Virtual Artifact Curation of the Historical Past and the NextEngine Desktop 3D Scanner

Bernard K. Means, Ashley McCuistion, and Courtney Bowles

ABSTRACT

Virtual curation of artifacts—the creation of intangible digital models from tangible artifacts—has clear benefits to opening up the historical past. Researchers and the general public anywhere in the world can access, manipulate, and share three-dimensional (3-D) digital models of artifacts that might otherwise be locked away behind display glass. This enhanced access will contribute to a broader reflexive archaeology and further archaeology as a tool for social engagement. This paper focuses on the efforts of the Virtual Curation Laboratory to curate and digitally conserve objects from historical sites using a NextEngine Desktop 3D Scanner. Virtual curation of historical objects is well suited to reflexive and collaborative research efforts between scholars and students located around the globe, and for public outreach both in brick-and-mortar museums and throughout cyberspace. Digital artifact models and plastic replicas created from these models can also be successfully and inexpensively integrated into K–12 and undergraduate educational endeavors, facilitating science, technology, engineering, and math goals.

Introduction

Our application of 3-D scanning technology in the Virtual Curation Laboratory at Virginia Commonwealth University was initiated as part of a project funded by the Department of Defense (DoD) Legacy Resources Management Program (Legacy Project No. 11-334) and sponsored by the U.S. Marine Corps. The goal of that study was to provide guidance related to the creation and application of 3-D digital collections of artifacts that have been or can be expected to be found on DoD installations. The overall goal of Legacy Project No. 11-334 was to test and demonstrate the effectiveness and usefulness of available 3-D scanning technology and software for potential employment in ensuring DoD compliance with historic preservation laws (Means, King et al. 2011a, 2011b; Means, Bowles et al. 2013). The scanner is not without its issues, as addressed below, but persistence will lead to the creation of many digital artifact models with a wide range of uses, some of which are touched on within this paper.

The lessons learned from the Legacy-Program-sponsored project by the Virtual Curation Laboratory have broad applicability to the preservation and presentation of the historical archaeological record (Means 2013). The creation of digital models of historic period artifacts, and those from earlier periods as well, is enabled through 3-D scanning. The Virtual Curation Laboratory has scanned a wide variety of artifacts ranging from a million-year-old Acheulian handaxe from South Africa to fragments of a German bomb recovered from World War II London. "Virtual artifact collections" of 3-D digital artifact models can significantly enhance the curation, analysis, and interpretation of historical archaeological objects recovered from across the world (Figure 1). The Virtual Curation Laboratory uses a NextEngine Desktop 3D Scanner to assist with the creation of "virtual archaeological collections" using material from heritage site locations such as Colonial Williamsburg, George Washington's Ferry Farm, James Madison's Montpelier, Jamestown Rediscovery, the Mount Vernon Estate and Gardens, and Thomas Jefferson's Poplar Forest, among other locations (Figures 2–4). Specific details of scanning efforts at these heritage site locations can be found on the project blog (<http://vcuarchaeology3d.wordpress.com/>).

Virtual Curation of the Archaeological Record

Virtual curation efforts represent an attempt to extend conservation and access to collections from the material into the virtual realm—simultaneously enhancing preservation of artifacts while increasing their accessibility (Means 2013; Means, Bowles et al. 2013). Creating digital media that can be shared and manipulated in multiple dimensions increases the ability to generate new interpretations and new insights into archaeological remains.

Figure 1. A World War I toy soldier from Thomas Jefferson's Poplar Forest in Forest, Virginia, is prepared for scanning (*left*), allowing the creation of a digital model (*right*). (Photo by Bernard K. Means, 2012.)

Figure 2. Courtney Bowles and Bernard K. Means scan a mended colonoware bowl fragment at George Washington's Mount Vernon in Mount Vernon, Virginia. (Photo by Ashley McCuistion, 2012.)

Figure 3. Rachael Hulvey scans an historical artifact at Thomas Jefferson's Poplar Forest in Forest, Virginia (Photo by Bernard K. Means, 2012.)

Figure 4. Ashley McCuistion scans an historical artifact in the Small Finds Laboratory at George Washington's Ferry Farm in Fredericksburg, Virginia. (Photo by Bernard K. Means, 2012.)

The NextEngine scanner used by the Virtual Curation Laboratory employs lasers to record topological (surface) attributes of an object. Presented here is a discussion of the basic operation of the scanner when applied to archaeological objects, detailing of common problems encountered with creating digital models from artifacts of varying types, and consideration of some solutions developed as part of the research for this project or that were encountered during the literature survey (McCuistion et al. 2013; Means, Bowles et al. 2013).

