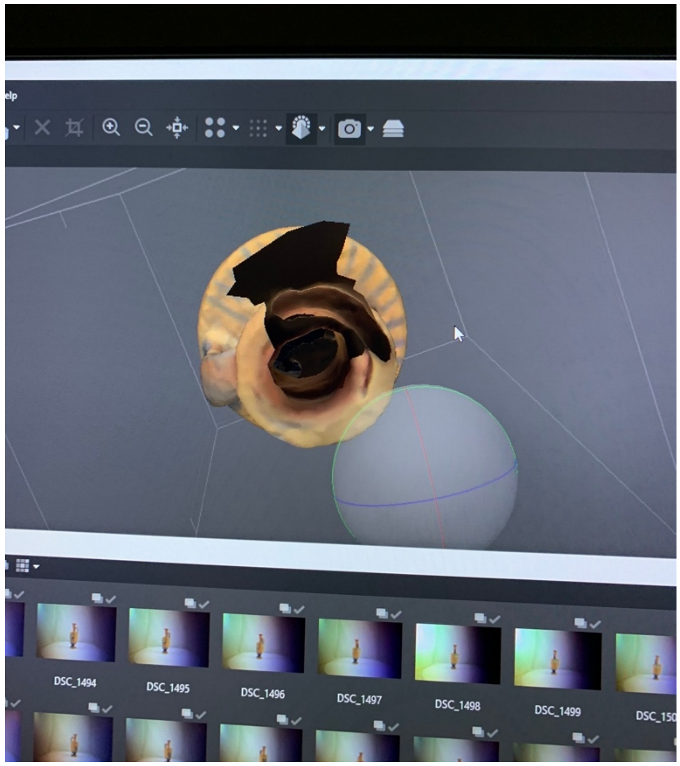

Figure 15: Hole on the lip of the lekythos in the first photogrammetric scan, courtesy of the author

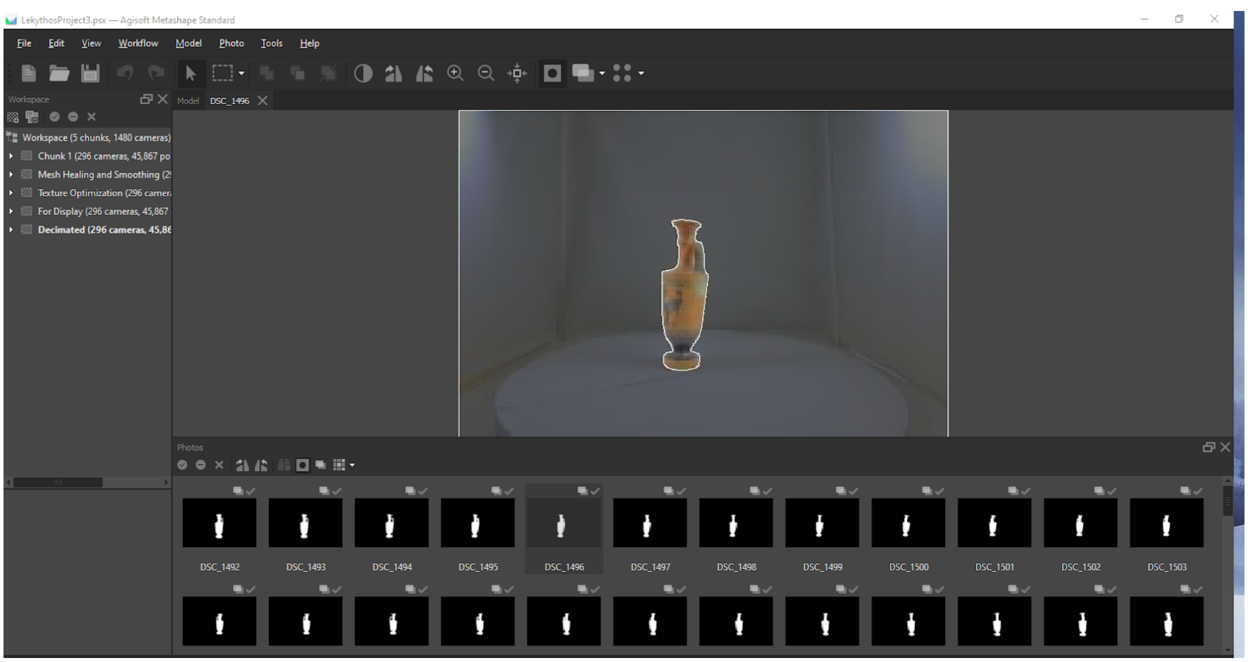

Figure 16: Appearance of masks. The white line around the object and everything highlighted within it show what has not been masked, so it will be included in the scan, courtesy of the author

