IMMERSIVE DEEP MAPS FOR ARCHAEOLOGICAL SITES: PRESENCE AND PLACE ACROSS TIME AND SPACE THROUGH VIRTUAL REALITY

by

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of
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Master of Arts
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DEDICATION

To my mother

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Many remarkable people were involved in this doctoral adventure. This research was possible due to the mentorship of Sven Fuhrmann, an advisor who has supported my work from independent study through Ph.D. His continued confidence in my abilities has helped me believe in myself, and I have learned from his guidance and friendship how to lead with kindness, respect, and an open mind. I was lucky in this process to have a second advisor, Matthew Rice, who took on the role during a stressful pandemic and shepherded me through daunting and seemingly impassible obstacles.

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LIST OF ABBREVIATIONS

Archaeology and Collections Branch .... ACB
Accelerator Mass Spectrometry .... AMS
Augmented Reality .... AR
Before Present .... BP
Computer-assisted Qualitative Data Analysis .... CAQDAS
Cave Automatic Virtual Environment .... CAVE
Electronic Cultural Atlas Initiative .... ECAI
Environmental System Research Institute .... ESRI
Autodesk file format .... FBX
Fairfax County .... FC
Fairfax County Park Authority .... FCPA
Friends of Riverbend Park .... FORB
First Person Shooter .... FPS
Functional State Machines .... FSM
Geographic Information Systems .... GIS
Global Positioning System .... GPS
History Geographic Information Systems .... HGIS
Head-Mounted Display .... HMD
High Tech Computer Corporation .... HTC
Igroup Presence Questionnaire .... IPQ
Institutional Review Board .... IRB
Immersive Virtual Environment .... IVE
Immersive Virtual Reality .... IVR
Material File .... MTL
National Park Service .... NPS
Organic Light-Emitting Diode .... OLED
Projectile Point/Knife .... PPK
Software development kit .... SDK
Structure from motion .... SFM
Unmanned Aerial Vehicle .... UAV
Virginia Cultural Resources Information System .... VCRIS
Virginia Department of Historic Resources .... VDHR
Virtual Environment .... VE
Virtual Reality .... VR

ABSTRACT

IMMERSIVE DEEP MAPS FOR ARCHAEOLOGICAL SITES: PRESENCE AND PLACE ACROSS TIME AND SPACE THROUGH VIRTUAL REALITY

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Presenting complex spatiotemporal environmental and cultural archaeological site information in traditional museum exhibits is a challenge. The site data exists, meticulously documented in modern archaeological mapping processes, but is not always effectively communicated to the public. Often, archaeology-and-history-focused exhibits highlight one period, person, or artifact and neglect to convey the many stories often connected to significant sites.

Deep map exhibits that link multifaceted archaeological data are one answer to presenting more inclusive histories. Immersive virtual reality (IVR) systems (e.g., Oculus Rift) take deep map exhibits a step further, offering audiences opportunities to learn about history by virtually being in representations of past environments. IVR experiences achieve this sense of being in the past by accessing an audience's sense of presence (i.e., the perception of being somewhere else); this sensation connected to user learning motivation and knowledge acquisition. Besides these educational benefits, IVR exhibits

offer museum visitors requested technology-based novel experiences that encourage audience engagement with typically inaccessible archaeological materials.

This research details the IVR deep map exhibit development process using accessible platforms and IVR systems for Clark's Branch, an archaeological site in Northern Virginia's Riverbend Park. Preliminary user testing suggests that audiences respond positively to the deep mapping concept and that the experience enhanced user understanding of the multidimensional information related to the site's different periods. Archaeological sites, parks, and museums can use the IVR deep mapping framework introduced in this work to create custom experiences that educate and engage with Digital Age audiences and better communicate complex histories connected to place.

To strengthen our sense of self, the past needs to be rescued and made accessible

Yi-Fu Tuan

CHAPTER ONE - INTRODUCTION

Archaeological sites are comprised of dynamic, spatiotemporal environmental and cultural layers that are challenging to display in traditional museum exhibits. This complex information is often presented to the public through static displays that emphasize individual artifacts, events, and people. These exhibits simplify multifaceted stories connected to place, elevating certain historical moments and individuals and omitting the histories of others.

Singularly focused exhibits are not accurate reflections of the multidimensional histories documented in contemporary archaeological practice. Modern archaeologists eschew the so-called "Pompeii Premise," a term coined by archaeologist Robert Ascher (1961), which assumes archaeological sites represent single snapshots in time. Archaeologists dismiss this premise and strive to document data encountered in excavations to interpret the full spectrum of specific historical events and broad patterns. Advancements in geographic information systems (GIS) and other emergent technologies improve the modern archaeological mapping process. This is particularly true of new technologies that enable the three-dimensional (3D) recording, processing, and visualization of archaeological information.

The modern archaeological mapping process results are different types of digital data, ideal for crafting novel exhibits using virtual reality (VR) technologies that showcase archaeological sites. Museums, the traditional knowledge bridge between archaeologists and the public, successfully use VR technologies and digital data to create engaging educational archaeology-and-history-focused exhibits for increasingly diverse audiences (Pujol 2004). Digital Age museum visitors respond positively to dynamic, entertaining, and interactive displays and desire these more technology-focused experiences (Rey and Cassado-Neira 2013). VR exhibits appear more and more in museum spaces, particularly in large institutions, meeting the technology requests of modern exhibit audiences. However, most of these exhibits interpret specific moments from the past or display data from archaeological sites in their current state. Though these exhibits employ new VR technologies, they still present history through a singularly focused lens.

One way to better present multidimensional archaeological information through dynamic virtual exhibits is by developing and displaying what spatial humanities scholars refer to as *deep maps*. Deep maps are the antithesis of traditional, static maps (Bodenhamer et al. 2013), serving as repositories for diverse data (e.g., oral histories, 360-degree video tours, and technical drawings) and acting as 3D platforms for exploring information from a holistic stance. Archaeologists can use deep maps to organize and analyze site data. More importantly, museums can create deep map exhibits to present complex archaeological information to the public.

For archaeology-and-history-focused exhibits, ideal deep maps would link environmental, cultural, and temporal layers, encouraging audiences to explore data from personal perspectives and at their own pace. Immersive virtual reality-based (IVR) exhibits serve as deep mapping platforms, experienced through virtual avatars that offer users an embodied, interactive approach to exploring complex information. The embodied experience in IVR systems helped users achieve a *sense of presence*, defined as the sensation of being in another environment. In immersive environments, a sense of presence is achieved when a) the space is realistic, b) real-world distractions are limited, c) the experience appeals to the senses, and d) the user perceives they are in control (Witmer and Singer 1998).

Embodied experiences accessing a user's sense of presence are the type of novel technological experiences Digital Age museum visitors require. Additionally, the sense of presence phenomenon is linked to user knowledge acquisition (Alzua-Sorbazal et al. 2005; Christou et al. 2006; Sumners et al. 2008; Zaharias et al. 2013; Chang et al. 2014; Reiff et al. 2014; Makransky et al. 2017).

IVR-based exhibits provide museum visitors with engaging interpretations to improve their knowledge of subject material through interactive and immersive experiences. Also, these exhibits can serve as deep maps that better communicate multilayered histories connected to archaeological sites. Still, in museum settings, IVR experiences are rare because early IVR systems were expensive, space-consuming, and sometimes displayed in systems that intimidated visitors (Carrozzino and Bergamasco 2013). Also, concerns have been voiced that technologies like VR might replace visitors' need to physically travel to archaeological sites (Hall 2014: 96). This is a valid worry, as a steady stream of visitors is necessary for many sites as a funding source to support interpretation and preservation efforts. If the public does not physically visit, they may not form an attachment to sites, which could negatively impact a desire to protect these significant places.

A fear that VR will keep visitors from sites is unfounded, and archaeology-and-history-focused IVR experiences may encourage archaeological-site visitation, in a similar way that movies and literature introduce people to new ideas and places. Crafting exhibits that present immersive, interactive interpretations of the past may assist users in developing bonds to places. IVR-based exhibits are a means of introducing audiences to sites where tangible remains have vanished, and histories are hidden below the surface.

Diverse Digital Age museum visitors require novel, technology-based exhibits presenting inclusive, multidimensional histories. Deep map exhibits can connect different data types collected during modern archaeological mapping to create in-depth, interactive maps for better communicating stories tied to sites. Lower-cost IVR systems, highly portable with user-friendly designs, are becoming real options for museums to present their own deep map exhibits. IVR systems can offer audiences embodied approaches to exploring deep maps, educating the public on important histories, and potentially building attachments that foster future inclinations to safeguard archaeological sites.

Scope of Work

This thesis details the development of an IVR-based deep map exhibit to present multidimensional histories to the public. This exhibit's subject is the pre-Contact (period before European contact) Clark's Branch archaeological site (44FX3226). The Clark's Branch Site is located in Riverbend, a regional park in Northern Virginia. At Clark's Branch, archaeological excavations revealed layers of pre-Contact occupations from the

Paleoindian (15000-8000 BC) through Woodland (1200 BC-1600 AD) cultural periods. Riverbend's museum features information on these cultural periods, exhibiting artifacts, replicas, and wall displays. Additionally, the park offers programs on early regional Native American lifeways.

Riverbend's presentation of pre-Contact histories is well done. However, information is scattered across the museum and park and emphasizes the Woodland Period over others. The Clark's Branch IVR-based deep map exhibit expands on Riverbend’s current exhibits and programs, displaying layers of information on Clark’s Branch in an immersive exhibit. The exhibit produced in this work guides users through Clark’s Branch's Paleoindian, Archaic, and Woodland cultural periods. A fourth period, the Present Period, is included in the experience to help orient users in space.

To move through time at Clark's Branch, exhibit users travel through virtual portals embedded in each period’s scene. These virtual portals link the four periods, each offering users a glimpse into the next consecutive period. Realistic 3D environmental (e.g., flora, fauna, and terrain) and cultural (e.g., artifacts, archaeological features, and animated characters) layers in each period communicate changes over time at Clark’s Branch. Exhibit development drew on the expertise and advice of regional archaeologists, soil scientists, historians, park employees, and descendants of the region's indigenous people.

This IVR-based exhibit was developed in the Unity real-time development platform (Unity 2019). Unity is a real-time gaming environment developers use to create archaeology-and-history-focused applications (Eve 2014; Gabellone et al. 2017; Bjorkl et al. 2018). Unity applications developed for immersive experiences can be displayed using new, accessible IVR systems (e.g., Oculus Rift and HTC Vive). The Clark's Branch IVR-based exhibit was developed in Unity and is displayed in an Oculus Rift IVR system, run on an MSI Stealth Pro laptop computer.

Research Questions

In addition to developing a deep mapping framework for an IVR-based exhibit, this research investigates if audiences experience learning gains following the exhibit. This study also seeks to identify if a relationship exists between potential learning gains and, if experienced, a user's sense of presence. Additionally, user attachment to Riverbend Park is evaluated. Finally, these investigations seek to assess the overall user experience in IVR-based educational exhibits. Four research questions guided this work:

RQ1: What is the general user experience of an IVR-based exhibit? Specifically,

a. are users generally receptive to IVR-based educational tools?

b. do users feel the deep map IVR-based exhibit improved their understanding of the multidimensional nature of archaeological sites?

RQ2: Do IVR-based exhibits enable users to develop a broader understanding of artifacts? Specifically, will study participants better understand artifacts contextualized in a virtual interpretation vs. displayed in a museum case?

RQ3: Will deep map IVR-based exhibits improve users' knowledge of time, space, and human-environment relationships at archaeological sites? Specifically,

a. major environmental shifts during the Paleoindian through Woodland cultural periods and how these impacted indigenous people's subsistence strategies in Northern Virginia, and

b. social and cultural changes in Northern Virginia over time.

RQ4: Will users experience a sense of presence in the IVR-based exhibit? If experienced, is a sense of place related to users' learning achievements?

RQ5: Will users experience place attachment towards Riverbend Park following the IVR-based exhibit? If experienced, is place attachment related to users' interest in visiting the park?

Limitations

George Mason University (GMU) geography students and Fairfax County Park Authority (FCPA) archaeologists evaluated the Clark's Branch exhibit to address these research questions. GMU students viewed a Story Map Virtual Tour on Riverbend's Museum, completed the exhibit, and answered pre-and-post-IVR exhibit questionnaires. Questionnaire items queried user experience, sense of presence, place attachment, and inclination towards visiting Riverbend Park. A comparison of pre-and-post questionnaire results was used to evaluate if study participants experienced learning gains following the IVR-based exhibit. FCPA archaeologists participated in a focus group discussion on their experiences in the exhibit and feelings toward IVR as an educational tool.

The major limitation of this study was access to participants. Originally, Riverbend Park visitors were this study's target population. The approximate number of annual Riverbend visitors is 300,000, (FORB n.d), and this research study aimed to collect data from a systematic random sample of visitors from this group. The IVR-based exhibit was set up outside Riverbend's Visitor Center, and study participants were asked to explore the park's museum before completing the study. This original study began in February 2020 but was shut down following the SARS-CoV-2 virus outbreak in the region. With Riverbend Park closed, the target population shifted to GMU geography students in a closed office at GMU. Instead of completing the Riverbend Museum tour, as initially planned, students viewed images of Riverbend's displays in a virtual tour format.

SARS-CoV-2 compounded other limitations of this study. IVR users can experience embarrassment learning how to operate the IVR systems, distracting from exhibit content (Ellenberger 2017). At Riverbend, the researcher mitigated this issue by showing users how to operate the Oculus Rift system and offering guidance if users experienced difficulties. At the park, the researcher could also help users accidentally tangled in the Oculus Rift's cords. The modified study did not permit person-to-person contact, making it challenging for the researcher to help the user confidently operate the IVR system

Another limitation with IVR systems is user distrust of "scary" HMDs (Carrozzino and Bergamasco 2010: 457). Though the Oculus Rift HMD is designed in a sleeker style than its predecessors, placing the system over the eyes and ears during SARS-CoV-2 likely added a new sense of user distrust. Though not proven, the low number of student participants in this study may reflect this apprehension during an unprecedented time.

Additionally, most classes at GMU switched to online learning during the pandemic. Thus, a limited number of students returned to campus in the Fall of 2020. These factors likely impacted the number of this study's student participants. Instead of collecting the original systematic random sample, this research relied on a convenience sample to investigate research questions.

Significance of Study

Existing archaeology-and-history-focused IVR-based exhibits neglect sites' multidimensionality and display singularly focused stories, elevating specific histories and neglecting others. These displays do not reflect the meticulous archaeological documentation process, which produces digital data that could populate new, more inclusive deep map exhibits.

IVR-based experiences add a further layer to deep map exhibits with an immersive component that helps users achieve a sense of presence and learn through embodied experiences. This research describes the development of an IVR-based archaeology-and-history focused deep map exhibit. This educational exhibit aims to better communicate the multidimensional nature of archaeological sites through a novel, technology-based approach, as requested by Digital Age audiences. This study will investigate the IVR-based exhibit's educational effectivity by assessing users' learning gains on complex spatiotemporal human-environment relationships and contextual artifact information. It will also evaluate the potential relationship between sense of presence and knowledge acquisition. The users' overall experience and place attachment will also be investigated to identify if a relationship exists between place attachment and desire to visit archaeological sites.

CHAPTER TWO – THE MAPPING AND PRESENTATION OF ARCHAEOLOGICAL INFORMATION

Presenting complex temporal layers of archaeological and historical information to the public can be challenging for archaeologists and museum specialists. One reason for this difficulty is that people understand time differently, especially in cyclical and linear senses. In cyclical time, the sun sets each day and rises again in the morning, seasons repeat, and life moves in phases of birth and death. Time is also structured linearly, with concrete start and stopping points. Archaeologists often apply time in a linear sense when they order events along a timeline with a start and, if applicable, an end date.

Additionally, archaeologists contemplate time in a cyclical sense when identifying overall cycles and patterns in the archaeological record. These different considerations of temporal patterns eschew the Pompeii Premise, that is, that archaeological sites represent frozen moments in time. Archaeological investigations lean increasingly towards excavating sites as dynamic, multilayered places, comprised of multifaceted information (e.g., stratigraphy and archaeological features) (Holdaway and Wandsnider 2008; Seawright 2015).

Technology, particularly GIS, has vastly improved documenting archaeological sites. However, the information collected during this documentation is often presented in static formats that highlight specific artifacts, events, or people. This presentation style emphasizes some people and pasts over others and does little to reflect archaeological sites' complex natures and histories.

Modern museums have begun to distance themselves from these static displays by incorporating emergent technologies (e.g., VR and IVR) in their exhibits. Exhibits that incorporate new technologies engage Digital Age audiences; however, most of these exhibits still focus on singular topics. There is a need for platforms that link comprehensive archaeological information in cohesive exhibits and entice diverse audiences' attention. IVR-based deep map archaeology-and-history-focused experiences can be this platform, one that connects different temporal, environmental, and cultural layers in sensory-stimulating environments. IVR deep mapping offers a more holistic method of interpreting and displaying histories, encouraging users to walk through different places and times virtually.

Mapping Multidimensional Histories

Deep mapping immersive platforms could also reveal different historical layers (e.g., broad patterns and events). Contemporary archaeologists consider time at sites as operating in different cycles and levels, these ideas stemming from theories on temporal structure from scholars like Fernand Braudel.

Braudel's (1972) theories on historical processes arrange temporal rhythms or levels into four categories: *events, conjectures, intermediate-term conjectures*, and *long-term conjectures*. Events constitute traditional historical moments (e.g., battles) and are essentially the snapshots in time often presented at museums. *Conjectures* cover larger swathes of history, subdivided into *intermediate-term conjectures* and *long-term conjectures*. Intermediate conjectures cover larger phenomena (e.g., wars) and long-term conjunctures represent broader changes (e.g., states and empires' evolution) (Braudel

1972; Smith 1992). Braudel's overarching category in this time structure is the *longue duree*. The longue duree considers broad historical events shaped by factors such as climatic change and physical geography over long periods.

In the late 20th century, archaeologist's intent on identifying broader patterns at sites embraced elements of Braudel's theories regarding temporal structure. Archaeologist Geoff Bailey's *time perspectivism* shared similarities with Braudel's temporal rhythms, time organized in episodic, cyclical, and structured levels (Knapp 1992).

Bailey's time perspectivism is founded on two primary principles: a) time operates on scales involving different processes and events and b) the palimpsest nature of the archaeological record. In an archaeological framework, palimpsest means that, though social and environmental factors expunge information at sites, traces of earlier cultures can still be detected. Archaeological findings are significantly impacted by human-environment factors, affecting archaeologists' abilities to understand the past fully. Time perspectivism emphasizes that sites are dynamic and that archaeologists should approach them as such in excavation and interpretation (Bailey 2008).

In modern practice, archaeologists strive to record excavations with a high level of accuracy. Since the 1980s, GIS has transformed how scientists document and organize archaeological sites' spatial information. In the early years, GIS was critiqued for promoting positivism and environmentalist agendas (Ebert 2004; Gillings 2017; Supernaut 2017). Since this critique, GIS platforms have evolved to incorporate multilayered 2D and 3D environmental and social information (Howey and Brouwer Burg 2017; Gilling 2017; Kowlessar et al. 2019).

GIS assists archaeologists in linking diverse datasets that aid in data management and enhance site analysis and interpretation. For example, the Commonwealth of Virginia maintains the Virginia Cultural Resource Information System (VCRIS), a GIS containing all of Virginia's documented archaeological sites (VCRIS 2019). Databases such as VCRIS allow scholars to digitally access archaeological information, including investigation methods, artifacts, and stratigraphic data.

To accurately collect this data, archaeologists use various traditional tools (e.g., line levels and plumb bobs) as well as digital technologies (e.g., laser theodolites, image-based modeling (IBM) techniques, and 360-degree videos). Identifying the best tools and methods to expedite the digital mapping process is a central focus in the cultural heritage sector (Fresa 2013; Wells et al. 2014; Povroznik 2018). Additionally, developing digital maps for public consumption is a central goal for many international heritage groups (e.g., Historic England 2017 and Royal Irish Academy 2017).

Remote sensing data has significantly impacted the archaeological discovery and mapping processes (Parcek 2009; Luo et al. 2014; Agapiou and Lysandrou 2015). More and more, unmanned aerial vehicles (UAVs) outfitted with various sensor equipment are employed at archaeological sites to record information rapidly and map previously unreachable areas (Remondino et al. 2010).

Archaeologists use data retrieved from UAVs and other tools in a variety of ways, including capturing artifact details (Karaksik and Smilansky 2008), digitally documenting landscapes (O'Driscoll 2018), and printing 3D models to engage with the public (Means 2015). In recent years, scientists have embraced structure from motion (SFM) commercial software (De Reu et al. 2013; Galeazzi 2016), and open-source software (Lerma and Muir 2014) to develop 3D digital heritage information. Collecting and preserving digital heritage in 3D is becoming less of the novelty it once was and more a component of systematic archaeological practice.