Hardware Requirements

A Dell Latitude E6420 laptop with 4 gigabytes (GB) of random access memory (RAM) and a 250 GB hard drive is normally used to operate the NextEngine scanner in the Virtual Curation Laboratory, on location at various collections repositories, or even in field archaeological settings. Although the scanner is portable, especially with the use of a laptop, it does require an external power source. Field operations require the use of a generator or other power source. The laptop is fine for most archaeological scanning purposes, but inadequate for processing data files for large or complex objects. Standard desktop computers are inadequate for this task as well, as they have insufficient memory, especially relative to video capabilities. Most digital models created using the scanner were therefore edited using an Alienware Aurora Desktop ASR3H with 16 GB of RAM, a 4 GB video card, and a 2-terabyte hard drive that was obtained to avoid the limitations of standard desktops.

Operation and Setup

In normal operation, archaeological objects are placed on a small platform that attaches to the NextEngine scanner (Figure 5). This platform turns an archaeological object a full 360º, and the lasers emanating from the scanner record the object as it rotates. The small platform does not rotate continuously but rather at fixed intervals, or "divisions." At each rotation, the scanner uses its lasers to record a "panel." The small platform upon which objects are placed needs 4–16 intervals to complete a 360º arc designed to capture all morphological data in a broad horizontal zone from the base to the tip of an object. As the number of

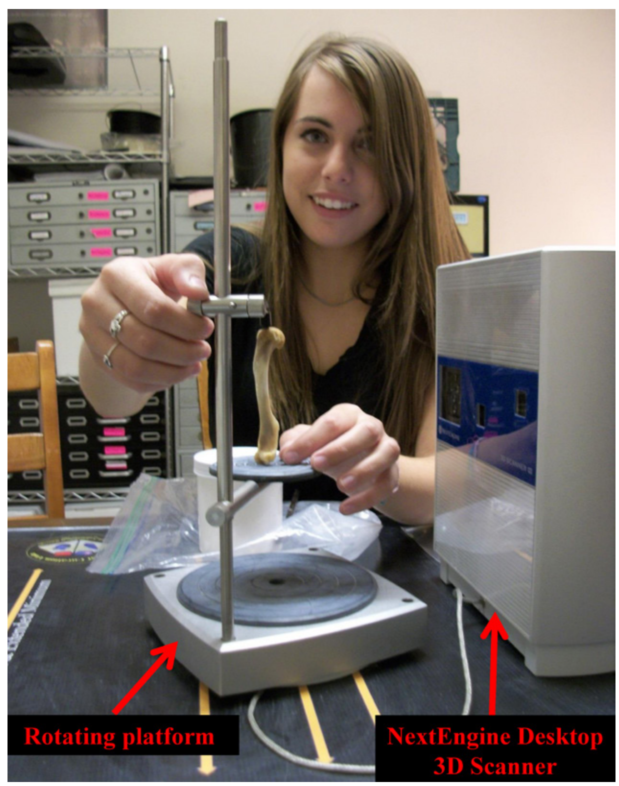

Figure 5. Mariana Zechini places a raccoon bone on the rotating platform attached to the NextEngine Desktop 3D Scanner in the Virtual Curation Laboratory in Richmond, Virginia. (Photo by Bernard K. Means, 2012.)

panels increases, the amount of data generated to create a digital topological model—and the time needed to gather that data—increases as well. A review of the literature and extensive experimentation by personnel associated with the Virtual Curation Laboratory indicate that the optimal scanning setup for most archaeological objects is an eight-panel interval. Fewer panels are generally not advisable, and some objects may require as many as 12 panels, but usually no more. In addition to the number of panels, the user has the option to select the "number of points per square inch" recorded for each panel in the ScanStudio HD PRO software that operates the scanner (Figure 6). These include quick, standard definition and high definition (HD) options. The HD option is ideal for most archaeological objects.

The user next selects a "target" option in ScanStudio: dark, neutral, or light. "Target" basically refers to the reflective qualities of an object. For most artifacts, the neutral option should be selected. The light option should be reserved for bright objects—usually very white objects such as historical ball clay pipes. In the experience of the Virtual Curation Laboratory, the dark setting rarely works. The lasers used by the scanner are simply absorbed by dark objects and do not reflect adequately back to the scanner. There are ways to mitigate this issue in some cases.