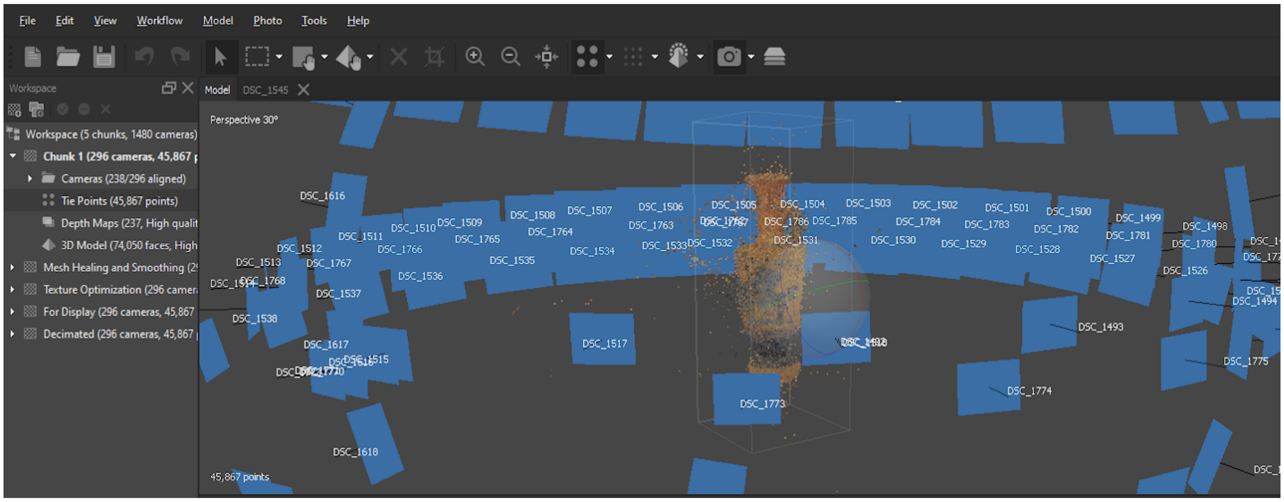

Figure 17: Point cloud of lekythos, courtesy of the author

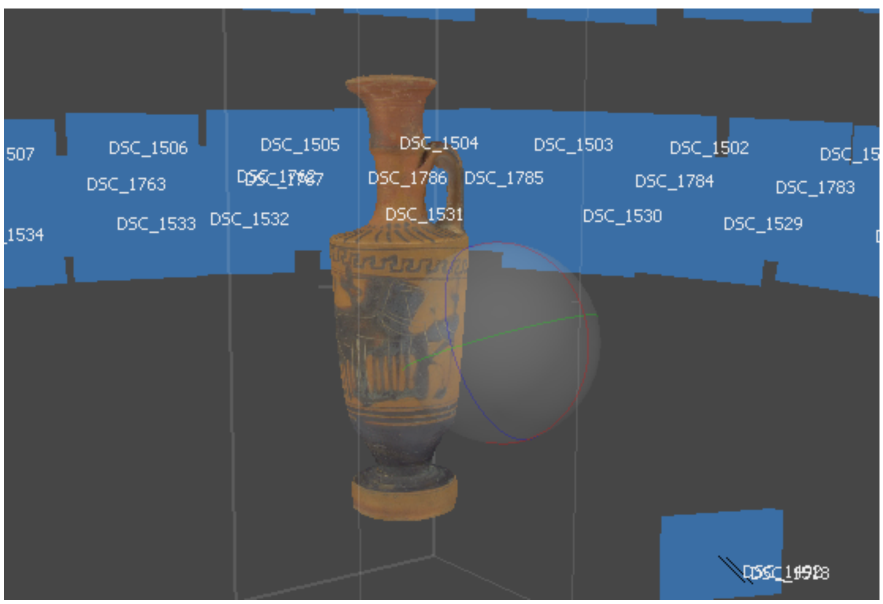

Figure 18: Finalized photogrammetric scan in Agisoft Metashape, courtesy of the author

Figure 19: Finalized photogrammetric scan in SketchFab. The change in quality is recognizable, courtesy of the author.