Emergent technologies, particularly 3D-GIS, are becoming increasingly important for documenting sites and disseminating information to national and international experts. Platforms that offer 3D mapping solutions, such as Environmental Systems Research Institute (ESRI) applications (e.g., ArcGIS Pro, ArcGIS CityEngine, and Scene Viewer), alter the way archaeologists think about site preservation and allow experts to share and collaborate online. 3D-GIS environments mirror real-world spaces and offer more holistic perspectives, encouraging a deeper understanding of archaeological sites for specialists and the public.

Presenting Histories to Public Audiences

Though archaeologists possess multidimensional data, much of this organized in GIS, sites are still often presented to the public through static displays highlighting singular histories. Exhibits that showcase individual subjects and objects are vestiges of antiquarian cabinets of curiosities, which functioned as exhibitors of "things." These relic exhibits present pedestalled artifacts, promoting the Pompeii Premise and severing archaeological materials from context. Contemporary museums attempt to distance themselves from the Pompeii Premise. These institutions understand their essential role as bridges between archaeologists and the public and that their presentation of archaeological materials influences visitor perceptions of archaeological sites and history (Barker 2010).

Although museum directors recognize these responsibilities, they face significant challenges such as funding and lack of exhibition space (Lepouras and Vassilakis 2004; Ekelund and DeMarsche 2018; Pickford 2018). Additionally, archaeological sites are comprised of diverse tangible (e.g., artifacts, buildings, and art) and intangible (e.g., belief systems and linguistics) information difficult to present through traditional displays.

In addition to these obstacles, museum specialists are tasked with developing exhibits to compete with the myriad of distractions encountered by Digital Age museum visitors (e.g., mobile devices and crowded museums). Also, visitors are asked to do the impossible and straddle two periods: a) the time presented by the museum and b) the visitor's present time. In this situation, visitors split their attention between the two periods, never truly immersed in either. Though traditional museum exhibits cannot fully capture visitors' attention, museums arrange displays to help audiences compartmentalize temporal information. Museum specialists and exhibit designers organize different periods following two main conventions: space and timelines.

Large memory institutions with ample room (e.g., Osaka’s Museum of History and Vienna’s Natural History Museum) commonly use their space to group collections by period. Visitors physically move across different floors and rooms, experiencing changes over time consecutively as they enter a new area. Traversing these spaces, the visitor encounters the information on the evolution of selected topics (e.g., culture, art, events, and natural phenomena)

Timelines are another main display tactic that museum specialists use to communicate changes over time (Lubar 2013). Exhibit timelines often present time linearly, chronologically organizing people, events, and periods. Displays that use timelines are frequently static and presented using wall space. These common timeline exhibits are found in large institutions (e.g., Dublin's National Museum of Ireland) and smaller museums (e.g., Virginia's Riverbend Park). New takes on the traditional timelines incorporate modern technologies to craft dynamic displays, encouraging visitors to explore different data tied to time and space (Marty and Jones 2008: 120).

Memory institutions recognize the importance of incorporating digital displays such as these in their spaces. Museums are currently improving websites and investing heavily in technologies, including games and multimedia, to connect with new audiences, increase attendance at museums, and enhance visitors' overall experience (Mortara et al. 2014). Virtual technologies are part of these new displays, presenting historical interpretations through vivid replications incorporating 3D archaeological data gathered from modern archaeological mapping. The majority of these VR experiences either: a) present specific periods, events, or people from the past (Kanter 2000; Roussou 2001; Sanders 2008; Forte et al. 2012; Richards-Rissetto 2017) or b) exhibit sites in their current state (Vote et al. 2002; Knabb et al. 2014; Bruno et al. 2018; Perot Museum 2019). VR exhibits are presented through a) web or screen-based VR, b) cave automatic virtual environments (CAVE), or c) HMD and HMD/CAVE hybrid applications.

Archaeology-and-history-focused VR exhibits appeal to audiences, but the bulk of existing VR exhibits neglect to show sites' temporal layers. Singularly focused displays claim sites for specific moments or people. Exhibits that center on particular people and histories can marginalize communities and incorrectly promote one-sided narratives.

Scholars are combatting this issue by building richer VR experiences for the public, encouraging the exploration of more inclusive pasts. The *St. Louis Regional History Project* is one of these experiences, developed by the University of Missouri-St. Louis. This project details changes in St. Louis between the 1850s and 1950s, melding data such as 3D models, addresses, imagery, and other sources into a cohesive website for public consumption (St Louis 2019).

In *Virtual Beijing*, another VR project, researchers are developing a History-GIS (HGIS) connecting maps with approximately 5000 photographs from Harvard collections (Virtual Beijing 2019). *Virtual Beijing* researchers aim to educate the public on the different lifeways of the many people who built Beijing, not just a privileged few (Virtual Beijing 2019). *Rome Reborn*, an international VR research project initiated in the mid-1990s, focuses on creating ancient Rome interpretations from different periods (Rome Reborn 2019). This project incorporates detailed architectural models of Rome with animated characters representing various socioeconomic backgrounds. The intent behind the inclusion of animated characters in the VR experience is to breathe life into the virtual city, moving away from a typical VR presentation style presenting past cities as ghost towns (Anderson et al. 2014).

The Electronic Cultural Atlas Initiative (ECAI) web page contains many examples of VR web experiences conveying changes over time at archaeological sites to viewers (e.g., Silk Road Atlas and Iraq Cultural Atlas). These experiences incorporate a time-filter plugin, Timemap, encouraging viewers to investigate significant sites' temporal changes and other multidimensional data (e.g., imagery, audio, 3D models, and narrative) (ECAI 2019).

Immersive Exhibits - Presenting Deeper-Maps

VR experiences that house and communicate layers of historical and archaeological information are examples of *deep maps*. Deep maps are repositories for diverse data types. These maps expand on traditional conceptions of space and place, communicating varied social, geographical, environmental, and potentially phenomenological information.

Deep map scholars Bodenhamer, Corrigan, and Harris (2013) have discussed the lack of adequate, non-positivist deep-mapping tools for humanists and social scientists to examine complex multivariate information. Newer commercial IVR systems (e.g., Oculus HMDs and HTC Vive) can serve as deep-mapping tools for digital humanities scholars, linking varied social, geographical, and environmental data types into a cohesive platform explored through immersion. Novel IVR systems build on conventional VR experiences' limitations by surrounding audiences with realistic, immersive virtual environments (IVE) and providing users with a virtual embodied experience. Immersive maps also offer a more holistic, phenomenological approach to understanding place. Also, IVR experiences access the deep map viewer's *sense of* *presence*. A sense of presence is defined as a feeling or sensation of being in another environment (Jung et al. 2016).

A Sense of Presence in Immersive Environments

The sense of presence phenomenon is difficult to achieve through conventional screen-based VR. However, the immersion element of IVR experiences effectively enhances a user's sense of presence (Witmer and Singer 1998; Tost and Economou 2009; North and North 2016; Markowitz et al. 2018; Selmanovic et al. 2018; Schwind et al. 2019). A sense of presence in immersive virtual environments (IVE) is often achieved through immersion platforms, but immersion is a separate concept from presence. Immersion refers to a technology's capability to present the user with a convincing portrayal of reality (Slater and Wilbur 1997; Schubert et al. 2001). Presence is a separate idea, a "psychological phenomenon" that considers the human element involved in immersive experiences (Schubert et al. 2001: 267).

In IVEs, users attain a sense of presence when their physical being is rooted in reality, while mentally, they perceive they are elsewhere. Researchers use sense of presence questionnaires to determine if IVE users experience this phenomenon. Witmer and Singer (1998) developed a popular presence questionnaire to evaluate sense of presence in IVEs. Witmer and Singer highlight four different factors related to user sense of presence: *Control, Sensory, Distraction, and Realism*. Witmer and Singer's 32-item questionnaire assesses user-perception of these four factors to identify if a sense of presence was experienced in an IVE (Witmer and Singer 1998).

If IVE users believe they are in *control*, they anticipate upcoming actions and are comfortable interacting with objects in the virtual world. Presence is also perceived in IVEs composed of rich *sensory* information. To achieve a sense of presence, the IVE should also block real-world *distractions*. Visuals should be consistent in the IVE, and movements should be natural. As users progress through the IVE, it should become more meaningful, connecting them to the virtual space. Finally, the IVE should feel authentic, consistent, and *real* (Witmer and Singer 1998).

Another well-known presence questionnaire is Igroup's Presence Questionnaire (IPQ 2016), containing 14 items. This questionnaire highlights three subgroups for assessing a user's sense of presence: *Spatial Presence, Involvement, and Experienced Realism*. *Spatial Presence* is defined as the user's perception of being in the virtual environment (VE). *Involvement* measures the user's attention to the VE and the amount of participation experienced. *Experienced Realism* is the subjective experience of realism the user feels in the VE (IPQ 2016).

Immersive Deep Map Experiences Benefits and Limitations

Sense of presence is the main factor distinguishing IVR over VR experiences, affording users with a level of control that opens their minds to learning experiences (Minocha et al. 2017; Johnson-Glenberg 2018). Additionally, studies have identified connections between a perceived sense of presence in IVEs and participant learning achievements (Alzua-Sorbazal et al. 2005; Christou et al. 2006; Sumners et al. 2008; Zaharias et al. 2013; Chang et al. 2014; Reiff et al. 2014; Makransky et al. 2018).

Achieving a greater sense of presence can benefit archaeologists, offering a new approach to investigating data. Archaeologists are developing immersive deep mapping platforms, creating spaces for scholars to explore layers of 3D data through immersive, embodied experiences. The Archaeological Virtual Environment (ARCHAVE) system is an example of an archaeology-focused deep-mapping platform. This system layers archaeological data (e.g., 3D models and stratigraphic information) in a CAVE environment for scientists to scrutinize from an immersive stance (Acevedo et al. 2001). Similar systems, such as the Virtual Interaction Tool for Archaeology (VITA) (Benko, Ishak and Feiner 2004) and DigIt (Lercari et al. 2017), connect archaeological information in IVR deep maps. The research teams behind these platforms developed these experiences to explore new theories from fresh and novel perspectives.

The public can also benefit from exploring archaeological information in immersive deep maps. When immersed in IVE, real-world distractions are blocked out. Users focus on exhibit content, and for a period, they are immersed in interpretations of different times and places. Also, museum visitors benefit from personalized experiences (Cranmer et al. 2016) achieved through embodied, inquiry-based learning experiences in IVE. Users can move through site representations at their own pace and investigate material personally interesting to them.

Additionally, IVR experiences permit users to walk around sites without dangers associated with real-world sites (e.g., inclement weather, preservation of site integrity, visitor injuries). Even for archaeological sites that encourage visitors, certain groups are excluded (e.g., people with disabilities). IVR-based exhibits are a more inclusive solution, inviting individuals to engage with immersive and interactive site representations intimately.

Museum visitors generally respond positively to IVR exhibits, expressing that IVR offers a more natural approach to understanding exhibit content than viewing items in display cases (Carrozzino and Bergamasco 2010). Additionally, IVR-exhibit users indicate their experiences in history-based IVR exhibits improved their understanding of specific historical periods (Rae and Edwards 2016).

However, not all IVR users indicate their experiences were positive. Sasinka et al. (2019) found some users felt disoriented when exiting their IVR experience. In other IVR encounters, users did not want to wear "scary" devices altering their vision (Carrozzino and Bergamasco 2013: 457). Even when users did enjoy their IVR experience, they did not always believe IVR improved their knowledge of subject matter (Alzua-Sorzabal et al. 2005). Also, Ellenberger (2017) noted that users did not feel learning gains were possible if exhibit content was disorganized and the HMD was challenging to use. If HMDs were challenging to use, users might also experience embarrassment, negatively impacting the user experience and potential learning achievements (Ellenberger 2017). Furthermore, users sometimes experience loneliness in HMDs (Carrozzino and Bergamasco 2013), and IVR experiences can cause simulator (motion) sickness (Hussein and Natterdal 2015).

Additionally, cultural heritage specialists have voiced concerns over using virtual technologies to create archaeology-and-history-focused IVR exhibits. They fear that virtually-based experiences will divert users from visiting the actual sites (Hall 2014: 96).

This is a valid concern since already resource-strapped archaeological sites rely on steady visitor streams for funding. The public may also not develop a *sense of place* if they do not physically experience sites, which could negatively impact protection and preservation inclinations.

Archaeological Sites and Place Attachment

A sense of place is challenging to define, and nuances connected to this concept make the idea challenging to measure. First, place needs to be defined separately from a geographical definition of *space*. From a human-geography perspective, space can be characterized as an open, empty void. When people assign significance to space, this emptiness transitions into place (Tuan 2011). This significance derives from the meanings people attach to space. Meaning is multidimensional and includes experiences, sensations, images, and other types of information (Osgood 1952; William and Carr 1993).

Place is not a readily quantifiable construct because of the complexities and multicomponent layers tied to meaning. Though there is a great deal of overlap in sense of place literature, three components of this phenomenon are frequently acknowledged as contributors to sense of place: *place identity*, *place attachment*, and *place dependence.*

Place identity refers to how people perceive themselves in relation to their surroundings. (Hernandez et al. 2010). *Place dependence* considers factors associated with a setting to meet an individual or a community's specific goals and needs (Stokols and Schumaker 1981). *Place attachment* refers to the bonds people develop to place (Jorganstne and Stedman 2001).

Place Attachment Theory, investigating ties between individuals and space, is a central component in Environmental Psychology. This theory is of particular interest to park administrators focused on bringing the public to their parks. Park administrators center on place attachment as deeply connected to the visitor experience (William 2000; Moore and Scott 2003).

Place attachment is hard to measure because of the unique nature of human relationships with parks. Parks are a respite from urban environments, and people travel to these spaces for different reasons, including recreation, employment, and learning. A visitor's bond with a park can impact contributions to park funding and support of spending decisions (Pitas et al. 2018; Groshong et al. 2020). An attachment to parks can also improve pro-environmental behaviors (Vaske and Kobrin 2001; Halpenny 2010; Ramkissoon et al. 2012; Wolf et al. 2015).

Identifying and increasing the public's attachment to parks is essential for archaeological sites because many sites are located in parks. Nurturing this bond can be a significant component of protecting and preserving sites and cultivating a visitor's sense of place.

Also, in educational settings, individuals that experience a sense of place are more motivated to learn (Huang and Chang 2017) and experience learning achievements (Fischer and Wentz 2020; Soheili et al. 2020). Further work in this field is necessary to identify if specific sense of place components, such as place attachment, lead to learning achievements and enhanced learning motivations on archaeological sites.

Williams and Roggenbuck (1989) developed a 27-item scale for measuring place attachment to outdoor spaces, considering two dimensions of recreational setting attachment. These place attachment dimensions tie in the two other components often related to place: identity and dependence. The first dimension, the *identity* dimension, assesses if the recreational place is a focal part of the visitor's life. The second evaluates the resource *dependence* dimension of attachment, identifying if individuals selected the recreational place above others to satisfy specific needs (Williams and Roggenbuck 1989). In later research, Williams (2000) expanded this scale, increasing it to 61 items. This scale provides standardized questions for evaluating place attachment perceived by park visitors.

Place questionnaires can help park administrators assess visitor attachment. This attachment may or may not be related to visitors' connection to archaeological sites in the parks, as visitors may not be aware of these sites. One reason for this ignorance is that tangible remains of many archaeological sites (e.g., North American pre-Contact sites) have vanished from the landscape or are buried under the surface. Also, site locations typically remain private to ensure protection from vandalism and looting. Even if exact site locations remain confidential and there are no tangible remains to view, visitors need to understand that parks are not historically empty spaces. IVR-based deep map exhibits can serve as platforms for creating rich, engaging displays that introduce sites and present their multilayered meanings to the public.

Audiences avoided early IVR-based exhibits due to scary-looking designs (Carrozzino and Bergamasco 2013), embarrassment over incorrect use of systems

(Ellenberger 2017), or simulator sickness (Hussein and Natterdal 2015). Newer IVR systems, with improved graphics cards and sensors, address usability issues with sleeker, potentially less intimidating devices and new organic light-emitting diode displays (OLED) that combat simulator sickness issues (Gutierrez-Maldonado 2017). Early IVR systems were unattainable for most museums due to expense and space, but contemporary commercial HMDs are highly portable and obtainable at low-costs.

The fear that that IVR experiences might discourage people from making physical trips to sites is unsubstantiated. IVR exhibits may encourage visitation to sites by introducing audiences to unknown histories, similar to how movies and literature introduce new places and ideas. For inaccessible sites, IVR experiences offer opportunities to visit unreachable places virtually, through immersive, embodied experiences where users feel transported to another place. Digital Age audiences require novel museum experiences, and IVR-based exhibits can satisfy this need. Additionally, much of the digital data necessary to populate IVR-based exhibits already exists from the modern archaeological mapping process. The difficulty is that current history-and-archaeology-focused IVR experiences highlight specific past moments. Focusing on singular topics is dangerous because it alienates groups, promoting some pasts at others' expense. New IVR-based deep mapping exhibits can, and should, act as immersive deep maps that educate audiences on multidimensional, inclusive histories and nurture an attachment to significant sites.

CHAPTER THREE - TIME IN PRE-CONTACT VIRGINIA AND AT THE CLARK'S BRANCH SITE (44FX3226)

Many archaeological sites, especially those with pre-Contact (period before European contact) components, are hidden beneath the surface in Virginia parks. This study sought to bring some of these sites' histories to light, educating public audiences on pre-Contact spatiotemporal human-environment relationships in an educational IVR-based exhibit. This exhibit focused on communicating pre-Contact changes at the Clark's Branch Site (44FX3226), a site located in Northern Virginia's Riverbend Park.

Situated in northwest Fairfax County, Virginia, Riverbend Park receives over 300,000 visitors a year (FORB n.d.) and is a popular regional park inside one of the Potomac River's many bends. Though Riverbend contains over 100 archaeological sites, only the Clark's Branch Site has undergone high-level archaeological investigations (e.g., data recovery). In Fairfax County parks, the ideal situation is to identify sites and preserve these cultural resources using minimally invasive methods (e.g., pedestrian reconnaissance and limited testing). Data recovery occurs before any development that will negatively impact archaeological sites. Because Riverbend is a natural and cultural resource-based park, development is limited. However, development is occasionally necessary to create and alter trails and construct recreational outbuildings (e.g., picnic shelters). In 2009, data recovery-level investigations occurred at Clark's Branch Site before a pedestrian bridge was installed connecting sections of the Potomac Heritage Trail (PHT).

The Fairfax County Park Authority (FCPA) contracted archaeologist Paul Inashima to complete 2009 investigations. A small cadre of volunteers from the Archaeological Society of Virginia (ASV) assisted Inashima in this work, which included the hand-excavation of tests and geoarchaeological studies (Inashima 2012).

An abundance of multidimensional data and a high level of chronological refinement made this site an excellent subject for developing an IVR-based deep map exhibit focused on communicating temporal information. Artifacts retrieved from Clark's Branch investigations represented three significant cultural periods in pre-Contact Virginia: Paleoindian, Archaic, and Woodland. Cultural periods are periods that share similar features or environments.

Riverbend Park's museum contains exhibits that include artifacts recovered from Inashima's excavations. These exhibits interpret each of the three pre-Contact cultural periods documented in Clark's Branch investigations. The exhibit displays organize information by cultural period (Paleoindian through Woodland) along an interpretive timeline. The exhibits illustrate significant technological shifts over cultural periods (e.g., the shift from atlatl to bow and arrow and the introduction of ceramic technology). In contrast to the Riverbend museum's static displays, the Clark's Branch IVR-based exhibit described in this thesis uses three immersive deep maps to interpret these three cultural periods. Both the Riverbend museum and IVR-based exhibits interpret the cultural periods using established criteria outlined by the Virginia Department of Historic Resources (VDHR).

The VDHR separates pre-Contact Virginia history into three primary cultural periods: Paleoindian (15000-8000 BC), Archaic (8000-1200 BC), and Woodland (1200 BC-1600 AD). The Archaic and Woodland Periods are divided further into Late, Middle, and Early subperiods. The separations in these periods factor in changes in environment, lifeways, and artifacts. Clark's Branch findings represent the main periods in this chronological framework.

In its interpretive displays on regional prehistory, Riverbend's museum follows the defined cultural-period guidelines outlined by the VDHR. Riverbend's exhibits combine artifacts discovered in the park with regional artifact replications, lifeways illustrations, and environmental interpretations (Figure 1). For example, archaeologists have yet to recover woolly mammoth remains from park excavations. Still, a drawing of this popular megafauna is illustrated in a museum exhibit to represent key Paleoindian Period fauna (Figure 2). The immersive Clark's Branch maps produced in this thesis present information following this approach, combining site-specific Clark's Branch archaeological data with central characteristics of Virginia's pre-Contact periods, as highlighted by the VDHR, and as illustrated in Riverbend's programs and museum.