The final option the user must select in ScanStudio is the "range," which refers to the distance between the scanner and the object being scanned. The option screen for ScanStudio indicates the minimum, maximum, and ideal distances for each range option. For most small artifacts, the macro range is ideal, ranging from a minimum of 5 in. to a maximum of 9 in., with an ideal location of 6.5 in. It is very important to ensure that an object does not cross outside of the minimum or maximum distances of each range option—otherwise a distorted digital model is generated.

To the right of these options on the computer screen in ScanStudio is a small viewing window created by the camera built into the scanner. The user should do a full rotation of the object to ensure that the object is completely within the window—and also stable on the rotating platform.

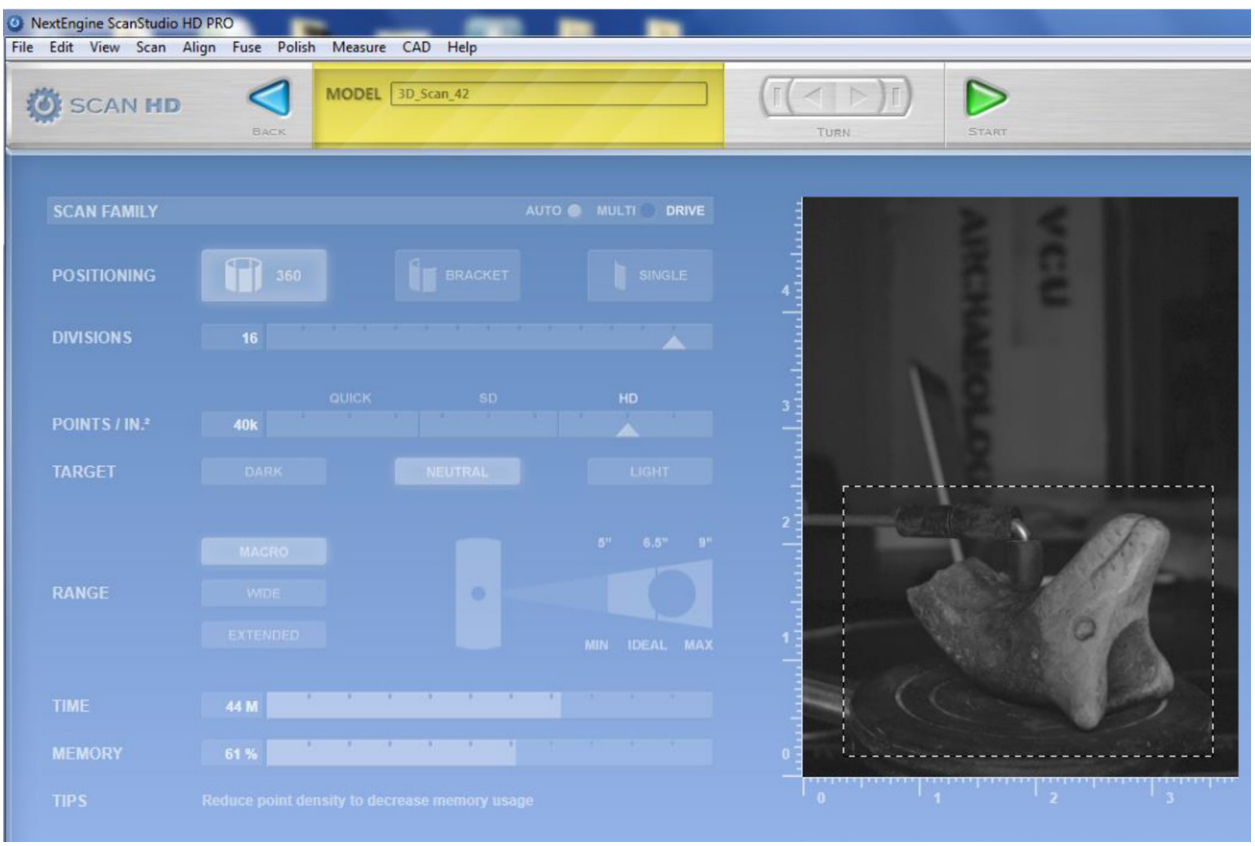

Figure 6. Opening screen setup for ScanStudio HD Pro. The object in the window is a Susquehannock smoking-pipe bowl in the shape of a canine's head. (Photo by Bernard K. Means, 2012.)