I was the most worried about the Bes amulet because of how small it is and its material. The amulet was made out of faience, the material discussed on page 28, which makes the artifact a little shiny. The faience is also fading a little bit in some places, making me worried that the contrasting colors would confuse the technology. This amulet is also very small, a little under two inches tall and not even an inch wide, so I was concerned that the software would not be able to pick up specific details. I had originally planned on working with a different amulet, but that amulet was miniscule. The small size of this amulet would have made it impossible for the software to render it well. When I was taking the photoset of the Bes amulet, I was able to capture photos of the artifact laying on its back, on its front and standing up straight, all at the -45-, 0-, and 45- degree angles mentioned above. As I was capturing the photos, I only grew more worried because the amulet was small compared to everything else in the photo, and I was worried about the software not focusing on the artifact. The editing of the photos went fine and nothing noticeable happened. Editing the masks on this photoset took the longest of any of the other artifacts because the mask of every single photo had to be edited by hand. The artifact was also very detailed, so I had to take care and make sure that the masks were as close to the artifact's edges as possible. The masking took a total of around five to seven hours. After the masking was finished, the rest of the steps went by with no problem. The point cloud looked a little messy, which can be seen in figure twenty. The messy point cloud made me worry that the rendered model would have holes. I was able to clean the point cloud up a little bit, and once I rendered the model everything on the artifact was perfect. The color was amazing, there were no holes, and the detail had been copied really well. I was very shocked because this was the first artifact that I did not have to redo at all. When I uploaded it into Sketchfab, the details copied over a little weird. Like the other artifacts, once I edited some of the settings the photo was fine.

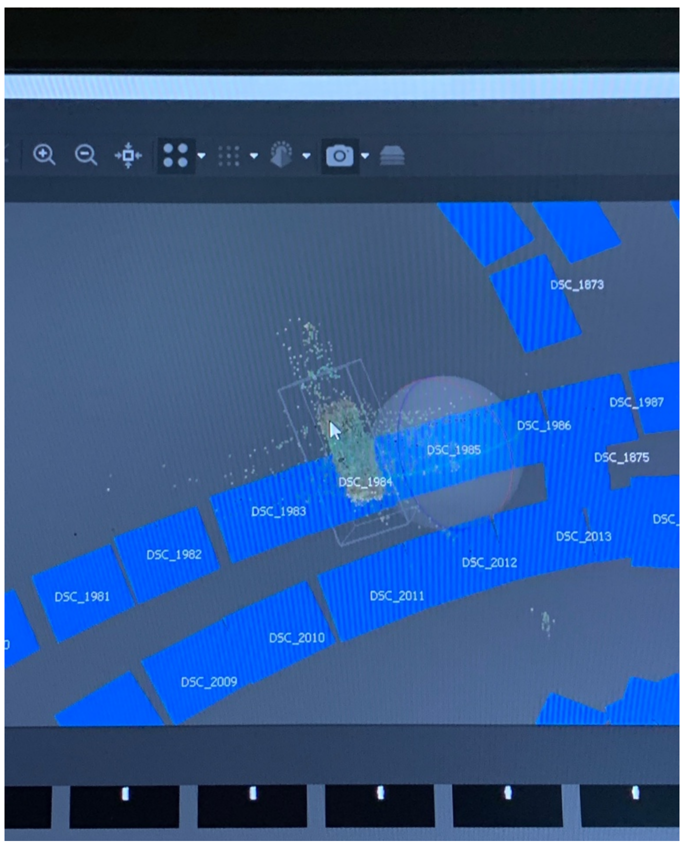

Figure 20: Bes point cloud – the concerning part is the points that are visible above and out to the side of the main artifact. I was worried they would mess up the mesh, courtesy of the author

Figure 21: Finalized photogrammetric scan of the Bes amulet on SketchFab, courtesy of the author