The VDHR outlines pre-Contact characteristics following Egloff and Woodward's *First People* (2006). Consequently, Riverbend's museum presents main themes and critical period features as summarized in *First People*. *First People* provides a broad overview of central themes in the main pre-Contact Virginia periods, outlining material culture, settlement and subsistence patterns, development stages, and environmental shifts (Egloff and Woodward 2006). The IVR-based exhibit content that was non-specific to Clark's Branch used information highlighted in Riverbend's museum and referenced *First People*.

Other sources used to craft the IVR-based exhibit content included Riverbend and National Park Service (NPS) programs on pre-Contact Native American lifeways. Riverbend's program, *Indians of the Potomac,* loosely follows *Native Americans of the Potomac,* a program offered by the National Park Service (NPS) at Great Falls National Park (NPS 2015). These programs highlight main pre-Contact environmental and cultural features, emphasizing the Potomac River as an essential regional resource.

Figure 1 - Displays in Riverbend Park

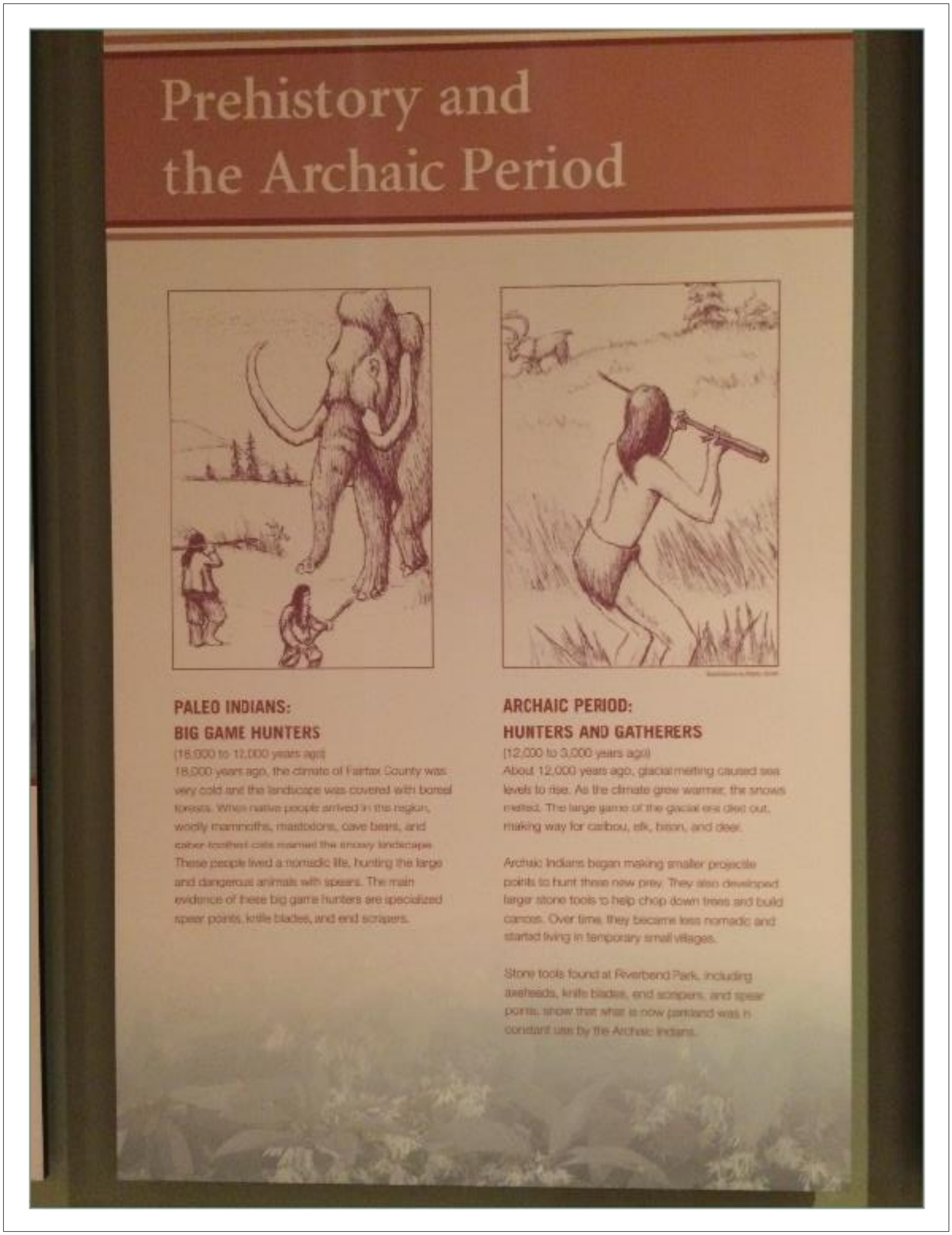


Figure 2 - Paleoindian and Archaic wall displays in Riverbend's museum

Another source to create exhibit content, Helen Roundtree's *The Powhatan Indians of Virginia* (1989), offered in-depth insights on early lifeways, gleaned from early European accounts of the New World (e.g., William Strachey, Thomas Hariot, and Robert Beverley.) Theodor de Bry's engravings from Thomas Harriot's *A Briefe and True Report of the New Found Land of Virginia*, based on drawings by painter John White, served as illustrative references for creating exhibit models (Harriot 1972). Jefferson Patterson Park and Museum (JPPM), a Middle Atlantic region-specific digital repository and research resource, was referenced for material culture information. Additional geological and archaeological reports and articles supplemented these chief sources. Rose Powhatan, a descendant of the region's indigenous peoples, reviewed the exhibit's narrative at Riverbend Park and provided essential feedback for the final script.

This chapter offers an overview of Virginia's three main pre-Contact cultural periods, but this overview is not intended to serve as an exhaustive review of archaeological and environmental data in the state. It is meant to highlight key features from these periods to illustrate why certain information was included in the Clark's Branch exhibit that was not recovered during Inashima's excavations.

This section also details site-specific information from Inashima's work at Clark's Branch. Exhibit content was created by combining Inashima's work with key environmental and cultural characteristics from the primary pre-Contact periods, as derived from sources discussed above. Chapter Three describes Virginia's cultural periods' chronologically, beginning with the Paleoindian Period.

Paleoindian Period in Virginia (15000-8000 BC) and at Clark's Branch

How and when the first peoples entered North American is heavily debated by New World archaeologists. Some scholars back the Bering Land Bridge theory that people traveled into the Western Hemisphere from Asia at the end of the Pleistocene across a 1000-mile-wide land bridge between the massive Cordilleran and Laurentide ice sheets (Egloff and Woodward 2006). Other scientists believe the first people entered North America by boat, traveling along the Pacific coastline (Pacific Coast Migration Model)(Potter et al. 2018). Archaeologists studying Cactus Hill, an archaeological site in southwestern Virgina, follow the theory that people entered the region earlier than the opening of the Beringia land bridge and occupied Cactus Hill between 18,000-20,000 years ago. Scientists that follow this theory (Solutrean theory) suggest these early peoples entered the Americas from Europe, following the edge of the North Atlantic ice pack along North America's eastern coast (VDHR 2020). Some archaeologists support one theory, and others believe the evidence supports multiple models of the Paleoindians' entry into the New World (Potter et al. 2018).

Regardless of when the Paleoindians arrived in the region around the Clark's Branch site, the climate was colder and inhospitable compared to the modern Northern Virginia environment. Around the end of the most recent Ice Age, approximately 10,000 years ago, the Late Wisconsin's glacial conditions shifted to more temperate climates. Compared to the present-day climate, Virginia winters were longer and chillier during the Paleoindian Period, and summers were cooler and shorter (Egloff and Woodward 2006).

In the Paleoindian Period, flora varied across the state. Open coniferous forests comprised of spruce, pine, and hemlock dominated Virginia's northern regions (Egloff and Woodward 2006). Pollen studies indicate that Picea (black or white) spruce in Northern Virginia were common in this forest-and-tundra setting (Watts 1979). In this colder climate, the region's Paleoindians traveled through these coniferous forests in bands, hunting and foraging along regional waterways. Early bands likely hunted large fauna (e.g., elk and deer), possibly also pursuing megafauna, such as mastodon. Faunal remains of megafauna (e.g., mastodon, giant sloth, muskox, short-faced bear, and woolly mammoth) have been discovered in Virginia at sites with Paleoindian artifacts (Schubert and Wallace 2009). These massive mammals are important markers of the Paleoindian Period, and their extinction marks the close of the last Ice Age.

Lithic (stone) tools help archaeologists identify pre-Contact archaeological sites in Virginia. Lithics are durable and do not disintegrate, unlike artifacts made from wood and fiber materials. Tipped-tool lithics identified at archaeological sites are often known as projectile point/knives (PPK). Archaeologists examine a PPK's material type, size, width, manufacturing technique, and hafting element (how the tool attaches to a handle) to date the artifact to a specific period. *Flintknapping* is the process of creating lithic tools, and the *flintknapper* refers to the artist who shaped stones into PPKs.

Fluted PPKs are the hallmark lithic technology of the Paleoindian Period. Paleoindians crafted these PPKs from high-quality cryptocrystalline materials, including jasper, chert, and chalcedony. These fluted tools are long and thinned lanceolate points with characteristic channels or thinning flakes, removed (usually from both sides) from the base (Figure 3) (JPPM 2020). Skilled craftsmanship was necessary to produce these thin, fluted points. Recent exploratory studies indicate that a Paleoindian preference for fluted PPKs may relate to these artifacts' shock absorption. Hunters could reuse these tools for extended periods because they were less likely to snap on impact than thicker-based tools (Thomas et al. 2017). For hunting parties traveling long distances from established lithic procurement areas, long-lasting and reliable fluted PPKs were important toolkit assets.

Figure 3 - Plastic cast replica of fluted PPK recovered in Fairfax County

Fluted PPKs often help archaeologists identify Paleoindian sites, but discovering these tools is rare. The Clark's Branch fluted rhyolite PPK (Figure 4), unearthed in three segments, represents the Paleoindian Period at Clark's Branch (Inashima 2012). Inashima also noted two biface fragments as potential Paleoindian artifacts. Inashima retrieved these Paleoindian artifacts from a stratigraphic layer comprised of small pebbles and schist fragments. A charcoal sample from below this layer provided an accelerator mass spectrometry (AMS) date of 2740 - 2370 calibrated years before the present (cal BP). Inashima interpreted that the Paleoindian artifacts had been trans-located to the site, likely from an adjacent knoll (Inashima 2012).

Figure 4 - Fluted projectile point/knife recovered from Clark's Branch with a plastic replica

Archaic Period in Virginia (8000-1200 BC) and at Clark's Branch

The warming trend that had altered Paleoindian cultural dynamics at the close of the last Ice Age continued into the Archaic Period. From this climatic shift, sea-level rise significantly changed the East Coast. In the Paleoindian Period, the ocean was 300 ft lower than today, and the rising seas covered areas where Paleoindians had lived. Rainfall increased, flooding rivers such as the Potomac and spreading nutrient-rich soils across floodplains. Wetlands and marshes formed, attracting new types of animals for Archaic people to hunt (Egloff and Woodward 2006).

The Archaic people's adaptation to changing climates and resources is observed in the archaeological record in new additions to lithic toolkits. Notched PPKs replaced fluted tools favored by Paleoindians (Figure 5).

Figure 5 - Early Archaic notched PPKs. Kirk Stemmed (left) and MacCorkle (right)

Tool typology evolved throughout the Archaic Period. In the Early Archaic, PPKs were finely flaked, made from chert and other cryptocrystalline materials preferred by Paleoindians. As the Archaic progressed, flintknappers began to rely more on locally acquired, coarser lithic resources (e.g., quartzite and quartz). Archaic flintknappers mined regional quarries and removed cobbles from waterways, like the Potomac River, to acquire these materials. Quartz artifacts recovered from regional sites dating to the Early and Middle Archaic subperiods (8000-2500 BC) indicate a particular preference for this rock.

In Northern Virginia, in the Late Archaic (2500-1200 BC), the flintknappers penchant towards quartz shifted to quartzite obtained from local outcroppings as well as river-cobble form (Johnson 1986). Flintknappers used quartzite and similar coarse materials to create large, stemmed PPKs.

Many of these large PPKs are known as broadspears. Broadspears are low-width/length bifacial tools associated with the Middle Atlantic region's Late Archaic Period (Custer 1991). Broadspears are typically constructed from durable, locally procured materials, like quartzite. Coarser materials produced sturdier multipurpose implements, similar to modern Swiss Army multitools. Archaeologists often recover broadspears at sites lining waterways, indicating early inhabitants may have favored broadspears for processing fish and other riverine resources. Broadspears discovered at Northern Virginia sites include Savanna Rivers and Leigh/Koens-Crispin (Figure 6).

Figure 6 - Broadspears. Savannah River (left and center). Leigh/Koens-Crispin (right)

The atlatl, a tool used to project a spear, was also introduced during the Archaic Period. This instrument converted large, handheld spears into tools akin to small javelins. The atlatl enhanced a spear's speed and impact, making it a useful asset for Archaic hunters pursuing prey like deer and elk. Archaic People constructed atlatls from wood, which typically decompose in Virginia sites due to acidic soil compositions. Components related to the atlatl that have survived in archaeological contexts include bone or antler hooks and bannerstones. Hooks held the spear base in place on the atlatl before the spear was thrown. Bannerstones served as atlatl weights. When thrown from the atlatl, bannerstones increased the spear's power. Atlatl technology was adopted in the Early/Middle Archaic Periods (~6000 BC) (Egloff and Woodward 2006).

Archaeologists have also uncovered mortars, pestles, and nutting stones from sites with Archaic components. These finds reflect a change in regional subsistence strategies, a change occurring as deciduous, nut-bearing tree species like oak, chestnut, and hickory replaced coniferous spruce forests. The Archaic People also created grooved axes from coarse materials like quartzite and basalt during this period which significantly improved chopping wood, facilitating the clearing of trees and construction of housing (Egloff and Woodward 2006).

Soapstone bowls appear in the archaeological record around the end of the Archaic. This material is durable but soft, and Archaic People carved, polished, and smoothed these stones to create vessels (replica shown in Figure 7). Soapstone does not break when heated, making it an ideal material for cooking pots. Soapstone bowls are a marker of the transitional Late Archaic/Early Woodland. These bowls are another indicator that indigenous people were settling down at the end of the Archaic Period, as these vessels were heavy and difficult to transport.

Figure 7 - Soapstone bowl replica in Riverbend's museum

In the Late Archaic/Early Woodland period, the climate began to stabilize, and populations began to transition from transitory hunters and foragers to sedentary agriculturalists. Hunting was still essential to survival, but the warmer, more welcoming Archaic environment offered abundant nuts and berries, and foraging grew in importance. Indigenous people relied increasingly on riverine resources and harvested large amounts of shellfish and fish. Rivers also attracted migrating waterfowl.

Virginia's populations increased, and small settlements, known as hamlets, began to line waterways. Hamlets consisted of 25 – 50 people, and by the end of the Archaic, these groups began to form tribal identities led by elders (Egloff and Woodward 2006).

At Clark's Branch, Inashima retrieved Archaic diagnostics from mixed contexts, speaking to the site's early occupation. Inashima grouped the Middle and Late Archaic subperiods for analysis. Approximately 50% of the Late and Middle Archaic diagnostics Inashima recorded were from flow deposits overlying Late Woodland features. Inashima interpreted these artifacts as trans-located, likely washed downhill from a knoll west of excavation units. He surmised that this knoll might have been a popular campsite (Inashima 2012: 6.1). Inashima recovered the other 50% of Middle/Late Archaic in mixed-context with Woodland artifacts.

Inashima recorded a variety of lithic tools dating to the Archaic Period from excavations, and he organized these by type, a selection shown below in Figure 8-9. Figure 8 shows "notched, eared triangle, and pentagonal points" (Inashima 2012: 6.6). Inashima typed these PPKS as, "a: Halifax Side-notched, b-d: Vernon Side-notched, e, i-j: Slade, f-g: Brewerton Eared Triangular, h: Untyped, k: untyped, and l: Pentagonal" (Inashima 2012: 6.6). Figure 9 displays stemmed and notched PPKs, "a: Poplar Island, b: Lamoka, c, d, e, h, k: Bare Island/Holmes, f: Clagett, g, i: Savannah River, j: Untyped, l: Calvert" (Inashima 2012: 6.4).

Clark's Branch Archaic Period artifacts align with other diagnostic Archaic artifacts commonly found at sites on Virginia waterways. The tributary cutting through Clark's Branch would have made an excellent fishing spot, and the fertile floodplain would have drawn deer and other mammals. This location on the river, north of the rushing falls, would also have attracted waterfowl. This resource-rich space would have been ideal for groups shifting to a more sedentary lifestyle towards the end of the Archaic Period.

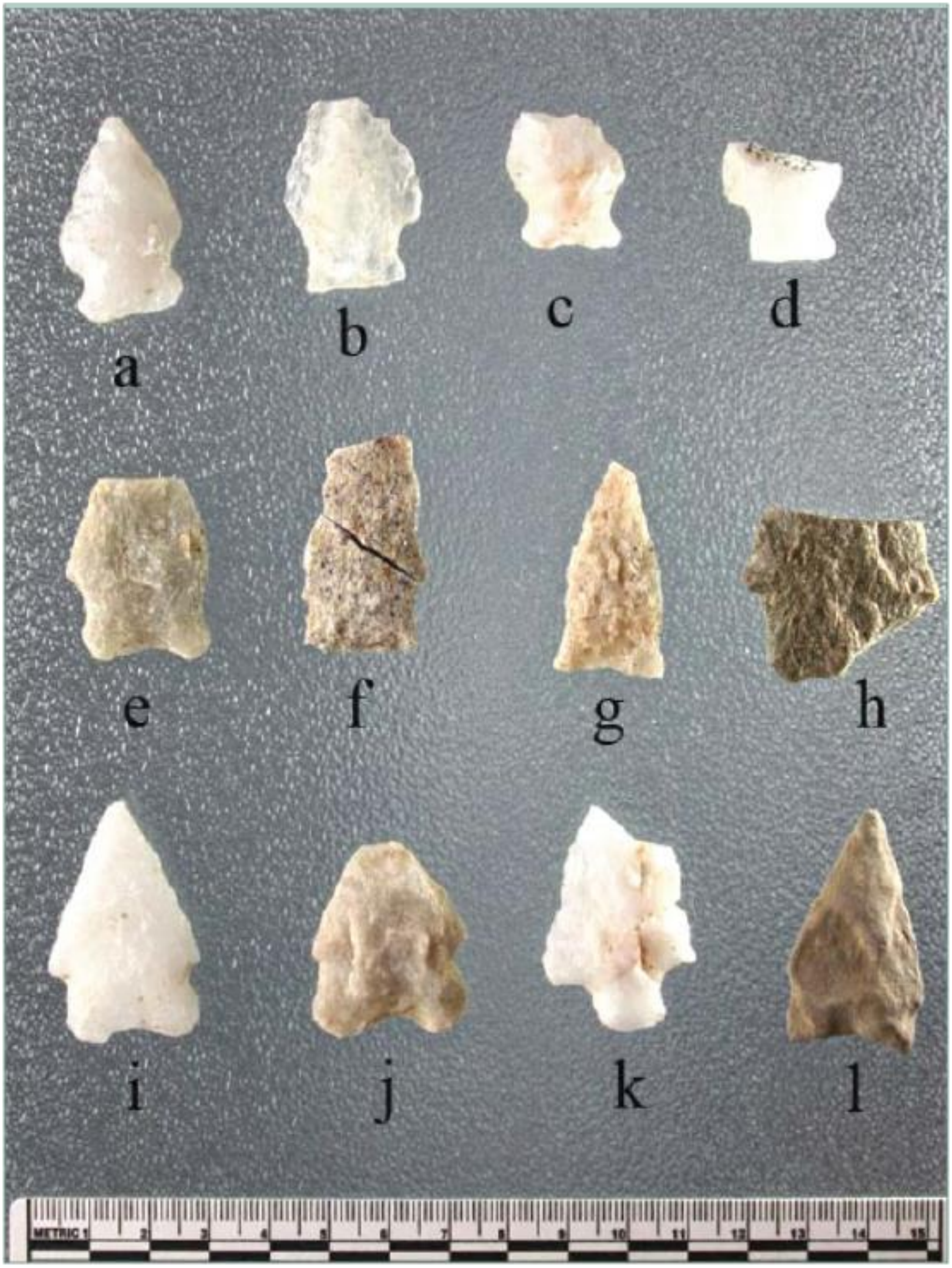


Figure 8 - "Figure 6.3. Notched, eared triangular, and pentagonal projectile points" (Inashima 2012 6.6)