Each archaeological object needs to be held immobile as the small platform rotates. A problematic scan of the artifact will be generated if it moves or vibrates during the scanning process. The user has the option of using the mouse to draw a box around the object to limit the amount of extraneous information that the scanner records.

Orienting an Object for Scanning

Most objects will be placed directly on a small adjustable steel mount covered with a removable black rubber disk; the steel mount extends from a steel pole fixed into the rotating platform (Figure 7). The adjustable rubber-covered mount has sufficient flexibility to grip the base of the object without being so rigid that damage to the object is a concern. An adjustable gripper with a rubber tip that can be moved and tightened also extends from the steel rod that can be fixed to the top of an object—again with sufficient flexibility and limited rigidity to hold an object in place securely without damaging it. While each object is held secure on the rotating platform, the very base and very tip of the object are obscured from the scanner's lasers. To capture these missing data, each object has to be physically rotated approximately 90º and scanned again.

Figure 7. Natalie Petrizza sets up a turtle shell for scanning in the Virtual Curation Laboratory in Richmond, Virginia. (Photo by Bernard K. Means, 2013.)

Thus, in order to get a complete digital model, most objects need to be scanned twice—subject to two scan sessions—unless there were no significant attributes obscured in the initial scan. In some cases, the missing base/tip data could readily be extrapolated from existing features. ScanStudio allows one to fill in the "missing" data from the initial scan when generating a digital topological model.

Large objects can also be scanned without using the rotating platform. For objects too large or unwieldy to be placed on the rotating platform, the object itself can be physically moved. A lazy Susan has been successfully used in the Virtual Curation Laboratory for this purpose. The scanner itself can also be moved relative to a large object by mounting the scanner on a tripod via a screw hole in its base. A very sturdy tripod is needed in this situation.

Known Issues

Some objects have attributes that are not conducive to 3-D scanning; the scanner's lasers do not interact well with reflective artifacts. One can mitigate some data recording problems by dusting objects with a fine powder, which dulls reflectivity but preserves morphological attributes. Conservators at the Colonial Williamsburg Foundation note that baby powder has a neutral effect on objects and is certainly suitable for this purpose. Dark objects generally also need to be coated with the fine powder—as noted above, the scanner does have an option to record dark objects, but this setting rarely works well. Transparent objects such as glass bottles obviously need to be well coated or the scanner's lasers would simply pass through them.

The scanner also has issues with recording items that are thin or that have thin edges. Coating these items with a fine powder increases their texture and the ability of the scanner's lasers to record the objects. Commercially available baby powder is inexpensive and well suited for this purpose. Consultation with conservators at Colonial Williamsburg Foundation revealed that off-the-shelf baby powder can be safely used for this purpose. Certain thin objects—notably small and round objects—generally cannot be scanned regardless of attempts to enhance their ability to be scanned. Staff at the Virtual Curation Laboratory had little success in obtaining digital models of coins, buttons, or similarly shaped artifacts. This appears to be at least in part a software issue. In some thin, round objects the digital model of the obverse of the object becomes superimposed on the reverse of the object. One solution is to scan first the obverse and then the reverse of the object, and integrate them through third-party software. ScanStudio is not capable of integrating these two digital models.

It must be emphasized that the scanner uses lasers that are specifically designed to record topological (surface) attributes of an object (Figure 8). A full digital model is not always possible for objects with certain forms, such as pipe bowls and hollowware vessels (particularly restricted jar forms). For these objects, the exterior attributes can be recorded without any difficulty, but this is not the case for their interiors. The digital models generated by the scanner can be edited using 3-D modeling software to "open up" interiors. One software solution is Rhinoceros (<http://www.rhino3d.com/>).