DISCUSSION

Based on this research, I have concluded that all ages could learn from photogrammetric scans and their different educational applications as a supplementary educational tool in a museum environment. However, I do think that specific age groups would largely benefit from specific technologies more than others. This was influenced by play-based learning, object-based learning and the Reggio Emilia approach, which show the benefits of using these different heuristic methods with younger individuals. 3D printers give museums the opportunity to let younger guests interact more personally with artifacts. I still think that the middle age group, nine- to eleven-year-olds, would benefit from looking at a 3D digital scan on a computer or tablet with guided adult interaction because they would need an adult to keep them on track. I believe that using these technologies to supplement other lessons or fun activities would help all age groups understand more about what they are seeing, while giving them greater context. Before my research, I thought that virtual reality or virtual environments would be most beneficial for the middle school age group. However, I have come to recognize that all ages at and above the middle school level would benefit equally from participating in virtual reality. At this age, these individuals can be more self-guided and do not need as much supervision. Overall, museums should begin to look at the other ways they can use the technology they already have in other areas of the museum. By doing this, they can enhance the visitor experience and experiment with different ways guests like to learn.

While photogrammetry is a great tool for making artifacts more accessible both online and within a learning institution, it is quite challenging and can be a very time-consuming project. The user is basically trying to predict how the software is going to react to the artifact, and then they plan their photoset around that. If the photoset is not sufficient or if the software does not like something about the artifact, then it will take altering the photoset and running it through the program again to see if the problem has been fixed. I ran into problems with the software rendering the artifact correctly at least once with three of the four artifacts, and I ended up having to redo those three scans multiple times. Potentially having to redo or edit the photogrammetric scans and how time consuming it can be is something that people should be aware of when they start this process.

All of the necessary materials also means that this is an expensive project, which might not make it possible for certain cultural institutions. Cheaper alternatives would be taking photos using an iPhone and the application Focos, which allows for a phone to take high-quality, well-focused images. This can be paired with Meshroom, a free alternative to Agisoft Metashape. I tried to occasionally use Meshroom when Agisoft Metashape was not working for me, and it never worked and never liked my photosets. For Meshroom to work well, the photoset normally needs to be of a larger object that is made of rougher material, and the aperture of the photos needs to be much higher than it does on Agisoft Metashape. The only artifact I worked with that Meshroom might have liked was the canopic jar because it was a little bigger and made of a rougher material. Even though Meshroom is free, Agisoft Metashape is much more user friendly because it can handle photos that are a lower quality and work with smaller objects. The Standard Edition of Agisoft Metashape is a one-time fee of $179, which is reasonable if a person is attempting to complete a large-scale project and is not just looking to do photogrammetry as a hobby.[63] The Professional Edition of Agisoft Metashape is much nicer because it allows for the user to do more with the object, the geometry of the scan, and the photos. However, this version is $3499 and is mostly for larger institutions or museums.[64] I worked primarily with the Standard Edition, but the Center for Academic Technology is purchasing the Professional Edition for use in future projects at the end of this academic year.

If I could do this project again, I would set aside more time in the digital lab for me to work with the software. I worked in the digital lab only during the second semester because of time conflicts, which resulted me feeling rushed to get all of the scans completed. Having more time would have allowed me to not feel as rushed and potentially produce higher quality scans. I needed to have the first Hercules statuette done halfway through February for a conference that I presented in, which resulted in me rushing to complete the scan. Another thing I might change are the artifacts themselves. The software did not react well to three of the four artifacts that I worked with. This gave me good experience with trying to create these scans with difficult

63 "Buy." Online Store. Agisoft. Accessed March 25, 2021. https://www.agisoft.com/buy/online-store/.

64 "Buy." Online Store.

artifacts but mixed with the time constraint it might have been better to stick with bigger artifacts that were made of non-reflective material.

Photogrammetry is a fantastic tool that can expand the accessibility of artifacts and other material culture for the general public. Even though creating high-quality photogrammetric scans can be time consuming and expensive, the positives of how this can impact collections data, collections accessibility, and museum education make this process worthwhile. The long-term benefits outweigh the time and financial efforts put into creating these scans. There are also cheaper alternatives that can create decent models depending on what the user or institution is looking for that helps make this software accessible to everyone.

CONCLUSION

When individuals go and visit museums, many expect to see artifacts in glass cases and quiet galleries filled with artwork. While this may be true for some institutions, others have started to recognize the benefit of having more hands-on activities and computer interactives to help the visitors understand the exhibit material. Photogrammetry is a technology that has grown more popular as an archival method within the last five years, but I believe that these photogrammetric scans can be used for more than just archiving artifacts. Photogrammetric scans of artifact can be used to increase accessibility to a museum's collection online, but they should also be used within the exhibits themselves to allow guests the opportunity to interact with artifacts more than they would normally be able to. Certain age groups also learn better from the use of specific technologies, so using photogrammetry with technologies like 3D printing and virtual reality helps make this form of hands-on museum education available to a wide audience.