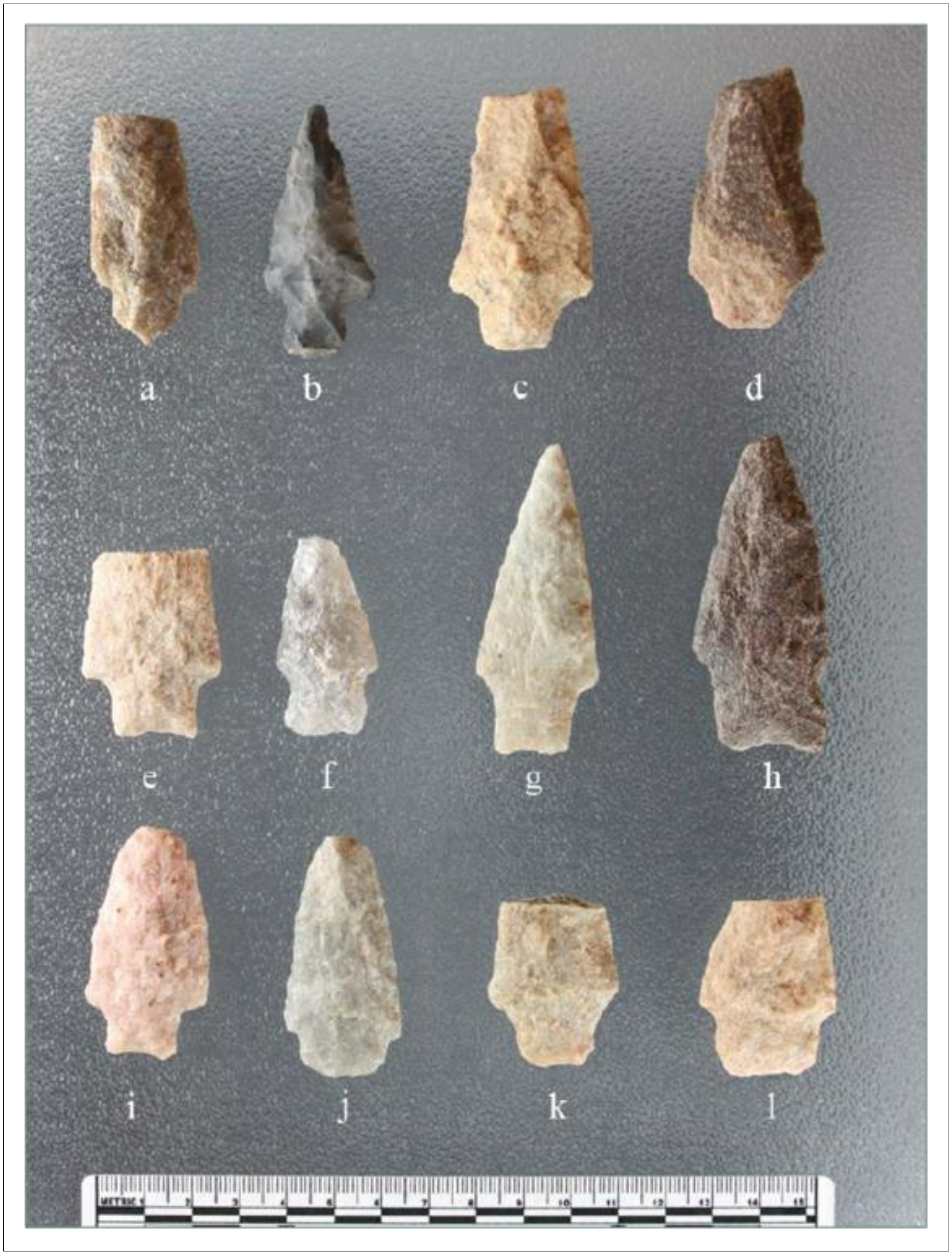


Figure 9 - "Figure 6.2. Stemmed and notched projectile points" (Inashima 2012: 6.4)

Woodland Period in Virginia (1200 BC-1600 AD) and at Clarks Branch

A more permanent shift towards sedentism is a key characteristic of the Woodland Period. Smaller tribes that had inhabited hamlets along waterways grew into villages of hundreds of people with unique political, economic, and social structures. Village layouts evolved from earlier hamlets' scattered homes to rows of structures around centrally located communal buildings (e.g., temples). Archaeological finds show that palisades, wooden defensive fences, surrounded some of these villages (Egloff and Woodward 2006: 26).

People lived in *yihakans*, homes constructed of saplings. Archaeological features related to these homes include the remains of posts, fires, and storage pits (Egloff and Woodward 2006). Yihakans are structures built by stripping branches from saplings and forming arch-shaped frames. The saplings are spaced at one-foot intervals and driven into the ground approximately one to two feet apart with lashing from root fibers, vines, and even deerskin holding these saplings together. The yihakan frame was driven into the ground and covered with fresh-cut reeds or bark mats (Figure 10). Women kept the fires burning inside the yihakans at all times (Roundtree 1989).

Figure 10 - Yihakan replica outside Riverbend's museum

In addition to village design, improvements were made in domestic craftsmanship and tool manufacturing techniques, evident in Woodland ceramic technologies. The switch from soapstone bowls to ceramics made from local clay was another key marker of the Woodland Period. Pottery vessels were much lighter than soapstone vessels, and clay to construct them could be readily sourced from riverbanks. Also, soapstone quarries were not always near village sites, and competition likely existed for access to them (Egloff and Woodward 2006).

Knowledge of firing clay for cooking and storage vessels likely arrived in the region from coastal Georgia and South Carolina. Women produced vessels, handcrafting these pieces by adding water and temper (usually crushed shell, rock, or grog) to clay, molding the mixture into containers, then firing the molded shapes. Early ceramic styles, flat-bottomed with lug handles, reflected previous soapstone bowls' design and were often created using soapstone temper (Johnson 1986).

Archaeologists document different types of pottery vessels from sites across Virginia (e.g., Accokeek, Selden Island, Watson, and Potomac Creek). Potomac Creek pottery fragments, with crushed quartz-and-coarse-sand temper, are common finds at sites with Woodland components around Riverbend (Figure 11). A standard Woodland vessel type is one with a conical base, a shape that would have enabled a pot's contents to heat rapidly (Figure 12). This vessel type's conical base could sit upright in hearths, supported by rocks and logs (Egloff and Woodward 2006).

Figure 11 - Potomac Creek pottery fragments

Figure 12 - Potomac Creek pot replica in Riverbend's museum

Woodland people were farmers, a practice supplemented by hunting and fishing, with women usually responsible for agricultural activities, including planting and harvesting corn (Roundtree 1989). By the latter Woodland Period, corn, beans, and squash were established in Virginia, three crops that grew best when planted together and became known collectively as the Three Sisters. If it was a fruitful year, women harvested the bounty and enjoyed the fruits of their labor from August through October (Roundtree 1989: 47). Floodplains, like those at Riverbend, were ideal areas to farm, with ample water and fertile soil

As regional populations increased and people settled the region, they began to clear large areas to construct homes and farm (Egloff and Woodward 2006). These cleared areas were hospitable environments for vegetation like fruit and berries to flourish. In turn, these berries and fruit attracted animals to hunt. Both men and women were involved in clearing, a laborious task involving cutting down and hauling away large trees, unearthing older roots, and burning small saplings (Roundtree 1989: 46). During this process, workers also removed underbrush for firewood, visibility, and travel ease through forests (Roundtree 1989: 58).

Bow and arrow technology arrived in Virginia in the Middle Woodland Period (500-900 AD). This technology impacted regional hunting, and Woodland men replaced their spears with turkey-fletched arrows and longbows (Egloff and Woodward 2006). The small, triangular projectile points recovered from sites with Woodland components (Figure 13) reflect this hunting apparatus shift. Popular culture often references PPKS as “arrowheads” when these implements only comprise a small portion of the pre-Contact lithic toolkit.

Figure 13 - Arrowheads

Bow-and-arrow technology was particularly advantageous for hunting deer, the most important animal to the region’s indigenous people. Deer were not only an essential source of nutrition; deer were also used to make clothing, tools, and tribute. Cooks prepared venison in several different ways, including smoking, boiling, in a stew form with the heads and intestines, and cooked over embers wrapped in leaves in a “barbecuted” fashion (Roundtree 1989: 50). The first people fashioned deer suet (i.e., animal fat) into cakes for smearing on bread or sometimes for trade. Deer sinew and glue created from boiling deer antlers were used to fasten arrowheads to shafts and were also used to make fishing nets. Deerskins were used for clothing and also as an indicator of wealth. Men were expected to be successful hunters, learning different deer-hunting techniques early in life to provide for their families and leaders (Roundtree 1989). By the period of European contact, deer were significantly overhunted in Virginia. To mitigate pressures on deer populations, Woodland hunters spread hunting ventures over different areas (Roundtree 1989: 40).

Other dietary staples for Virginia’s Woodland populations included turtles, snakes, crabs, oysters, clams, mussels, and numerous fish types (e.g., sturgeon and bass.) Birds were abundant, and hunters pursued wild turkeys, quail, passenger pigeons, and waterfowl (e.g., ruddy ducks, teals, and geese) (Roundtree 1989: 23).

At Clark’s Branch, Inashima documented Woodland finds as “spatially displaced, in situ mixed, and partially intact contexts” (Inashima 2012: 5.1). Woodland artifacts from Clark’s Branch include stemmed, notched, triangular PPKs, ceramic sherds, and three hearth features. Radiocarbon assays from identified hearth features date to the Late (900-1600 AD) and Early (1200 BC-500 AD) Woodland subperiods.

Inashima identified a range of ceramic types from excavations, including those shown in Figure 14: “a: untyped Late Woodland cord-marked black and micaceous temper, b: Early Woodland Selden Island Cord-marked, c: Late Woodland untyped sand-tempered ware, d: Middle Woodland Mockley Cord-marked, e: Middle Woodland

Mockley Net Impressed, f: Late Woodland Potomac Creek Cord-marked, g: Middle Woodland Mockley Net-Impressed, h: Late Woodland Shepard Cord-marked, i: untyped quartz grit tempered sherds, j: untyped quartz grit tempered sherd fragment, k: untyped quartz grit tempered sherds, l: possibly Early Woodland Marcey Creek lug fragment, m: untyped quartz grit tempered sherd" (Inashima 2012: 5.2).

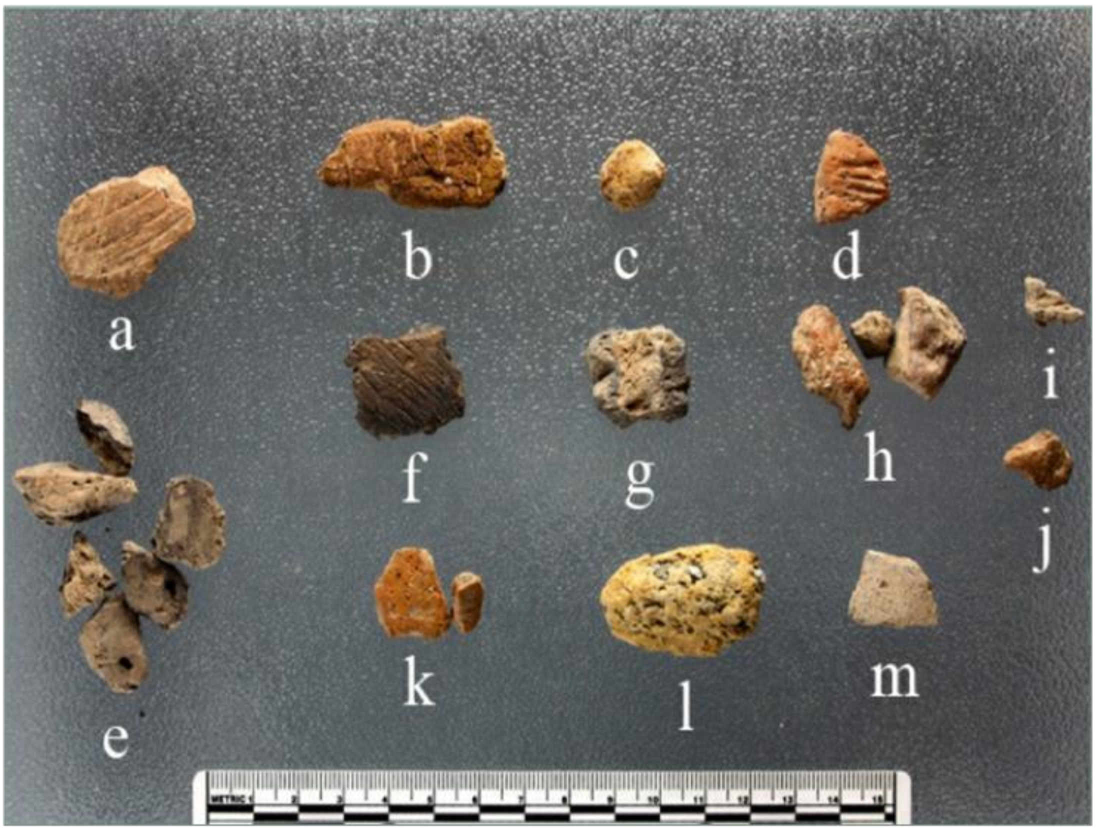


Figure 14 - "Figure 5.2: Representative ceramic sherds from Clark's Branch" (Inashima 2012: 5.2)

Inashima also recorded a variety of lithic tools representing the span of the Woodland Period. Both triangular and non-triangular PPKs are noted in this assemblage.

Triangular PPKS recovered shown below in Figure 15: “a-h untyped but attributed to Late/Middle Woodland, f: Madison” (Inashima 2012: 5.3).

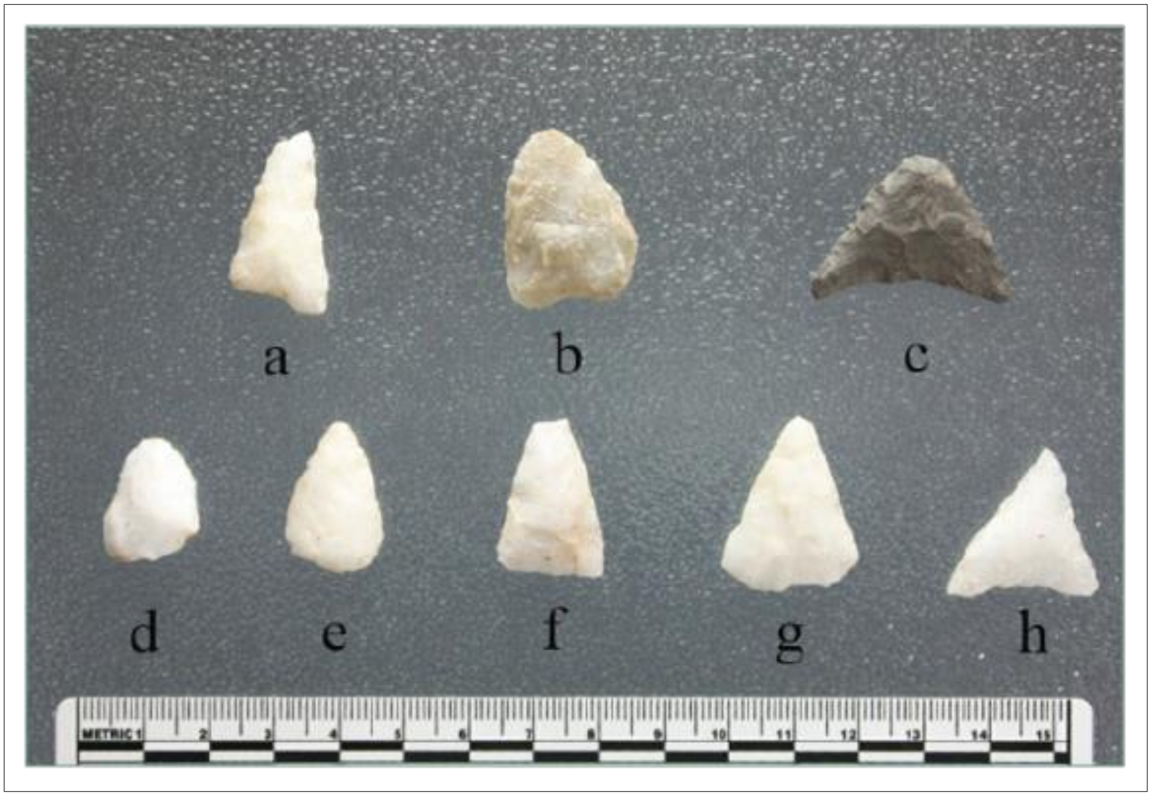


Figure 15 - “Figure 5.2: Triangular Points” (Inashima 2012: 5.3)

Non-triangular Woodland PPKs depicted in Figure 16 include, “a: Clark’s Branch Stubby Side-notched, b: Clark's Branch Stubby Side-notched, c: Piscataway, d: Piscataway, e: Otarre Stemmed, and f: Jack’s Reef Corner-notched” (Inashima 2012: 5.5).

Figure 16 - "Figure 5.4. Non-triangular Woodland projectile points from Clarks Branch" (Inashima 2012: 5.5)

Inashima attributed hearth features recorded at Clark's Branch to the Early Woodland (1200 BC-500 AD) and Late Woodland (900-1600 AD) subperiods. The Late Woodland hearth features were designated Feature 1 and Feature 22. Feature 1 was comprised of fire-cracked rock, wood charcoal, and stones, with a diameter of 2.5 ft and an AMS date between 1050 and 920 cal BP (Inashima 2012: 5.7). The second Late Woodland hearth feature, Feature 22, contained thin-walled, friable, sand-tempered pottery (Figure 17)(Inashima 2012: 5.7).

Inashima recorded the Early Woodland feature (with AMS date of 3450 to 3280 cal BP) as the Early Woodland Selden Island Ware feature. The feature consisted of "an area of concentrated wood charcoal, fire-cracked rock, lithic debitage, a ceramic sherd, and stone tools" (Inashima 2012: 5.13).

Flooding episodes had negatively impacted these hearth features. Still, they speak to a continued Woodland occupation at the site. Just upstream, archaeologists have recorded Late Woodland village sites, with structural evidence and burials, although Inashima did not record evidence of large village settlements at Clark's Branch.

The variety of cultural materials from Clark's Branch point to the continuity of the site. A varied lithic tool assemblage spans all pre-Contact periods at the site, with fluted Paleoindian PPKs, Archaic broadspears, and a wide assortment of notched, eared, stemmed PPKs, and triangular arrowheads representing the Archaic and Woodland Periods. Various types of pottery fragments, tempered with materials from steatite to fine sand, reflect multiple occupational Woodland episodes, in addition to the remains of several features. Clark's Branch was a resource-rich place indigenous people used across the pre-Contact cultural periods.