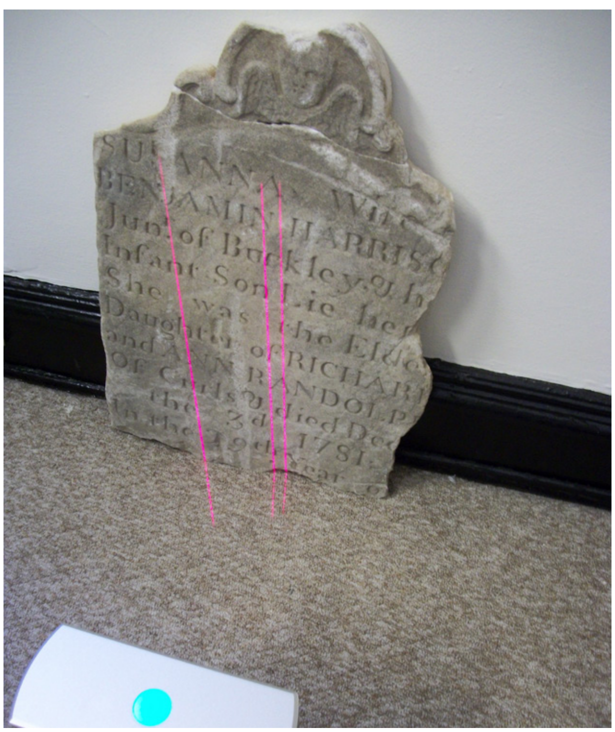

Figure 8. An archaeologically recovered tombstone as it is being scanned in the Virtual Curation Laboratory in Richmond, Virginia. (Photo by Bernard K. Means, 2011.)

When successful, the digital models generated from the scanner are generally very accurate in how they record surface topology and can certainly produce precise measurements. They cannot, however, always accurately capture an important attribute: color. Digital topological models are dynamic representations that go beyond static images, but still can lose critical details. The scanner is equipped with a basic camera that does record color attributes, but it often does not record these attributes well. This is a significant limitation of the scanner. Third-party software can be used to map high quality color digital photographs onto a digital topological model, but this is by no means an easy process.

The proprietary ScanStudio software associated with the scanner is relatively unsophisticated, and the two digital models created for most objects have to be manually aligned by a Virtual Curation Laboratory team member. To manually align two scans, at least three points of shared reference need to be visible within each digital model. For many objects scanned as part of this study, the reference label applied to the object was sufficient for this purpose. For objects lacking an artifact label, painter's tape was placed in a location visible in each of the two scans. Consultation with conservators at the Colonial Williamsburg Foundation indicated that painter's tape is ideal for this purpose, as the tape is noninvasive (Figure 9).

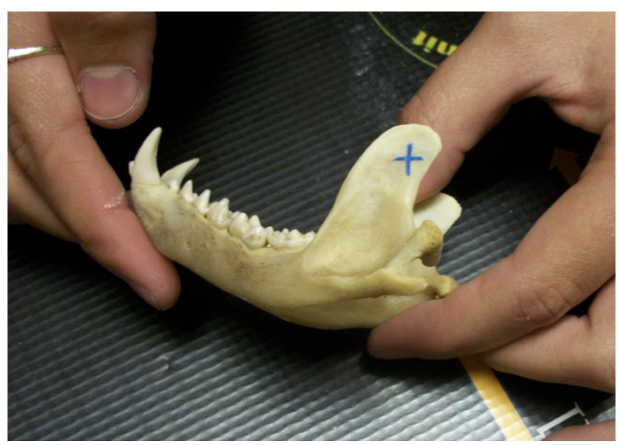

Figure 9. Raccoon mandible with painter's tape arranged to form an X. (Photo by Bernard K. Means, 2012.)

The operation of the e-scanner is influenced by environmental variables, notably heat and light. The scanner works best in a well air-conditioned room and in minimal lighting conditions. In situations where excessive lighting cannot be easily mitigated, one solution is to completely cover the scanner and the rotating platform with a box or other container. Failure to mitigate excessive heat or light will create rough, oddly textured digital models—or no digital models at all. In extreme heat, the scanner will simply stop functioning (Figure 10). Shading the scanner in the field—a sufficiently large cardboard box will do—can be used to mitigate excessive light, and external cooling can be used to mitigate the heat issues. The Virtual Curation Laboratory has successfully used the scanner in field settings.

Scanning of Select Historical Artifact Classes

Generating a complete 3-D model for whole ceramic vessels or smoking pipes is generally problematic, unless the objects are shallow. Low-fired and unglazed wares, regardless of origin, generally scan quite well. Researchers at the Virtual Curation Laboratory initially thought that glazed refined earthenwares would prove problematic for the scanner because of the reflective properties of the glazes. This proved generally not to be the case, however (Figure 11). The lasers from the scanner simply penetrate the clear glaze and reflect back from the underlying ceramic paste. White clay tobacco pipes scan well if the scanner is set to record on the light setting.

Silver, gold, copper, or steel artifacts generally need to be coated with a fine powder to make 3-D scanning possible. Unconserved iron objects usually do not have to be treated. Some conserved iron objects are coated with a black wax to help protect them from further decay and degradation. The scanner is usually unable to create a digital model of dark objects. Normally, dark objects can be coated with a fine powder, but this is not possible with conserved iron objects as the fine powder adheres to the wax and is not easily removed.