I based this hypothesis off of three different pedagogies – play-based learning, object-based learning, and the Reggio Emilia approach. Based on these three pedagogies, I argued that the youngest age group, six- to eight-year-olds, would benefit mostly from playing with a 3D printed version of a photogrammetric scan; the middle age group, nine- to eleven-year-olds, would learn the best from interacting with a digital scan on a tablet; and that the oldest age group, twelve- to fourteen-year-olds, would have the best experience interacting with a virtual environment. My research led me to believe that all of these technologies could help with museum education for every age group, but that some age groups would have trouble learning from specific technologies. For instance, while the youngest age group might have fun in a virtual environment, I believe that it would be too hard for them to really grasp what is going on or what they are looking at. I also believe that all ages, not just these three age groups, could benefit from using these three technologies in a museum setting. By applying object-based learning, play-based learning, and the Reggio Emilia approach to photogrammetric scans, one can understand the benefit of including photogrammetric scans in exhibits as an educational tool. If museums began to use the photogrammetric scans with the public, instead of just seeing this technology as an archival method, then they would increase the visitor experience and the education value of their visit.

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Appendix

Program Title: Canopic Jar Lesson
Program Description: Participants will learn about archaeology and how archaeologists can understand the past through material culture, while also learning about Ancient Egypt and how Ancient Egyptians preserved the dead. They will participate in an online mummification activity to see the stages of mummification and the various tools that were used at different stages. They will look at a canopic jar scan up close to see what real canopic jars would have looked like. They will also look at any possible images of mummy x-rays/scans or quotes from Herodotus to understand how archaeologists can learn from material culture. Afterwards, they will go through a Kahoot to answer questions about mummification in Egypt.
Target Audience: Grades 3-6
Goal: Participants will learn about archaeology and how they discover things about the past while learning about Ancient Egyptian mummification
Objectives: Participants will

- Define archaeology
- Define mummy
- Define artifact
- Ask questions about mummification
- Ask questions about archaeology/archaeological process
- Use what they learned to answer questions
- I would like them to use a little more critical thinking so maybe think of a way where they could work in teams and discuss the answer??

Academic Standards:
3.1.6 Use a variety of resources to gather information about your region's communities; identify factors that make the region unique, including cultural diversity, industry, the arts, and architecture.

4.1.16 Identify different opinions in historical documents and other information resources and identify the central question each narrative addresses.

5.1.20 Using primary and secondary sources to examine an historical account about an issue of the time, reconstruct the literal meaning of the passages by identifying who was involved, what happened, where it happened, what events led to these developments, and what consequences or outcomes followed.

6.1.2 Describe and compare the beliefs, the spread, and the influence of religions throughout Europe and Mesoamerica.

6.1.20 Differentiate between fact and interpretation in historical accounts and explain the meaning of historical passages by identifying who was involved, what happened, where it happened, and relating them to outcomes that followed and gaps in the historical record.

Supplies:

- Canopic Jar photogrammetric scan (on Sketchfab)
- PowerPoint with link to "Making a Mummy" game and pictures of Herodotus
- Game: https://www.childrensuniversity.manchester.ac.uk/learning-activities/history/ancient-egypt/making-a-mummy/

- Kahoot game
- Back up white boards/markers (6) and a PowerPoint with questions/answers in case the school does not have access to individual devices

Setup:
- Put students into groups of four or five depending on the size of the class
- Set up PowerPoints on the projector and have the links for the game, canopic scan, and Kahoot ready, so that the students can either type in the link or have it shared with them

Presenter Info/Procedure (with steps):