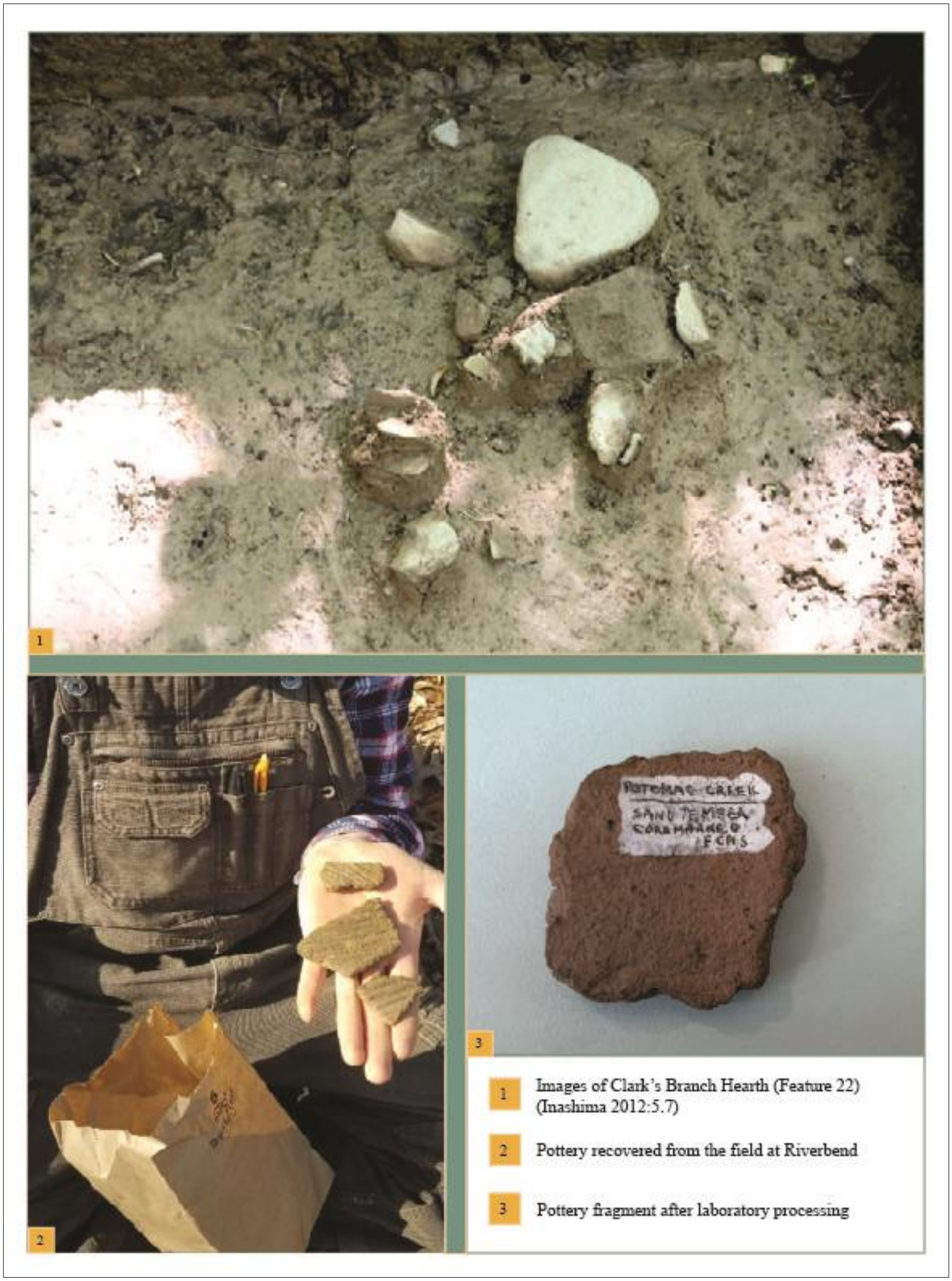


Figure 17 - Clark's Branch Feature 22 and pottery fragments recovered from other Riverbend Park sites

Landform Interpretation – Major Events at Clark's Branch

In addition to displaying occupational episodes at Clark's Branch, the IVR-based exhibit sought to interpret and present topographical and hydrological changes at the site. The main hydrological features at the site are the Potomac River and Clark's Branch, a small Potomac tributary. The Clark's Branch Site's core is situated on an alluvial fan below several knolls. West of these landforms, the topography shifts to high river bluffs. The site's soils are primarily colluvial and alluvial sediments deposited during major events.

Inashima details four main events impacting site formation at the Clark's Branch Site. He interprets the most recent event as a significant flow or landslide during the historic period. This event covered the Woodland Period land surface with a sediment deposit containing high quantities of rock. Inashima attributes the Paleoindian/Early Archaic through Late Woodland artifacts recovered in this deposit as likely trans-located from a knoll adjacent to the site's core (Inashima 2012).

Inashima interprets the preceding event at the site as an erosional one, in which Late Archaic/Middle Archaic occupation soils were impacted. He noted that the event before this episode was a flooding deposition and scouring event. Inashima interpreted these soils as a dense schist/cobble lens overlying sterile soils. The sterile stratum, overlaying another thick cobble/schist lens, was the earliest flooding and scouring event Inashima interpreted at the Clark's Branch Site (Inashima 2012).

Inashima noted that excavations never reached bedrock. He observed that buried deposits, indicating further scouring and flood events, could be present below tested areas

(Inashima 2012: 8.7). In the Potomac River Valley, deep-testing in floodplain sites is rare, as this process can be time-consuming and expensive. Increased flooding over the past few years has ravaged Riverbend's floodplains, negatively impacting both surface and buried sites. It is not uncommon for large storms to tear away entire riverbank swathes, though these banks are primarily composed of modern silt/sand matrices.

Overall, Riverbend and the surrounding area, aside from localized riverbank damage and flood deposition, have not changed dramatically from the last Ice Age. The Potomac River began to carve into the present valley approximately 2 million years ago at the beginning of the Pleistocene. Above Great Falls, steep cliffs line a shallow region of the Potomac, with occasional rapids and low-lying bedrock islands breaking up the river. This area's bedrock consists of metamorphous and igneous rocks, more challenging to penetrate than the soft sandstone and shale bedrock of the region upstream. The harder, erosion-resistant bedrock present in Riverbend is virtually unchanged from that of the pre-Pleistocene valley (Reed et al. 1980: 9).

Following the retreat of the glaciers at the end of the last Ice Age, the area around Clark's Branch began to silt in, though not as rapidly as floodplains further upstream. In his Clark's Branch analysis, Inashima presented a diagram interpreting landform formation at Clark's Branch from the Paleoindian Period to the Present (Inashima 2012 4.6)(Figure 18).

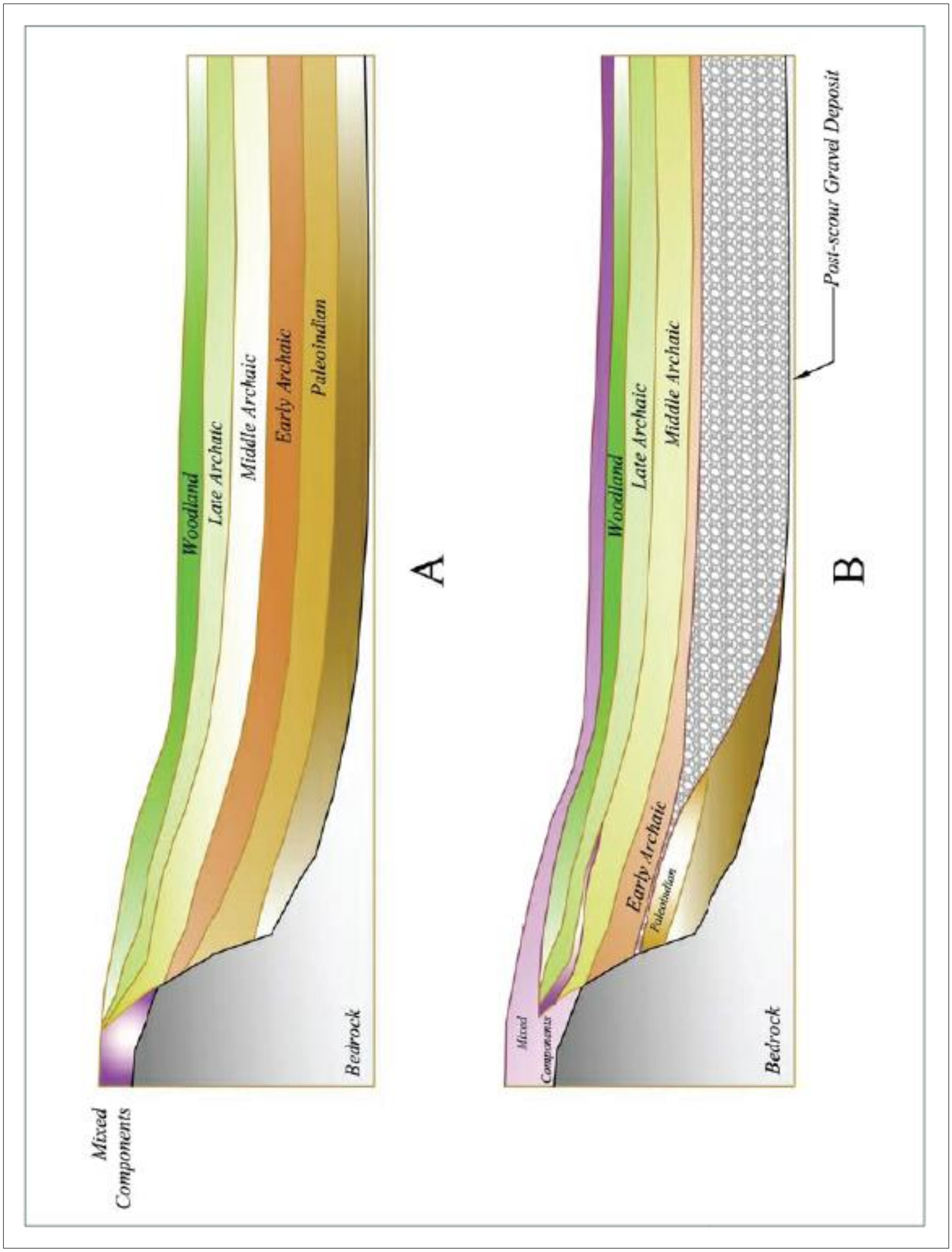


Figure 18 - Inashima's graphic illustrating stratigraphy encountered along the south bank at Clark's branch (A: Theoretical idea; B: Interpreted stratigraphy) (Inashima 2012: 4.6)

Time in Riverbend's Museum

The displays in Riverbend's museum highlight the Potomac River and regional geology, though these features are interpreted separately from information on the park's first inhabitants. When visitors enter the museum, large wall displays introduce them to the Potomac River, detailing its formation. The wall displays note that families have frequented the park for "more than 12,000 years" (Figure 19). On the other side of these displays, exhibits present Virginia's cultural periods with materials from Clark's Branch and artifact replicas organized along a timeline (Figure 20).

These timeline artifacts are arranged chronologically in a glass display case, beginning with the Paleoindian Period. Above the timeline display case are wall displays with text and illustrations offering information on each period's environment, material culture, and associated lifeways. Inside the timeline display case are smaller illustrations related explicitly to the presented artifacts. For example, the Clovis PPK replica is close to an illustration depicting hunters with spears, a woolly mammoth, and spruce trees.

Another replica, a Potomac Creek conical pot, is featured at the end of the timeline with a plaque below this pot featuring Theodor de Bry's *Their manner of fishing in Virginia*. A full-sized model of a Taxuenant (a regional indigenous tribe) hunter gazes out over the displays from the museum's corner (Figure 20). A dugout canoe is also featured inside the museum, depending on the time of year and interpretive programming.

Riverbend's museum is an excellent resource for educating public audiences on Virginia's early lifeways, tribes, material culture, and past environments. Still, in these exhibits, the display materials are detached from both the people who made them and the public observing them. Separating artifacts from the public is necessary for preservation and protection purposes, but pedestalling them strips these materials of context and severs them from human connection. Riverbend Park and NPS programs encourage audiences to make connections between contemporary societies around Washington, D.C., and the Potomac's first people, but no matter how well presented, these programs suffer from inherent weaknesses related to the user's inability to interact with the exhibited materials.

To best understand the spaces around us, humans need learning experiences that mimic how we maneuver through the world. It is impossible to walk through past environments and see artifacts and the people who created them in context. However, immersive maps can offer interpretations that help transport audiences to the past, reconnecting artifacts with context and culture. Exploring these deep maps through immersion provides an embodied experience, tapping into the user's senses and allowing them to walk in past landscapes virtually. These novel experiences could help the public better connect with layers of time and history.

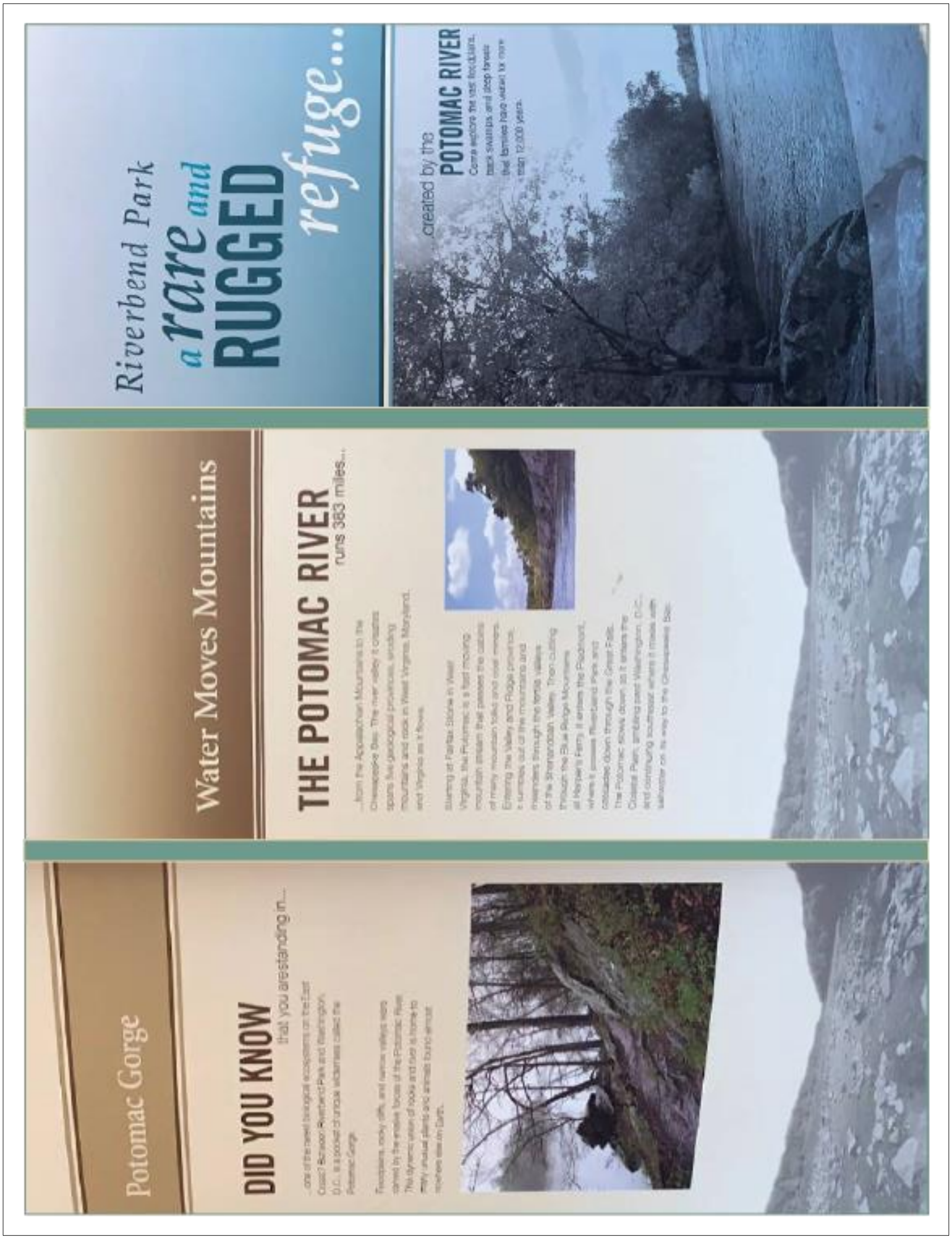


Figure 19 - Riverbend Wall Displays about the Potomac River

Figure 20 - Riverbend's Museum and Close Up of Timeline Exhibit

CHAPTER FOUR - CLARK'S BRANCH EXHIBIT DEVELOPMENT

The Clark's Branch IVR-based exhibit highlights significant features of Virginia's three main pre-Contact cultural periods. It also includes information from Riverbend's museum timeline, the park's *Indians of the Potomac* program, and site-specific Clark's Branch data. Exhibit development occurred in three stages: 3D data collection and creation, narrative construction, and virtual portal development. A central research focus was on creating realistic 3D scenes to help application users experience a sense of presence. To create highly realistic models to populate these scenes, photogrammetric and 3D scanning technologies were used for digitizing cultural and environmental features.

Four maps represented the Paleoindian, Archaic, Woodland, and Modern cultural periods. Each map contained 3D representations of flora, fauna, artifacts, archaeological features, narrative, soundscapes, and climatic interpretations. These four maps served as the immersive exhibit's core, linked together by virtual portals. Figure 21 details the deep map exhibit development process, and Appendix A provides a link to a video demoing the completed Clark's Branch exhibit.

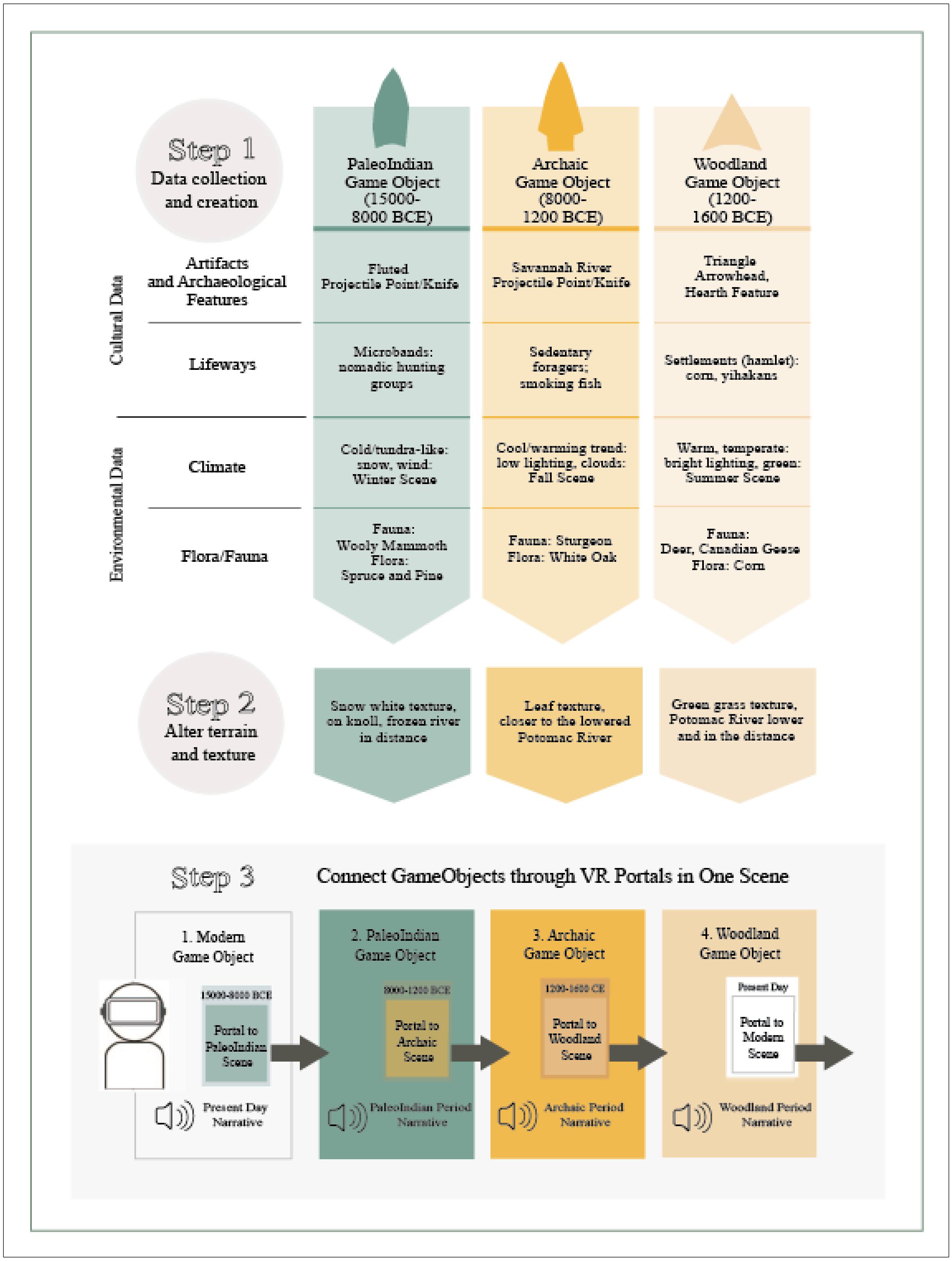


Figure 21 - The Clark's Branch immersive deep map exhibit development process

3D Data Collection and Creation

Data collection and creation was the first stage in populating the exhibit's deep maps with engaging, lifelike content. Agisoft Metashape, a NextEngine 3D scanner, ScanStudio Pro HD, MeshLab, Blender 3D, and several Adobe applications were used to develop animated, photorealistic models to capture the user's attention and enhance their sense of presence. Other models used to populate this exhibit were obtained through the Unity Asset Store and 3D content marketplaces (e.g., CGTrader).

The Unity Real-Time Development Platform (Unity) version 2019.2.8f1 was used to create this exhibit. Unity is a real-time, cross-platform gaming environment often selected by developers to craft 2D and 3D history-and-archaeology-focused applications (Eve 2014; Gabellone et al. 2017; Bjorkl et al. 2018). Exhibit development relied on three main Unity components: *Scenes, GameObjects, and Cameras*. A project-specific Unity 3D project housed these components.

Unity *scenes* are the building blocks of Unity applications, used by game developers to break games into manageable segments and organize different ideas and environments. Scenes serve as containers for managing the game's content. Scenes also help separate computationally expensive data (e.g., photorealistic 3D models), which is advantageous for improving game rendering and loading speeds.

Game content, such as 3D models, audio, and lighting, is typically stored within *GameObjects*. GameObjects are the different types of data that make up the game. In this exhibit, GameObjects were the 3D models of artifacts, terrain, and environmental information. The 3D data imported into Unity were placed inside empty GameObjects and were organized in the exhibit's scene hierarchy. Without GameObject organization by cultural period, it would not have been possible to create and implement the virtual portals discussed later in this Chapter.