Only a few glass objects were scanned by the Virtual Curation Laboratory because of their translucent qualities. Some glass objects were coated with a fine powder, but the powder did not adhere well. One solution recently suggested was to create a static charge and apply it to the glass—this could make the powder adhere to the glass. Team members have not yet had the opportunity to test this possible solution.

The opportunity did arise to scan some wooden artifacts recovered from the *Betsy*, a British ship sunk off of Yorktown, Virginia, at the end of the Revolutionary War. The e-scanner works very well with these conserved

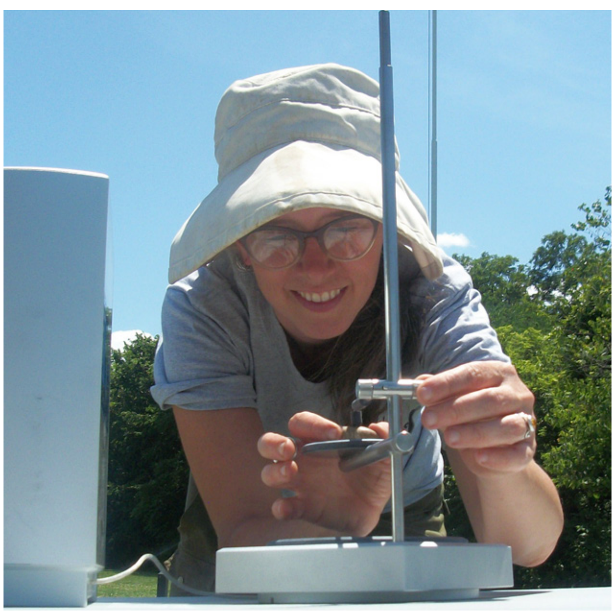

Figure 10. Courtney Bowles attempts to scan a minié ball in the field at George Washington's Ferry Farm in Fredericksburg, Virginia. The scan failed because of excessive heat and light. (Photo by Bernard K. Means, 2012.)

Figure 11. Three-dimensional digital model of an ironstone bowl fragment recovered at Marine Corps Base Quantico and now in the collections of the Fort Lee Regional Archaeological Collections Facility in Fort Lee, Virginia (Photo by Bernard K. Means, 2012.)

wooden objects (Figure 12). Scanning of archaeological bone, whether modified or unmodified, tends to work well (Figure 13). Shell artifacts are often not conducive to scanning. This is partly because the objects are generally thin, but also because they tend to be very white. The light setting on the scanner helps mitigate this latter issue in many cases. Other types of faunal remains, such as a seahorse exoskeleton, are more conducive to scanning.

Figure 12. Virginia Commonwealth University graduate Jolene Smith examines a deadeye from the *Betsy* shipwreck site as it is being scanned. The digital model of the deadeye is shown in the inset, *upper right*. (Photo by Bernard K. Means, 2011.)

Figure 13. Taft Kiser holds the plastic replica of a raccoon skull made from a digital model of the skull held by Mariana Zechini, which she scanned in the Virtual Curation Laboratory in Richmond, Virginia. A digital model of the skull is shown in the inset, *upper right*. (Photo by Bernard K. Means, 2013.)

Creating Digital Models for Sharing, Viewing, and Manipulation

The ultimate goal of the 3-D scanning process is to generate digital models that can be manipulated by researchers and potentially used in public venues. The generation of digital models using the scanner is relatively straightforward—despite some of the issues outlined above—and this action can be performed even by individuals with minimal familiarity with archaeology or computers. Editing of the resulting digital models within ScanStudio is a more complex endeavor. It can take up to two hours to edit the "noise" associated with a digital model for a single scan session. The idiosyncratic nature of archaeological objects—especially shape, material, reflectiveness, and color—also influences the "noise" associated with digital models in a manner that cannot be predicted in advance.

Editing an object that has been subject to two scan sessions takes more than twice as much time as an object scanned once. Not only do both scan sessions have to be edited separately, the two scan sessions then have to be merged into a single file. The merged single file often exhibits additional "noise" that needs to be edited out. It can also take time to create a well-integrated, single digital model resulting from two scan sessions. The user needs to manually select reference points from the digital models created in each scan session and then merge them into an integrated single digital model. This process varies from artifact to artifact, and the user must become well experienced with the editing process in ScanStudio to minimize editing time.