1) Introduction (5-7 min)
    a) "Today we are going to be learning more about archaeology by looking at Ancient Egyptian mummification and how archaeologists have been able to figure out more about how and why the Ancient Egyptians practiced mummification."
    b) But first, what is archaeology? What do archaeologists do?
    c) Archaeologists are scientists who study the things (artifacts) left behind by people in order to learn more about how these people lived in the past. Sometimes archaeologists search for and dig up these artifacts themselves. Other times they study artifacts that have been previously discovered by someone else.
    d) "What do you think an artifact is?"
        i) Object left behind by people who lived in the past. Could be anything from a temple, house, skeleton, their trash, whatever. By studying these things and learning more about them, it helps tell us more about how people would have lived and used those things.
        ii) Anything that a human has made, changed, or used
        iii) Archaeologists also learn from the area around the artifact (context) and will record everything about where the artifact was found. This gives them more clues or information to look at when they are trying to piece together how or why something was used. Without this context, it would be harder and maybe even impossible to answer these questions.
    e) Archaeology is a science. Archaeologists work in a methodical way to obtain information from what they are studying, and then make a conclusion based on the evidence they have collected and studied.
2) (3-5 min) Who here has heard of Ancient Egypt? Ancient Egypt was a civilization that was around for over three thousand years. When people would die in Ancient Egypt, they would mummify that person. Has anyone here ever heard of mummies or mummification before? (Expect one of the kids to say something about how they come alive or something) Mummification is just a form of preservation, which means that the body doesn't go away over time like it normally would. Have you ever been to a park? When you go to the park do you see dead animals like squirrels or chipmunks all over the ground? This is because their body slowly goes away over time. However, the Ancient Egyptians believed that in order to go to the afterlife, a person's body needed to be preserved.
3) (1 min) Archaeologists and Egyptologists can learn more about Ancient Egyptian mummification by studying mummified bodies and other artifacts, as well as reading accounts from historians who lived during the period like Herodotus. (Histories, Book 2, pages 126-128)
4) Activity (15-20 min)
    a) (At this time have the link copied and pasted onto the PowerPoint so that the students can type in the link. This way they will not be messing with the game while the introduction is happening) Okay, now you will all be working your way through an activity in order to see the process of mummification in Ancient Egypt. Make sure to read through the activity carefully. When you are done, feel free to play around on one of the other activities about Ancient Egypt.
5) Photogrammetric Scan (15-20 min)
    a) Now that you have all completed the activity, we are going to be looking at a real canopic jar online. Canopic jars are artifacts that are found in a funerary context, which means that they are

artifacts found around or concerning a burial. These kinds of artifacts are what tell us more about how these people are mummified, why the Ancient Egyptians believed in body preservation, and their overall religious practices and beliefs. This canopic jar belongs to the Ancient Mediterranean Cultures and Archaeology Lab at Butler University. It is a Late Kingdom canopic jar, which means it would have been made about 2,500 years ago. The lid of this jar has the head of a jackal-headed god named Duamutef. Do any of you remember which organ/body part goes into this jar? Stomach, right! Okay, spend the next five minutes looking at the artifact and making as many observations as you can. When we're done we will write some of the observations on the board. Okay go!

b) Now that you all have looked at the artifact, we are going to write different observations on the board. Who would like to write an observation first?
    i) Then take the next ten to fifteen minutes to have the students write their observations on the board and then talk these observations out with the students. Ex: one writes that there were numbers on the bottom of the jar, ask them why they think those numbers might be there, tell them it is an accession number, ask them why an accession number might be important for a museum.

Kahoot (20 min):

You all have done a great job so far! Because you all are experts at this point, we are going to play a game of Kahoot. Have you ever used Kahoot before? (start the game of Kahoot and explain to them how the game works, even if they have played it before)

1) What do archaeologists study? Artifacts
2) What side of the Nile do they take the person to be mummified? West
3) How do the people who are mummifying the body remove the brain? through the nose
4) How do they get the organs out of the body? A cut on the left side
5) Which organs are placed in the canopic jars? Stomach, liver, intestines, lungs
6) Which organ goes into the jackal-headed canopic jar? Stomach
    a) Bonus question - what is the name of the god on the lid of the stomach jar? Duamutef
7) How long do they let the body sit in Natron salt? 40 days and nights
8) What kind of amulet is put over the cut in the body for protection? Two-fingered amulet
9) What material do they wrap the mummy in? Linen
10) What do they place the mummy in once it is done? Sarcophagus

Conclusion (1 min):
You all did a great job today, learning about the different ways archaeologists can learn more about people who lived in the past by studying artifacts that are left behind. You did this by going through an activity on Ancient Egyptian mummification, looking at a canopic jar, making observations, and then answering questions about what you had learned!