Cameras were another essential component for developing the IVR-based exhibit. In Unity, the cameras are vital components of the game because cameras present the game's visuals to the player. Depending on the game, different cameras can be placed across a scene to render features or alter the user's perspective.

Users experience the exhibit from a first-person perspective, often referred to in gaming environments as a first-person shooter (FPS) perspective. From an FPS perspective, the user experiences the exhibit through the scene's *Main Camera*, attached to the FPS's character's "eyes." The user views the game through these "eyes," virtually inhabiting the FPS avatar. The FPS perspective was selected as the user perspective for this exhibit to create an embodied experience and enrich the user's sense of presence.

VR studies reveal that game users access a greater sense of presence and feel "body-ownership" when experiencing games from first-person scenarios, compared with VR experiences from third-person perspectives (Borrego et al. 2019). The FPS perspective allowed the user to learn about Clark's Branch from a pseudo-inquiry-based approach. The exhibit user exercised control over their avatar with the freedom to move around portions of the exhibit and investigate features they found interesting.

Oculus Utilities, a Unity plugin from Facebook Technologies, was used to create an FPS that would work seamlessly in Oculus Rift systems. The Oculus Utilities package included a *prefabricated* FPS character, the OVRPlayerController GameObject. A *prefabricated* (prefab) object in Unity is a GameObject that contains pre-selected components. The OVRPlayerController prefab stores script elements for an FPS (i.e., character, player, and direction controller scripts). This prefab also included tracking information necessary to communicate with the Oculus Rift HMD.

Unity cameras, attached to the right, left, and center anchors of the OVRPlayerContoller prefab, tracked the user's head movements and displayed the scene's data in the exhibit application. The center anchor camera presented the exhibit through a monoscopic display. A monoscopic display, and center anchor camera, were selected to ensure the VR portals correctly displayed the exhibit data. IVR-based experiences often use stereoscopic displays, where two cameras mimic what the user's two eyes would see in a real-world space. Stereoscopic experiences allow the brain to create a sense of depth and are similar to how people visually absorb real-world information.

However, using a stereoscopic display for the OVRPlayerController camera was not a good option because the stereoscopic display format duplicated all the portal data. Choosing a monoscopic display, and selecting only the center camera, alleviated this issue and allowed the user to experience the portals without seeing double. Further work is needed to evaluate if using monoscopic display formats over stereoscopic impact a user's sense of presence in IVR-based experiences.

Apart from the camera and display alterations above, the factory settings for the OVRPlayerController prefab were unchanged for this exhibit. Additionally, the main properties of the OVRPlayerController prefab were similar to that of Unity's standard

FPS character. These properties are significant because they control the virtual body's vantage point and impact how users experience the space. If the virtual body is positioned too low, the user might miss high features embedded in the immersive maps. Alternatively, the user might miss features closer to the ground if the body is positioned too high. Unity's approach to fixing this Goldilocks conundrum is to set their FPS prefab (essentially a 3D capsule with an attached camera) at 1.8 meters. The standard OVRPlayerController is set a bit higher than this, at 2 meters.

The circumference for the OVRPlayerController was left on the original setting at 0.5 meters. The circumference of the player impacts how the player moves around objects with *rigid body* scripts. Rigid body scripts assigned to GameObjects ensure the FPS cannot walk through objects. These scripts are added to objects so that players interact with objects as they would in the real world, with no chance of walking through trees or other characters. The majority of GameObjects in this exhibit had rigid body scripts and gravity modifiers to prohibit walking through objects and allow users to pick up and interact with select exhibit models.

Environmental Components

Terrain and Hydrology

Gravity scripts assigned to the OVRPlayerController kept the user in an upright position and tethered to the exhibit terrain. Four terrains, created from elevation models of current topography at Riverbend (focused on the Clark's Branch region), were the first models added to this exhibit. These terrain models provided horizontal planes for the

OVRPlayerController to move across and served as the exhibit's foundation and setting for 3D flora, fauna, cultural, and environmental models.

The Real-World Terrain Unity tool was used to develop the exhibit's terrain models. This tool generated a digital elevation model of the Clark's Branch site at Riverbend Park. The center point of the site (in decimal degrees) was used as a reference point to create this model (Figure 22). Then, the Gaia Stamp option was selected for Clark's Branch terrain from four formatting choices: *Terrain, Mesh, Gaia Stamp, and Raw File* (Infinity Code 2019).

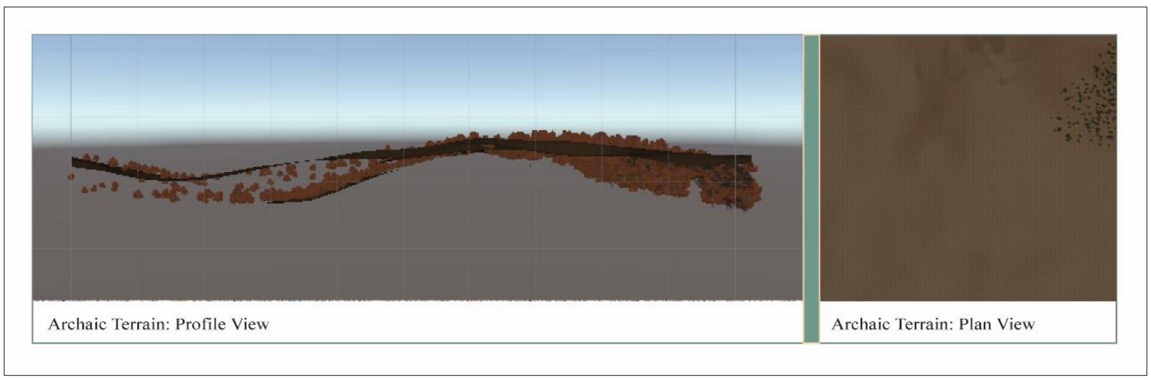


Figure 22 - Archaic Terrain Profile and Plan View

A Gaia Stamp was selected with a high resolution of 2048 pixels per image and real-world elevation values as the exhibit's terrain format output. This Gaia Stamp's terrain format works in conjunction with Unity's Gaia asset, another terrain and scene generator asset game developers can use to produce procedural worlds. This asset can also be used to "stamp" (i.e., place) features onto terrains. Stamped features can include elevation data, textures, and 3D models. A custom Gaia Stamp terrain featuring Clark's

Branch topography, with real-world elevation data from ArcGIS (accuracy of 10 meters), was generated in Real-World Terrain. Real-World Terrain also provides real-world image *textures* that can serve as overlays on the terrain. Choosing a real-world texture image could help game developers place 3D building models and other features in urban environments. For this IVR-based exhibit, no real-world textures were added to the Gaia Stamp. Custom textures were selected to cover each terrain specific to the particular cultural period (Figure 23).

Figure 23 - Textures in the exhibit's Pre-Contact cultural periods

Unity's Duplicate function was used to make three copies of the Clark's Branch Gaia Stamp. These four terrain stamps represented the exhibit's cultural periods: Present, Paleoindian, Archaic, and Woodland. Each terrain stamp was placed under its corresponding GameObject, then imported into the scene with the object's coordinates centered at zero. Unity's 3D scenes operate on a three-dimensional Cartesian coordinate system, with objects placed at points on the X, Y, and Z-axes. Objects were centered at zero coordinates when imported into the exhibit's scene (i.e., X=0, Y=0, and Z=0) then manually moved across each axis into different positions.

Initially, exhibit development plans included modifying the terrain's geometries to reflect topographical changes over time. Inashima's interpretations, with Hayes' geomorphological analysis (Inashima 2012), served as a comprehensive reference for geomorphological changes at the site. Site formation at Clark's Branch was impacted by natural events and cultural influences, including agricultural activities and a masonry dam just downstream. Though slight, these natural and cultural factors influenced the overall cultural landscape at Riverbend and Clark's Branch.

At first, to display these changes, each period's terrain was modified following Inashima's work. This process involved altering the height of the terrain using Gaia's elevation modification tools. These terrain modifications proved to be so slight they were not detectable inside the immersive exhibit. Next, the measurements were exaggerated, so the elevation difference would be evident to exhibit users. The terrain was either raised or lowered several feet as the user moved between cultural periods. This alteration caused the user to fall several feet as they moved across the terrain or to get stuck underneath the terrain. Getting stuck beneath the terrain caused the user to fall into infinite and empty game space, prematurely ending their exhibit experience.

Instead of modifying the terrain geometries, other exhibit features were altered to reflect topographical changes over time. For example, in the Woodland Period, the Potomac River was lower than it is today. To indicate this shift in the exhibit, extra terrain was added to the Woodland Period Terrain to position the user further from the river than where they had stood in the Archaic scene. Additional terrain also made the Woodland scene appear more open, another feature of Woodland Period Virginia.

The exhibit's exaggerated terrain modifications are not adequate for specialist audience's intent on studying exact landscape changes. The final exhibit does not adjust the terrain and hydrological features to reflect Inashima's exact interpretations. Specialists are more likely interested in answering specific site formation questions, necessitating precise modifications in analysis platforms. This exhibit did not attempt to modify the terrain following these exact measurements, focusing instead on presenting materials to public audiences in a format offering seamless movement over the terrain, meant to communicate broad changes over time.

The main hydrological feature at the Clark's Branch Site is the Potomac River. Water models representing the Potomac were added to each of the cultural periods. The four water models were altered along the Y-axis to reflect hydrologic changes over time.

Overall, the Potomac River above Great Falls has not changed dramatically since the last Ice Age (Reed et al. 1980), so modifications to the exhibit's water models were minimal. In the Paleoindian Period, the user was placed on the terrain on a knoll above Clark's Branch. Inashima interpreted that Paleoindian artifacts had initially been located on this knoll before trans-location to the floodplain. In the exhibit, the Paleoindian Potomac River water model appeared frozen and covered under ice and snow.

During the Archaic Period, the floodplain began to silt in. To reflect this change in the Archaic scene, the river model was moved slightly down the Y-axis, and the exhibit user was placed in the floodplain closer to the Potomac. Placing the user closer to the water ensured they saw the river while hearing about the Potomac's importance in the narrative. In the Woodland Period, extra terrain was added to the scene, and the user was placed further from the river. This alteration was made to communicate to users that the floodplain continued to silt in during the Woodland Period.

Climate and Flora

Textures, particle effects, and models communicated climatic changes over the cultural periods. *Textures* are flat images assigned to GameObjects, adding visuals such as color to game models. Each cultural period terrain was covered with a specific texture to enhance the period's climatic tone. Different colors, hues, and textures for the sky, terrain, and water communicated a sense of "cold' and "hot" to users and were the main components of indicating the shift from a frigid, tundra-like environment to a temperate, warm one.

Varying types of 3D flora models also communicated climatic changes. The exhibit's 3D flora models were selected to represent major Virginia species tied to each cultural period. Inashima retrieved limited archaeobotanical data from Clark's Branch excavations, so interpretations of period-specific flora came from the information presented in Riverbend's museum, programs, and the VDHR.

Thus, the flora models chosen for the exhibit represented specific cultural periods and communicated different climates. For example, corn arrived in Virginia during the Middle Woodland period, so corn was selected as the flora to represent the exhibit's Woodland Period. Additionally, the 3D models of corn chosen for the exhibit were ripened ears of corn, as they would appear in late summer. These visuals were included to communicate a sense of warmth and a warmer Woodland climate to exhibit users (Figure 24).

The central climatic theme presented across the exhibit was the shift from colder to warmer weather. The exhibit user moves through time from the temperate, Present Period onto a bright-white, snow-covered Paleoindian landscape. An animated snow *particle system* falls around the user in this period, emphasizing their frozen surroundings. Particle systems are comprised of animated graphics, moving to simulate a particular effect, such as snowfall. In addition to the snow particle system in this period, a snow-white texture was used to "paint" snow over the entire Paleoindian terrain.

Figure 24 - Flora in the exhibit's Pre-Contact cultural periods

3D models of spruce and pine dotted this Paleoindian scene; these flora models were also covered in bright-white snow. One spruce tree was labeled "spruce" and positioned on the trail right in front of the Archaic Period portal to draw attention to the model and offer the user a label if they were unfamiliar with the tree. Highlighting this feature also accentuated that coniferous forests were connected to the Paleoindian Period. A twilight skybox was selected as the Paleoindian sky backdrop to communicate the cold sensation felt when the sun sets. *Skyboxes* are squares that wrap around the game and show a graphic (typically a sky image) instead of a generic blank, grey game background.

For the Paleoindian Period, a winter soundscape also conveys a sensation of cold. Users can see the wind shaking the spruce needles and hear the wind in the background. The audio in the soundscape was incorporated into this scene to enhance the user's sensory experience and cultivate an overall embodiment of cold.

As the user moves into the Archaic Period, the scenery shifts from an icy winter world to a cool, colorful fall scene. An autumn leaves texture, created from an image of acorns and colorful fall leaves, was painted across the Archaic terrain. As the user moves onto the Archaic terrain, the snowy Paleoindian trail transforms into one created with a dirt texture, covered in 3D acorn models. The texture and flora changes communicate the climatic shift to a warmer yet still-cool environment. 3D models of white oaks cover the terrain in this scene, with yellow and orange fall leafage to match the Archaic terrain's leafy texture. White oak models dominate the scene, but several spruce and pine models were also included in the Archaic terrain. These coniferous trees were included on this terrain to indicate that though forest composure was changing over time, these species were not wholly supplanted in the Archaic.

The clusters of oak models in the Archaic Period represent a shift from open, coniferous forests to dense, deciduous stands. The importance of nuts as a resource for the Archaic People was why white oaks were chosen as the flora representing the Archaic

Period. The exhibit user was required to walk over the acorn models scattered on the trail to move to the next cultural period.

The Potomac River was a central feature of the Archaic landscape. A custom soundscape highlighted this feature, with ever-present river audio in the background. Crackling fire audio highlighted the hearth in the scene and drew the user's attention to the smoking sturgeon fish. A dugout canoe and canoe-builders were also included in the Archaic Period scene to emphasize the importance of riverine resources during this time.

As the user moves from the Archaic Period into the Woodland Period, the fall scenery shifts to a bright-green flora, similar to the foliage users experienced in the Present Period. The forest is sparser in the Woodland Period, containing large swaths of open terrain. Corn planted in these open areas represents the Woodland Period. People living in the Woodland Period relied on corn as a dietary staple. This crop is also emphasized in Riverbend's programs and museum.

The cornfields in this scene also help communicate a Woodland Period cultural shift from foraging to farming. Animated women characters appear to speak and gesture to one another in these fields, a subtle reference to women as those responsible for planting and harvesting this essential crop.

White oak (with green leafage to match the summer scene), beech, grass, and ferns were other flora models included in the Woodland Period. Floodplains were resource-rich areas in the later Archaic and Woodland Periods, and the greenery of these models conveys a sense of a lush environment. Apart from the corn, the same flora was displayed in the Woodland and Present Periods. Also, the same green grass, ferns, and rocky texture was used to paint both terrains. This choice indicated the continuity of these species and similar climates of these two contiguous cultural periods.

A forest background soundscape begins when the user moves from the Archaic into the Woodland Period. This soundscape includes background noises of chirping birds and babbling water. Cricket audio takes center stage in this soundscape. This insect noise surrounds the user with audio reminiscent of a late Virginia summer afternoon when chirping crickets' sounds fill the air.

Color, hue, and texture communicate climatic changes at Clark's Branch to exhibit users. Elements such as bright white snow and fall leaves exaggerate each period's climatic tone to enhance the user's visual perception of the period's overall climate. Soundscapes and specific audio clips appeal to the user's auditory senses. Both contribute to building an embodied experience for exhibit users through the creation of rich sensory spaces.

Fauna and Animations

Inashima did not identify any faunal remains during his Clark's Branch excavations (Inashima 2012). As with the exhibit's flora, the fauna chosen to represent each cultural period was highlighted in Riverbend's museum and programs and noted by the VDHR.

For example, woolly mammoth (Mammuthus primigenius) models were the only fauna displayed in the Paleoindian Period. These models were based on woolly mammoths, megafauna that were roughly elephant-sized, with long, ivory tusks and thick fur that enabled them to live in frigid, Ice Age climates. These massive mammals are depicted in an interpretive sketch at Riverbend and mentioned several times during Riverbend's *Indians of the Potomac* program.

Megafauna, like the wooly mammoth, are hallmarks of the Paleoindian Period. Remains of woolly mammoths and other Late Pleistocene megafauna have been recovered in Virginia at archaeological sites (Schubert and Wallace 2009) though none have been identified at the Clark's Branch site. Woolly mammoth megafauna models were included in the exhibit to paint a comprehensive picture of the Paleoindian Period.

All the 3D faunal models, apart from the woolly mammoth, were imported into Unity with accompanying animations. Faunal models typically were imported with several animation options attached (e.g., idle, walking, and attacking.) Unity Animation Controllers, created from these animations, controlled the model's movements in the scene. For example, the Deer Idle Animation Controller operated the deer idle.fbx animation. When the Deer Idle Animation Controller was created and attached to a deer model, the deer model became animated, moving its head idly from side to side on a loop cycle.

The woolly mammoth model was imported in Unity with no associated animation. To enrich the user's sense of the Paleoindian Period with a moving, lifelike woolly mammoth, custom animations were created for the model in Blender. Blender is a free, open-source software developers can use to create 3D models, animations, and visualizations (Blender 2019). Before starting an animation for the mammoth model, it was necessary to *rig* the model. *Rigging* is the process of creating a digital bone structure for 3D models. Different points on the character's digital skeleton (the rig) are posed in various positions on an animation *timeline* in Blender to create the model's animations.

The various poses on the timeline are set at different points, called *keyframes.* The model moves through the keyframe sequence when the timeline starts until the animation timeline is complete. In Unity, there is an option to set animations on a loop, which will start the timeline over from the beginning keyframe. The animation can also be added to a series of animations on another type of animation timeline within Unity. Triggers are often used in Unity and other game environments to control specific animation timelines. In the exhibit, animations are triggered when users move through the virtual portals. Additionally, some animations were set on loop throughout the game. The loop cycle was assigned to models close to the portals so that these animated characters would catch the attention of exhibit users, enticing them to move through the portals.

To create realistic animations, animators often use detailed graphics of skeletons to create model rigs. It is essential to use biological skeletal references in rig development to ensure the model's natural movement in the gaming environment. A photograph of a woolly mammoth skeleton in profile, shot at a woolly mammoth exhibit at the Miraikan Museum in Tokyo, Japan, was used as a reference image to create the mammoth model's rig (Figure 25).

Figure 25 - Woolly mammoth skeleton reference image from Miraikan exhibit, Tokyo

To build a rig, such as the one used for the mammoth, the developer begins with a single digital bone from Blender's Armature tool. Other bones are added to this bone at the bone's *pivot points*, following the reference image's bones (Figure 26). The *pivot points* on the rig connect the skeleton's digital bones. These points also serve as joints for rotating the character into desired poses for animations. Once the mammoth rig was built, it was placed inside the woolly mammoth model in Blender, and the rig was fused to the model, so they were one cohesive unit. A woolly mammoth animation was created on a Blender animation timeline, with the mammoth model moving its head from side to side.

The rigged model and animation were imported into Unity and set on a loop so that the animation repeats itself throughout the Paleoindian Period. The users can also see the mammoth model moving through the virtual portal in the Present Period, catching their eyes and enticing them to walk into the next scene.