The ScanStudio software can export digital data in formats that can be more readily shared, viewed, and manipulated. A common file type that can be exported from ScanStudio and used for a wide variety of purposes is the stereolithography, or STL, format. STL files contain imperfections that have to be further edited in other software. The Virtual Curation Laboratory uses the freely available version of the Netfabb software (<http://www.netfabb.com/>) for this purpose. Digital models of archaeological objects exported in an STL format can be viewed, manipulated, and even measured using freely available software. 3D-Tool (<http://www.3d-tool.de/english/cad-viewer.htm>) is an STL viewer that also allows the user to make complex measurements of an object beyond simple linear measurements (Figure 14). STL files can also be viewed on portable electronic devices such as smart phones or computer tablets, thus enabling their integration as virtual "objects" into guided tours at actual archaeological sites. MeshLab is another freely available software program (<http://meshlab.sourceforge.net/>) that has a version enabling STL files to be viewed on portable electronic devices and also has a suite of sophisticated editing tools.

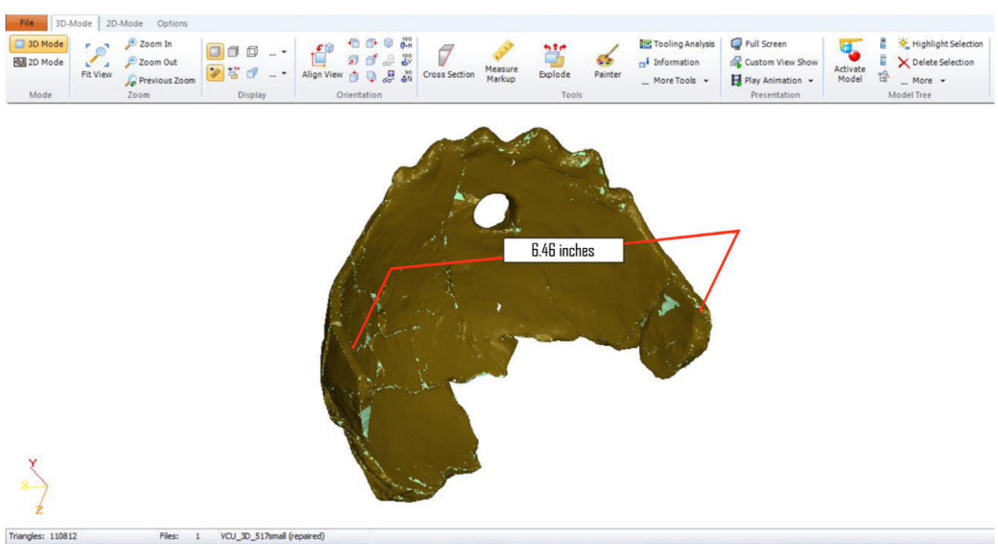

Figure 14. The free version of the 3D-Tool program allows one to measure the digital model of a colonoware vessel recovered at George Washington's Mount Vernon in Mount Vernon, Virginia (Photo by Bernard K. Means, 2013.)

Who Benefits from Virtual Artifact Curation?

Creating virtual collections of artifacts using a scanner provides real and tangible benefits. Digital models can be avatars for otherwise inaccessible physical objects. Access to virtual typologies created from 3-D digital models ensures that archaeologists can readily identify artifacts in field or laboratory settings without the expense of travel to distant facilities. Virtual curation can prove critical for fragile objects by minimizing handling and "preserving" them digitally, especially when conservation funding is limited. A virtual extension of an existing museum can highlight collections not on exhibit due to lack of space or curatorial concerns about the object itself. Digital scanning can make artifacts more tangible for public interpretation while preserving the actual artifacts in secure storage. Tablet tours of historical landscapes can integrate digital models of key findings to enhance the visitor's experience. Virtual models of unique or culturally significant artifacts can be made accessible to teachers, students, and researchers that otherwise would be unavailable. Three-dimensional scans of artifacts can be incorporated into science, technology, and history educational efforts in primary and secondary schools (Figures 15 and 16). Plastic replicas of artifacts generated from 3-D scans attract the attention of people of all ages who desire a tactile connection to the past, which would be unavailable to them with the actual artifacts (Figures 17 and 18). The plastic replicas can also be scaled at varying sizes to enhance their use in educational settings (Figure 19). Virtual curation has tremendous potential for promoting collaborative research efforts between students, faculty, and researchers at institutions across the globe and can be a key element in preserving the past for future generations (Figure 20) (Means, King et al. 2011a, 2011b; Means 2013; Means, Bowles et al. 2013).