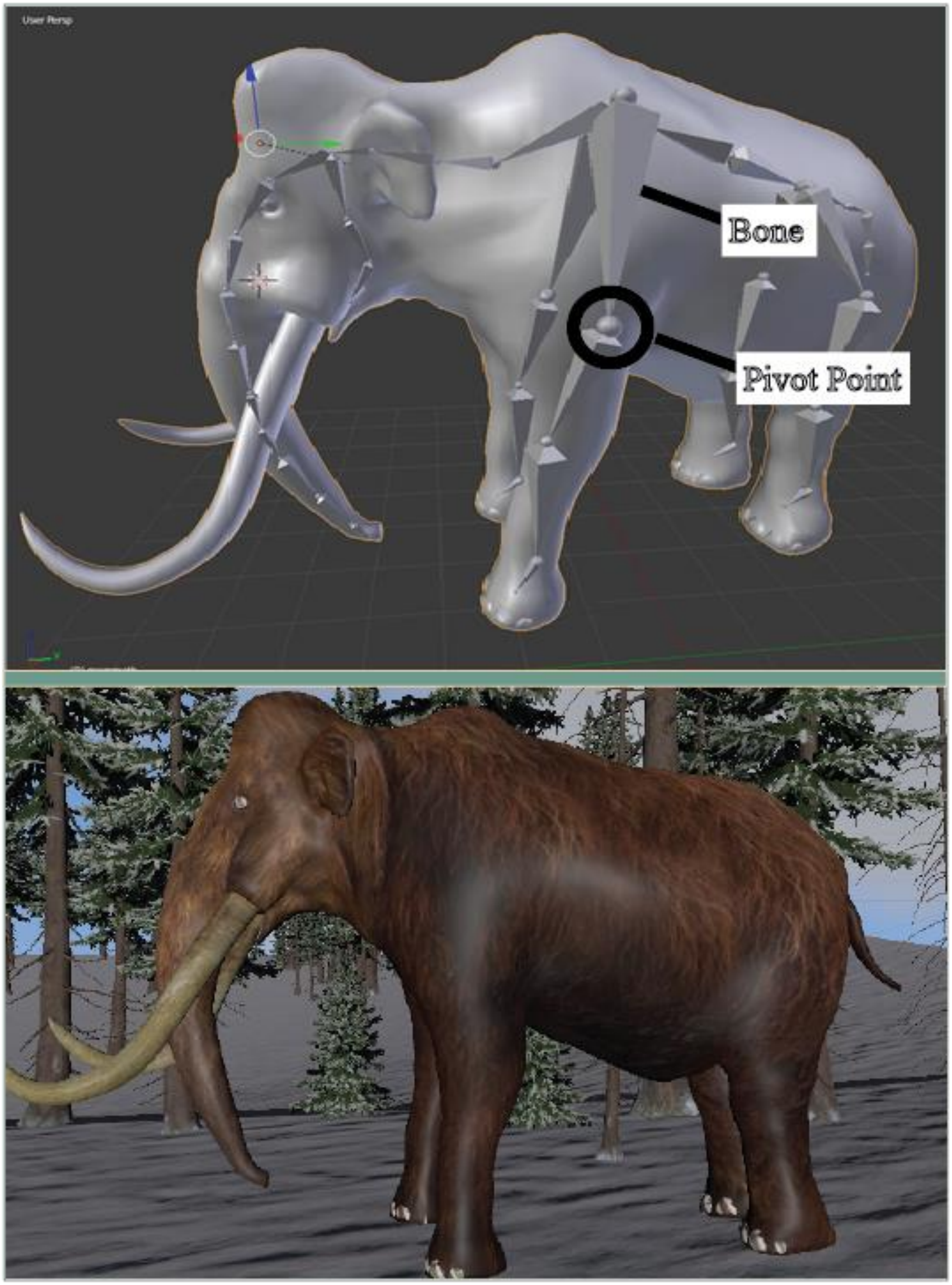


Figure 26 - Woolly mammoth Blender rig and model (Top). Woolly mammoth model in the exhibit (Bottom)

For the Archaic Period scene, a sturgeon fish represented the period's fauna. Fish were essential riverine resources for Archaic People and primary incentives for settling along Virginia's waterways. No animation was necessary for the sturgeon fish, as the models appeared in the scene as lifeless, shown smoking over a hearth.

The sturgeon was a notorious fish in Colonial Virginia, noted by sources such as John Smith for its ubiquity and size. At Historic Jamestown, archaeologists have recovered tens of thousands of bony plates and fin bones from sturgeon (Erickson 2013). Atlantic sturgeons grow to be over ten feet long, known to jerk fishermen from their boats. In Colonial Virginia, sturgeon were abundant and seemed to have made a big impression on colonists. These species were rare during this period in Europe (Roundtree 1989).

Today, sturgeon sightings are scarce, and several scaly sturgeons are endangered species (USFW n.d.). Due to these fish's significant role in early Virginia, the sturgeon was selected as the fish species to display smoking over the Archaic Period's hearth. The hearth and smoking sturgeon fish display in this scene was modeled after a Theodore de Bry engraving (after John White), *The Broiling of their Fish over the Flame* (Harvard College 2020a) (Figure 27).

This hearth scene with smoking fish also communicates the changing relationship between Virginia's Archaic People and the natural world. Many of Virginia's Archaic sites are transitory camps, used for short periods, and abandoned. Transient sites are glossed over in Riverbend's programs but are essential to understanding the evolution of regional Native American lifeways. Inashima (2012) noted that he believed Archaic features were likely present at the site but were not identified during investigations due to their ephemeral nature.

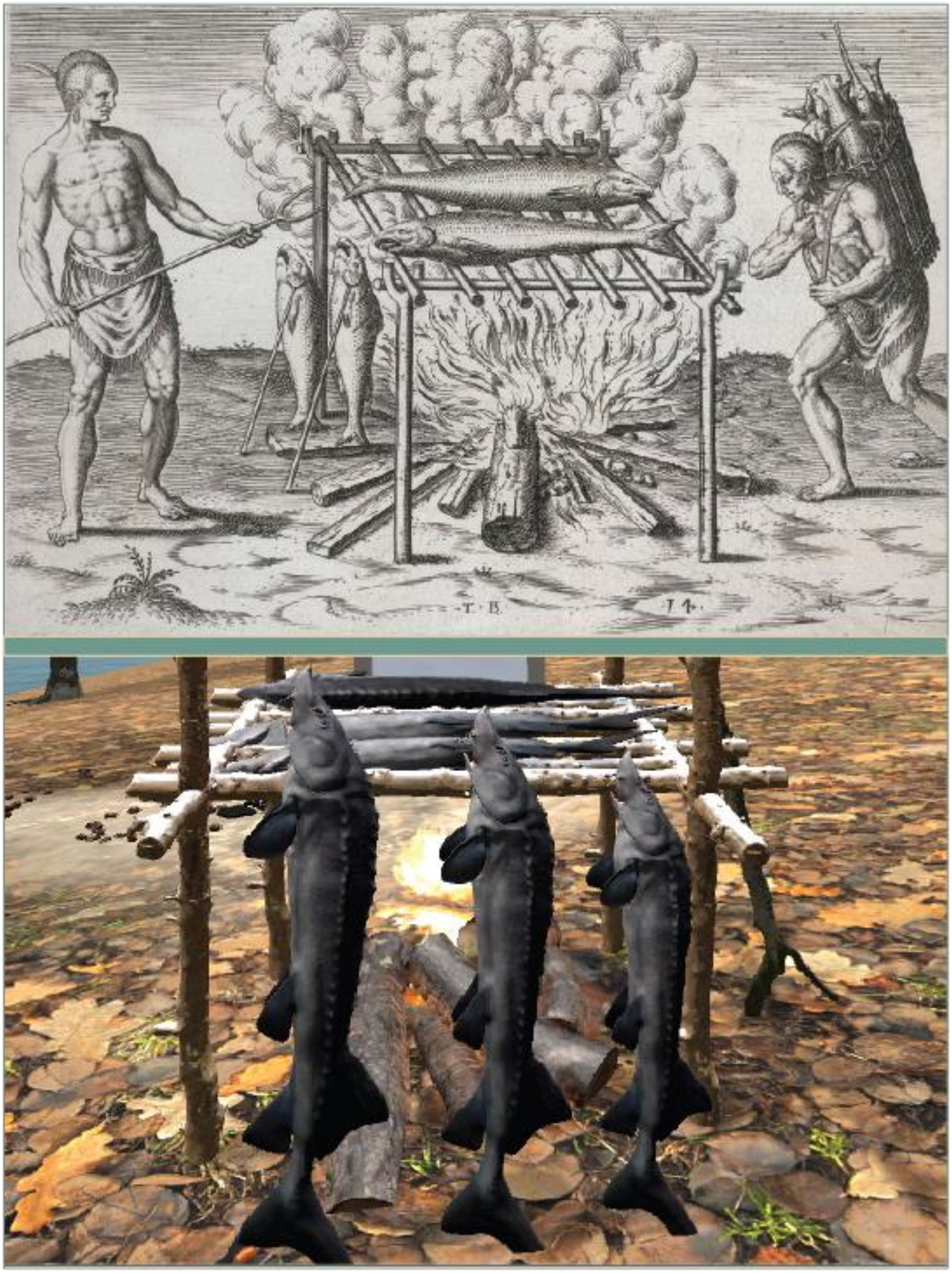


Figure 27 - Theodore de Bry (after John White), *The Broiling of their Fish over the Flame* (Harvard College 2020a)(Top) Smoking fish and hearth in exhibit (Bottom)

Deer represented fauna in the exhibit's Woodland Period. Though deer are frequently spotted today throughout Northern Virginia (even in urban areas), deer in Woodland Virginia were over-hunted. Of all the animals hunted in pre-Contact Virginia, deer held a special significance. Deer meat was an essential protein, and at feasts, venison was often the main dish. People living in Woodland Period Virginia also used deer for clothing, tools, and tribute (Roundtree 1989).

Men began learning how to hunt at a young age, developing an in-depth understanding of what terrain and plants attracted which animals. Capturing and killing a deer earned the hunter the respect of his fellow hunters and community. Hunting deer was chiefly conducted through stalking and surrounding approaches (Roundtree 1989).

The exhibit's Woodland Period scene is the only pre-Contact cultural period in containing more than one faunal model. Following a discussion of the exhibit narrative with Rose Powhatan, a Pamunkey and Taxuenant tribal elder, geese were also highlighted in the Woodland environment.

Above Great Falls, the Potomac River where Riverbend Park is situated was called *Cohonkarutan* by the region's Woodland inhabitants due to the abundance of geese on this stretch. Cohonkarutan in the Algonquian language translates to "River of Geese," or "Goose River." *Cohonk* is the Algonquian word for Canadian Geese. Waterbirds, such as geese, were a firm fixture on early Virginia waterways. They included abundant Canadian and snow geese and a wide variety of ducks, illustrated in a John White drawing, *The manner of their fishing* (Figure 28)(British Museum 2020). Adding the geese and the Algonquian name for the Potomac introduced the exhibit user to the original name for this stretch of the Potomac and the reasoning behind the name.

The region's early inhabitants also used deer and geese to measure time. Lunar months were marked by "the Moon of Stags, the Corn Moon, the first and second Moon of Cohonks" (Beverly 1947: 211; Roundtree 1989:49). Deer and geese are still spotted on hikes, hunted, and heard honking at Riverbend Park.

A black bear was the last faunal model added to the exhibit. The bear model appears in the exhibit's final scene. Bear are species present across all cultural periods displayed in the exhibit, and the visitor follows the footprints of the bear through time. In this way, the bear acts as an unseen guide, connecting the four cultural periods into a cohesive unit and lending its footprints as key wayfinding elements. There are no bear footprints in the final scene, signaling to the visitor that their trail journey has ended and the exhibit is complete.

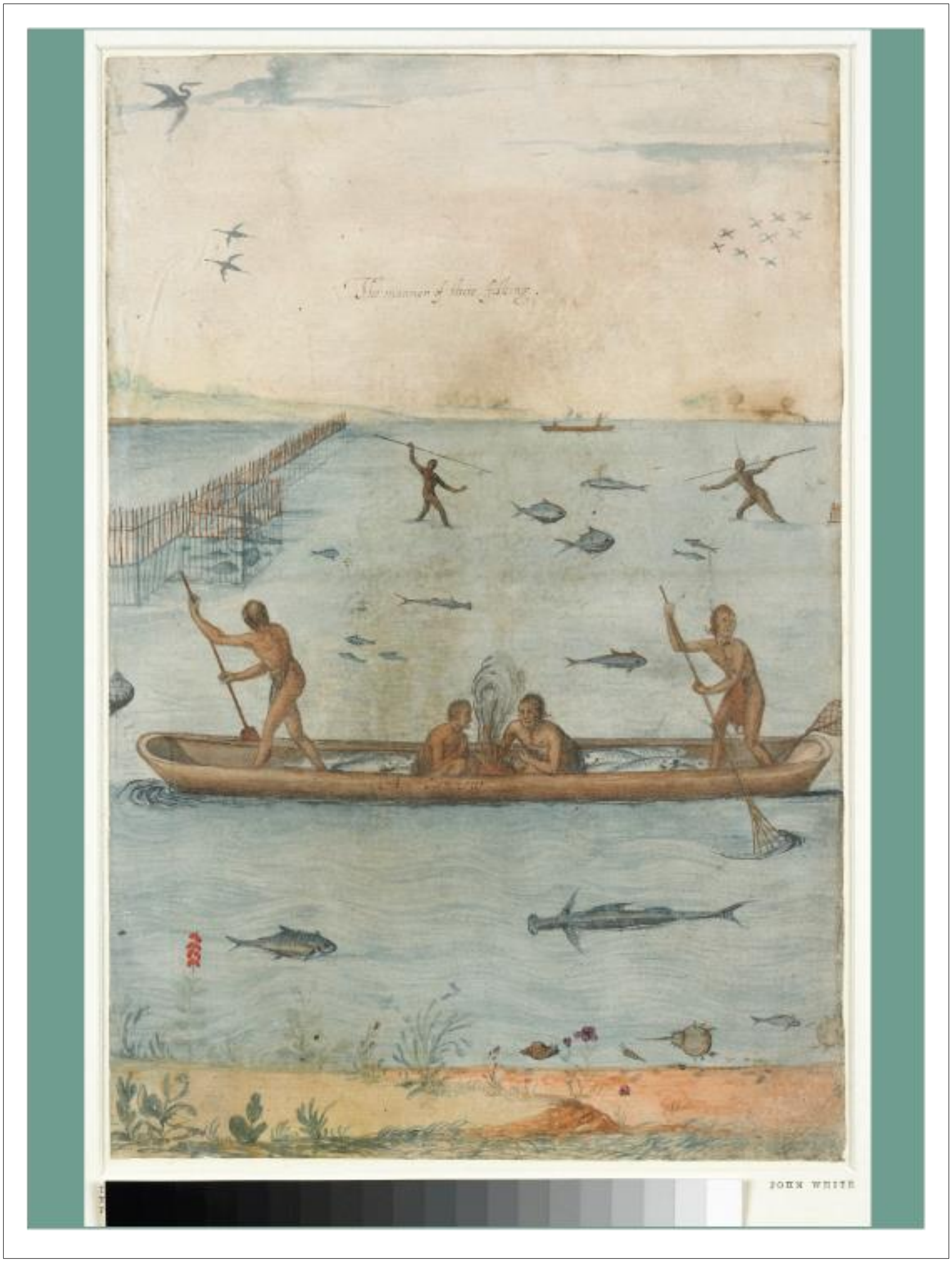


Figure 28 - John White's, *The manner of their fishing* (British Museum 2020)

Cultural Components

Artifacts and Tools

Three PPKs discovered at the Clark's Branch site were selected to represent artifacts for the exhibit's three main cultural periods. These artifacts were scanned by Bernard Klaus Means, Director of Virginia Commonwealth University's (VCU) Digital Curation Laboratory. Additionally, Means processed and 3D-printed some of these artifact scans. Means created these artifact models using a NextEngine Desktop 2020 3D laser scanner. The NextEngine scanner contains an array of lasers used to collect an object's surface features (Means 2013). Essentially, the scanner records how long it takes the laser's light to return to the scanner after the light bounces off the object being scanned. Four lasers are used to scan the object. Two of these lasers are wide-set, and two are positioned closer together. The NextEngine scanner has three focal distances: macro, wide, and extended. The macro option was used to scan the Clark's Branch PPKs, an ideal setting for creating high-resolution scans of smaller objects.

Means scanned each of the PPKs individually. The artifact representing the Paleoindian Period, a fluted PPK, was discovered at Clark's Branch in three fragments. Means scanned each of these fragments separately. To complete the scans, Means placed the artifacts on a small platform attached to the scanner. This platform rotates in set intervals during the scanning process, allowing the lasers to collect artifact data in "panels." Typically, between four-sixteen intervals (or divisions) are needed to collect the data necessary for developing a model. The more divisions completed, the higher resolution of the scan. However, as the number of divisions increases, the file size increases, and the data becomes redundant and difficult to manage. Typically, seven-eight divisions are sufficient to scan an object (Means 2019). The Clark's Branch artifacts completed seven rotations to collect the necessary data to develop the exhibit's artifact models.

The artifacts were firmly fixed to the scanner's platform using a rubber-covered grip attached to a small, steel mount. A larger pole held this mount securely to the platform. Ensuring the artifacts did not move during the scanning process was essential to obtaining an accurate scan. Securing the artifact also protected the object from falling. Typically, objects need to be scanned twice, rotated 90-degree on the second scan to account for the missing top and bottom artifact data. Means positioned the artifacts so that the need for two rounds of scanning was negated. For some objects, such as the Clark's Branch artifacts, the missing data is so slight it can be modified in post-processing following the object's existing geometries (Means 2013).

NextEngine scanners use ScanStudio Pro software to develop scans. In ScanStudio, the scanner operator evaluates the scanning process through a viewing window focused on the platform. This viewing window allows the scanner operator to inspect the rotations of the object. This check ensures that the object is completely scanned and remains firmly fixed to the platform (Means 2013). In ScanStudio Pro, the "neutral" target option was selected for the Clark's Branch artifact scans. This option considers an object's reflective features and was not an issue with the three artifacts' matte coloring.

A benefit of using laser scanners to create artifact models is that scanner operators can observe the scanning process in the moment and see the results to gauge if the scanner is collecting the necessary data to develop an accurate model. The downfall of using photogrammetric software (e.g., Agisoft Metashape) over laser scanning is that the scan's outcome is unknown until the data is processed (Means 2019).

The scanner operator can edit the mesh when the scan is complete in ScanStudio. Another option for processing and effectively "cleaning" the scan is exporting the model into a mesh-editing platform, such as MeshLab. MeshLab is an open-source, cross-platform system for processing 3D meshes (Cignoni & Montoni 2020). Post-processing scans is an important step to "heal" areas in the mesh with data gaps (e.g., the missing top and base sections of the three artifacts.)

ScanStudio offers several tools that can effectively clean and prepare models for 3D printing. Extra points collected by the scanner but unrelated to the artifact (e.g., points from portions of the platform) were removed during post-processing. The final product was a 3D artifact model without extraneous geometries. The finalized models, in OBJ format, with accompanying color MTL files, were imported into Unity. Other formats (e.g., STL and PLY) can also be exported from Scan Studio for Unity game development. Means printed one of the three artifact models, the Clark's Branch fluted PPK, using a MakerBot 3D printer (Figure 29).

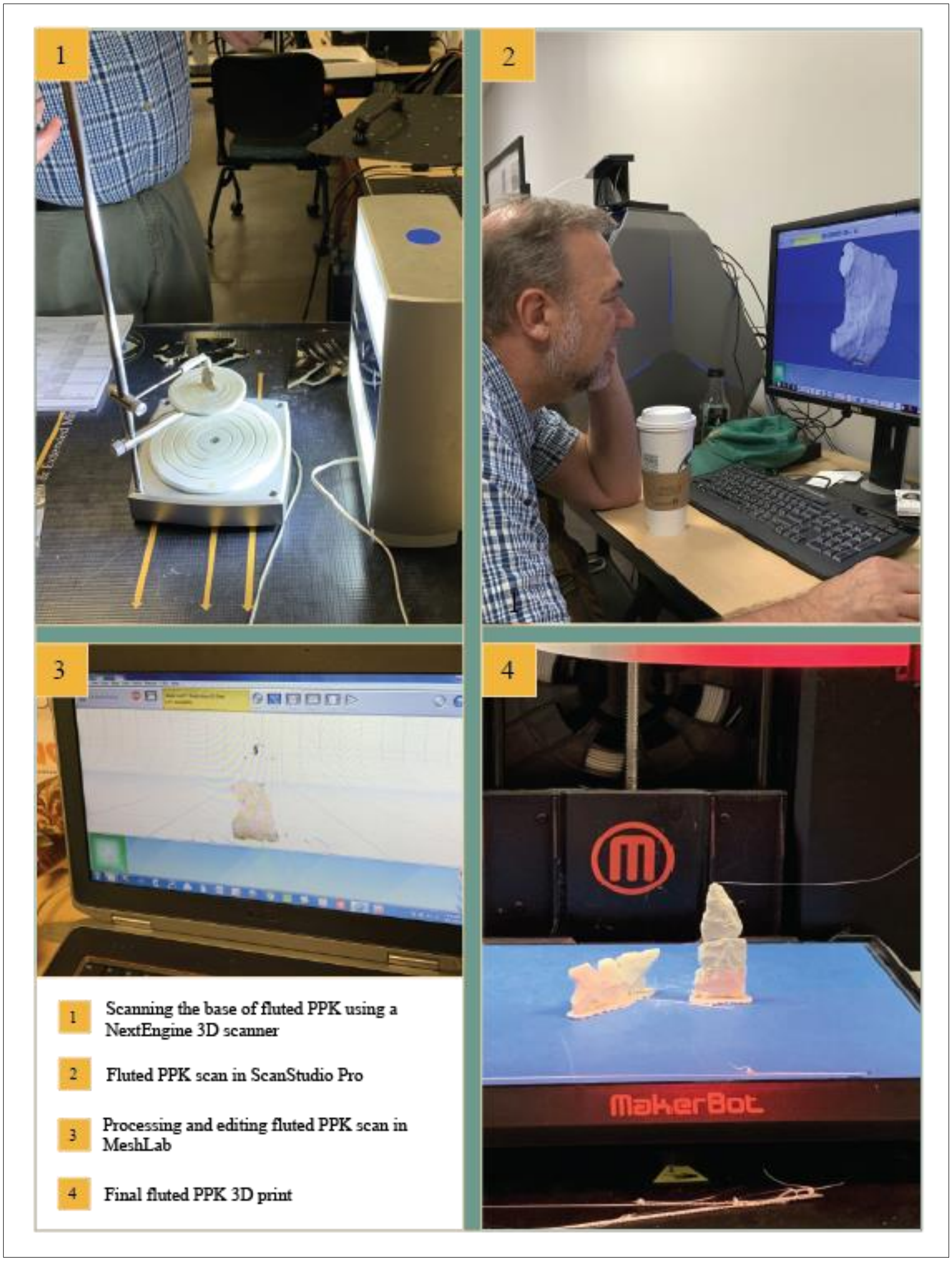


Figure 29 - Scanning and printing process using NextEngine scanner and MakerBot printer

The Clark's Branch artifacts scanned by Means to create the exhibit models included a fluted PPK (representing the Paleoindian Period), a Savannah River broadspear (representing the Archaic Period), and a triangle arrowhead (representing the Woodland Period) (Figure 30-31).