Figure 15. Ashley McCuistion discusses historical artifacts, recovered from George Washington's Ferry Farm, with Virginia Commonwealth University students in Richmond, Virginia, using 3-D digital models and plastic replicas generated from the models. (Photo by Bernard K. Means, 2013.)

Figure 16. At the 2013 Middle Atlantic Archaeological Conference in Virginia Beach, Virginia, Jamie Pham (*far left*) and Crystal Castleberry (*far right*) demonstrate digital models of artifacts recovered from antebellum free and enslaved contexts in Virginia and Pennsylvania. (Photo by Bernard K. Means, 2013.)

Figure 17. Rachael Hulvey and Allen Huber look on at the MakerBot Replicator in operation at the 2013 Middle Atlantic Archaeological Conference in Virginia Beach, Virginia. (Photo by Bernard K. Means, 2013.)

Figure 18. A young visitor examines the MakerBot Replicator in operation at the 2013 Middle Atlantic Archaeological Conference in Virginia Beach, Virginia. (Photo by Bernard K. Means, 2013.)

Figure 19. Red plastic replica of Masonic pipe recovered at George Washington's Ferry Farm alongside the actual pipe at same scale (*top*) and enlarged six times (*bottom*). (Photo by Bernard K. Means, 2012.)

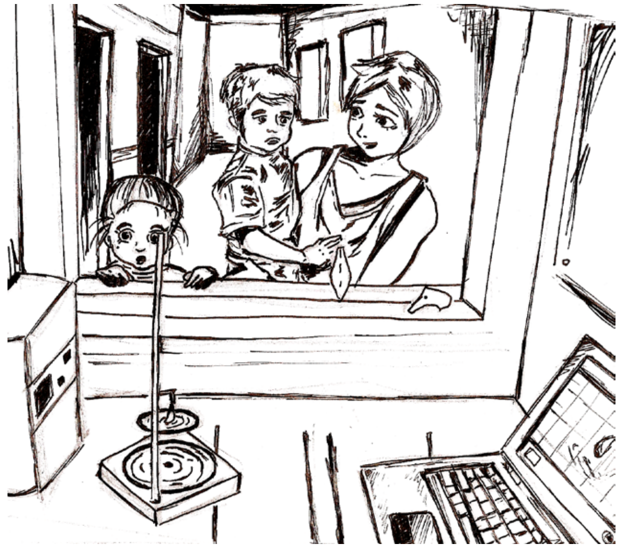

Figure 20. A mother and her children look on as an historical artifact is scanned in the Small Finds Laboratory at George Washington's Ferry Farm in Fredericksburg, Virginia. (Illustration by Jamie Pham, 2012, based on a photograph.)

References

McCuistion, Ashley, Courtney Bowles, Bernard K. Means, and Clinton King
2013 Protocols for Three-Dimensional Digital Data Collection from Artifacts Using the NextEngine Desktop 3D Scanner. Report to Department of Defense, Legacy Resource Management Program, Legacy Project No. 11-334, from Virtual Curation Laboratory, Virginia Commonwealth University, Richmond.

Means, Bernard K.
2013 From the Tangible to the Intangible: Virtual Curation of America's Historic Past. Paper presented at the 46th Annual Conference on Historical and Underwater Archaeology, Leicester, UK.

Means, Bernard K., Courtney Bowles, Ashley McCuistion, and Clinton King
2013 *Virtual Artifact Curation: Three-Dimensional Digital Data Collection for Artifact Analysis and Interpretation*. Report to Department of Defense, Legacy Resource Management Program, Legacy Project No. 11-334, from Virtual Curation Laboratory, Virginia Commonwealth University, Richmond.

Means, Bernard K., Clinton M. King, Courtney Bowles, and Victoria Valentine
2011a 3D Digital Scanning Archaeological Project at Virginia Commonwealth University. *Virginia Archaeologist* 28(2):10–11.

2011b What Do (Digital) Objects Mean? Paper presented at the 2011 Conference of Contemporary and Historical Archaeology in Theory, Boston University, Department of Archaeology, Boston, MA.

Bernard K. Means
Virtual Curation Laboratory
Virginia Commonwealth University
1205 Littlepage Street
Fredericksburg, VA 22401

Ashley McCuistion
Virtual Curation Laboratory
Virginia Commonwealth University
7159 Vaden Drive
Gloucester, VA 23061

Courtney Bowles
Virtual Curation Laboratory
Virginia Commonwealth University
724 Jessamine Street
Richmond, VA 23223