Figure 30 - Clark's Branch fluted PPK (left), Savannah River broadspear (center), and triangle arrowhead (right)

Even though the Clark's Branch fluted PPK is fragmented and heavily weathered, this artifact is a unique find for the region. Fluted points are characteristically

Paleoindian, and recovering these artifacts from excavations is rare. The fluted PPK model served as a focal point in the exhibit's Paleoindian Period.

Due to heavy weathering, the fluted component of the Paleoindian PPK artifact is challenging to detect. However, this feature stands out on the digital and printed plastic model. The printed plastic model provides users with the additional benefit of touching the groove without worrying about potentially marring the artifact. In the exhibit, to draw the user's attention to this artifact's fluted component, text and an arrow in bright blue were attached to the fluted PPK digital model (Figure 31). To provide additional context for the artifacts, each cultural period contained an artifact model attached to a tool. For example, in the Paleoindian Period, the fluted PPK model was attached to a spear model.

A Savannah River broadspear was chosen as the artifact to represent the Archaic Period in the exhibit. Broadspears are markers of the Late Archaic/Early Woodland transition. These PPKS are large and broad-bladed, typically crafted from coarse, durable materials (e.g., quartzite, rhyolite, and hornfels). Inashima identified several broadspears from Clark's Branch excavations, including Savannah Rivers on display in Riverbend's museum.

Figure 31 - Artifact models in the exhibit

Archaeologists debate how early Middle Atlantic inhabitants used broadspears. The Savannah River broadspear was likely not used for spearing fish; PPKs for spearing fish were narrow and barbed (Custer 1991: 53). These PPKs are often discovered at sites with large, rock features that possibly represent the remains of hearths related to food procurement and preparation (Kinsey 1972:346-347; Custer 1991:53). These PPKs are durable and would have made hardy multitools for processing fish and other resources from rivers like the Potomac. Materials to create these broadspears could be locally obtained from river cobbles, negating the need to travel long distances to quarries. Narrative and model placement in the exhibit's Archaic Period highlighted connections between the Savannah River PPK artifact models, the Potomac River, smoking fish, and hearths. The user first encountered these features when they walked through the portal into the Archaic Period scene (Figure 31).

A jasper triangular arrowhead model represented the Woodland Period in the exhibit. Riverbend's *Indians of the Potomac* program emphasizes the bow and arrow. An entire segment of this tour involves children shooting rubber-tipped arrows with a bow in an open pavilion. This hands-on activity is an understandably popular interactive part of the program. The other tour components mainly involve listening to a tour guide.

The IVR-based exhibit also includes bows and arrows. One of the triangular jasper arrowhead models is hafted to an arrow model in the Woodland scene. The arrow model is fletched with turkey feather models. A bark quiver model containing arrows is displayed close to this arrow model. A second triangle arrowhead model is presented on a stump (Figure 31). Shooting the bow and arrow is not possible in the IVR-based exhibit.

This interactive feature is not included to ensure the users are not distracted from other content or attempt to shoot characters in the scene. Future iterations of the IVR-based exhibit could include a more interactive bow-and-arrow component.

At events where the public has increased opportunities to interact with physical artifacts in spaces other than museums, a common misconception is that all PPKs presented are “arrowheads.” In actuality, most PPKs on display are other tool types (e.g., spear points, knives, drills, and atlatl darts), not arrowheads. Bow and arrow technology did not arrive in the Clark’s Branch region until the Middle Woodland Period (500-900 AD). A central component of Riverbend’s *Indians of the Potomac* program is bows and arrows, with other tool types mostly neglected. Bow and arrow technology replaced many other hunting implements when introduced in the Woodland Period, but arrowheads only represent a fraction of pre-Contact lithic tools.

The Clark’s Branch exhibit presented the bow and arrows close to a stump, in the same manner the spear and knife are shown in earlier scenes. The narrative introduces this technology to the user in the exhibit’s Woodland Period and emphasizes the association between bow-and-arrow technology and hunting deer. An animated deer, placed close to the bow-and-arrow artifact models, cements the connection between deer and bow and arrow technology for the exhibit user.

IVR users can get overwhelmed by sensory stimulation (Bauer and Andringa 2020). The six artifact and longbow models were the only artifacts and interactive objects included in the exhibit to avoid overstimulation and emphasize the cultural periods’ important lithic tool technology.

The exhibit user operates the right-hand Oculus Touch controller to interact with these artifacts by “picking up” the artifacts with their digital right hand inside of the exhibit. The Oculus Rift sensors track this controller and the user’s right-hand movements. In the exhibit, the tracked controller is displayed as a dull-grey right hand. Users can pick up artifacts and move them around the exhibit by placing this digital grey hand on the artifact and selecting the controller’s large trigger button. Instructions on how to interact with the artifacts are provided before entering the exhibit and in the Present Period narrative.

Archaeological Features

Archaeological features are significant components of understanding sites. In archaeological contexts, features are non-portable artifacts (e.g., soil stains, hearths, and foundations) (Renfrew and Bahn 2016). Feature identification assists archaeologists in site interpretation and analysis. However, features are not always discovered at sites. At Clark’s Branch, Inashima documented several features, interpreted as the remains of Woodland hearths. (Inashima 2012). A digital representation of one of these Early Woodland hearths, Feature 22, was chosen for display in the immersive exhibit’s Woodland Period scene.

Feature 22 was digitally reconstructed using 3D models of rocks and wood. A conical Potomac Creek pot was placed inside this hearth model. During excavations, Inashima recorded pottery fragments associated with Feature 22, and Riverbend’s museum displays several of these artifacts. Prehistoric pottery fragments are notoriously difficult to understand in exhibits and often challenging to identify in the field due to their typically amorphous shape, weathered-condition, and colors that match the surrounding soils.

Also, archaeologists typically recover pottery fragments in small, friable, and fragile pieces. An archaeologist’s chances of removing a whole pot during excavations are minuscule but discovering an artifact such as a whole lithic PPK at a site is common. Fairfax County has numerous, durable lithic PPKS to exhibit that are easier for audiences to understand because they are in one piece. Displaying small pottery fragments is more of a challenge. The Riverbend museum tackles this issue by displaying Potomac Creek pottery fragments close to a whole Potomac Creek pot replication. In the IBR-based exhibit, a 3D model of this Potomac Creek pot replica is propped up with rocks inside the Feature 22 hearth model. A flickering flame particle system is attached to this hearth model to bring this feature, and the scene, to life.

Agisoft’s Metashape photogrammetric processing software was used to create the 3D Potomac Creek pot model from replica images. To obtain the necessary imagery, the pot was placed on a turntable inside a white shadow box (Figure 32). Then, an iPhone XR camera captured 20 photographs of this pot from different angles. These images were imported into Metashape.

Metashape offers developers a straightforward pipeline to develop photorealistic 3D models. There are four main steps in this model-building process. In the first step, the software identifies commonalities in the uploaded images and detects the camera’s position. Second, Metashape generates a dense point cloud based on the detected camera position and imagery. Based on this point cloud, the software generates a 3D polygonal mesh that captures the object's surface features. The final step involves adding texture to the 3D mesh. This texture is developed from the images so that the final result is a photorealistic 3D model. Metashape contains tools to edit this model to remove extraneous geometries before exporting the object in the chosen format (e.g., OBJ and FBX).

Figure 32 - Development process for 3D pot model. Figure 1- Theodor de Bry (after John White), *The Seething of Their Meat in Earthen Pots* (Harvard College 2020b)

Unity's AR + GPS Location asset helped position the 3D pot model and hearth on the exhibit's Woodland terrain model in the location where Inashima (2012) recorded pottery fragments and the hearth feature (Feature 22). The AR + GPS asset assists developers in placing objects onto real-world terrain models. This asset is useful for developing AR experiences because digitized data can be layered atop real points in space. When the user moves to a specific point in space in an AR application, the object will appear overlaid on real-world space. In this asset, developers achieve this AR result by inputting an object's real-world coordinates (Fortes n.d.). The AR functionality was not necessary for developing this exhibit. However, the assets positioning tool was useful for placing Feature 22 on the Woodland terrain using coordinate data.

Maps from Inashima's Clark Branch report (2012) were digitized and georeferenced into a Riverbend project geodatabase to identify the hearth's coordinates. This geodatabase was developed with ESRI's ArcGIS Pro application, since the project's original digitized information was misplaced following excavations and unavailable for this research.

Data Replications

Artifact replicas are useful for communicating information on material culture to the public but are expensive and can take up valuable museum space. However, Riverbend has several replicas for educating the public on Native American lifeways. These objects are situated in and outside the museum in close proximity to the Potomac Heritage Trail. Two of the replications displayed outside, a *yihakan* and a dugout canoe, were used as references to create 3D models in Blender for the IVR-based exhibit.

To craft these custom models, reference images of these objects were imported into empty Blender projects. A basic cube was added to these empty scenes, comprised of eight points, twelve edges, and six faces. Basic shapes of the yihakan and dugout canoe were created by manipulating the cube's geometries in Blender, following a *box-modeling* technique. Box-modeling is a 3D-modeling method that involves altering the edges, faces, and points of basic shapes like spheres, using scaling, extrusion, and rotation tools available in 3D-modeling software.

Textures were created and attached to the yihakan and dugout canoe models in Blender, using personal images of these objects. Without textures, models designed in Blender appear as grey shapes. Textures give models a realistic look, adding essential colors, patterns, and lighting that assists viewers in object identification.

An image of bark served as the yihakan model's main texture. This texture covered the entire model except for the open door of the structure. A black texture covered this opening. Inashima (2012) did not encounter evidence of yihakans at Clark's Branch. However, Riverbend's tour discusses yihakans as important shelters and homes, and the park displays yihakan replicas, so yihakan models were added to the Woodland scene. In the exhibit, smoke was added to these yihakan models to indicate the importance of the fires inside these structures, fires which the women kept burning at all times. The inclusion of yihakan models in the exhibit also pointed to the shift to settled societies, a primary feature of the Woodland Period.

The dugout canoe replication, one of which is located next to the yihakan replications at the park, was used as a reference to create a dugout canoe model for the

Archaic scene. Dugout canoes were effective tools for maneuvering Virginia's waterways and were essential means of transportation for the region's early inhabitants. Creating dugout canoes was a labor-intensive process that involved carving out the center of a large log, a process made more manageable by burning the log's center in segments. Canoe-builders then scraped out these burned centers using stone axes and shells (Roundtree 1989). Theodore de Bry (after John White) illustrates this process in, *The manner of making their boates* (Harvard College 2020c)(Figure 33). Typically, before the annual Native American festival in September, Riverbend employees create dugout canoes by following this burning-scrapping method in preparation for the event (Figure 33).

The dugout canoe 3D model was created by manipulating a cube in Blender following a reference image, then assigning a wood texture to the model. The model was positioned by the Potomac River in the Archaic Period of the IVR-based exhibit. A smoke particle system was placed in the canoe's center, so the model gave viewers the impression of a fire burning inside. Two animated characters worked on building the canoe in the IVE exhibit, their actions simulating working to scrape out the trunk's insides (Figure 33).

Figure 33 - Dugout canoe images. Theodor de Bry's (after John White) *The manner of makinge their boates* (Center) (Harvard 2020c)

Characters

The animated characters were the last 3D models added to the exhibit. Fuse, Mixamo, Photoshop, and Illustrator Draw (all Adobe Creative Cloud applications) were used to create custom characters to populate the Archaic and Woodland Period scenes. As users progress through the exhibit, the number of characters increased from zero in the Paleoindian Period scene to ten in the Woodland Period scene. Increasing the number of characters was purposeful to subtly indicate an increase in regional populations from the Paleoindian to Woodland Periods.

The Adobe Fuse application was used to create the main components of these characters. Fuse is an Adobe Creative Cloud suite application developers can use to build humanoid 3D models. In Fuse, the developer is presented with a series of options for creating custom 3D characters, including altering the character’s skin, eye, and hair color. Developers can also change the size and shape of their characters. Fuse also offers clothing models for characters, but these options are limited. For the exhibit, basic Fuse skirts and tops were selected to cover the characters. The clothes’ geometries were customized later in Blender. Adobe’s Photoshop and Illustrator Draw applications were also used to add finishing touches to these models.

At first, editing the imagery for these characters was conducted using only Photoshop, an application used to edit imagery, including editing capabilities for 3D graphics. In Photoshop’s 3D window, features such as shell beads, clothing details, and tattoos were painted directly onto the character models. Theodore de Bry’s sketches served as jewelry and attire references, as well as descriptions from early Europeans, compiled by Roundtree (1989).

Editing directly onto the models in Photoshop was a challenging task. Rotating and panning in and out inside Photoshop while trying to draw features on the model was cumbersome, slow, and difficult to accomplish on the first try. Attempts to simultaneously pan, rotate, and draw often produced mismatched and overlapping lines on the characters.

Illustrator Draw was another method used to draw features directly on these models. This process involved editing the models in 2D versus 3D. Drawing on models in Photoshop involved using the pen tool. In Illustrator Draw, an Apple Pencil, a digital stylus, was used to draw directly on the character images stored in an Apple iPad.

To create a 2D image from a 3D model, the character model's mesh first needed to be *unwrapped*. *Unwrapping* is a process in which the 3D mesh of a model is converted into a series of 2D images. This process essentially flattens out the 3D meshes of the character's clothing, body, and hair. The characters created in Fuse had separate 3D meshes associated with them for their bodies and clothing. These meshes were unwrapped and imported into Illustrator Draw. Once imported into Illustrator Draw, an Apple Pencil was used to draw on the unwrapped 2D imagery. Drawing with this stylus offered a more holistic approach to adding detail to characters than Photoshop's 3D editing option. Of course, the characters flattened into a 2D image little resembled their 3D form, and the characters had to be converted back into 3D to evaluate the final result (Figure 34).

The final step to editing and importing the characters was modifying the geometries of their clothing in Blender. Files from Photoshop and Illustrator Draw were imported into Blender. Then, the geometries of the character's simple skirts and dresses were altered (e.g., scaled, extruded, and deleted) to customize character looks following clothing depictions in Theodor de Bry illustrations. This step was the final one in creating the exhibit's characters. After the finalized models were complete, the characters were imported into Adobe Mixamo in .FBX format.

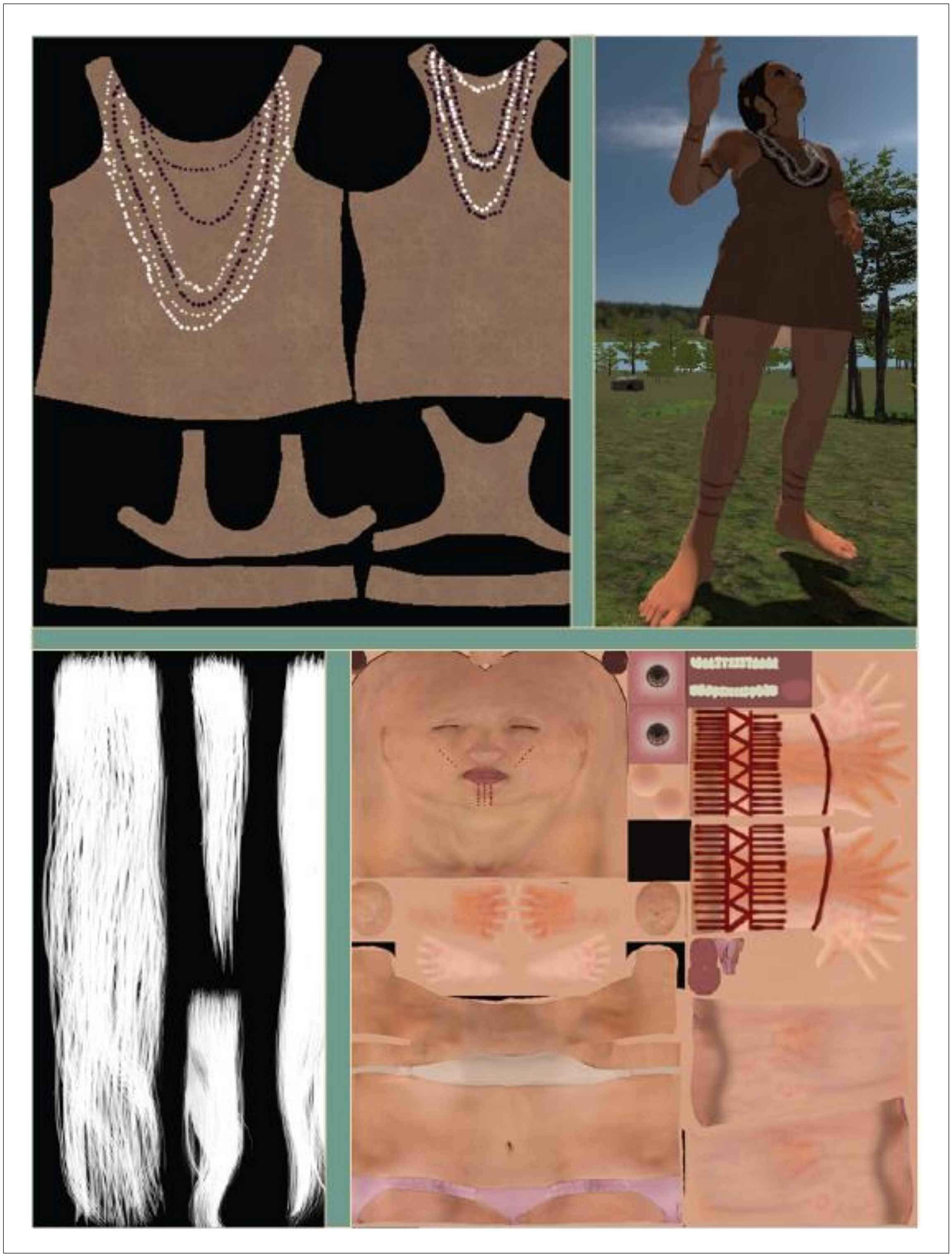


Figure 34 - Unwrapped 2D images from the Fuse models and the finalized 3D character in the exhibit

Mixamo is an application that provides developers with instant 3D models, rigs, and animations. Just like the woolly mammoth model, the animated people in the exhibit needed to be rigged. Rigs could have been made in Blender, but Mixamo offers a streamlined process for rigging bipedal, humanoid characters. In Mixamo, exhibit character models were assigned a standard humanoid skeletal rig. Once rigged, the characters could be easily animated. Instead of animating the characters using the Blender timeline, custom Mixamo animations were assigned to specific characters. Mixamo contains hundreds of animations to get humanoid models moving from basic jumping actions to the full Chicken Dance. Mixamo animations that were attached to exhibit characters included canoeing, walking, talking, and working.

Animator Controllers in Unity controlled these character animations. Only one animation was attached to each animator controller to keep scenes simple. This meant the characters only completed one animation. For example, in the Archaic Period, the dugout canoe builders were assigned a scraping animation controller set on a loop cycle. The exhibit user only observed one action from the dugout canoe builders, a simulation of these men scraping out the dugout canoe. The animated characters were the final 3D models added to the exhibit.

Constructing the Exhibit Narrative

When the exhibit's main 3D models were added to the scene, audio clips of the exhibit's narrative were imported into the project. A pre-existing Riverbend program on early Native American lifeways along the Potomac was used to develop this narrative. Riverbend's program generally follows a National Park Service (NPS) lesson plan, *Native American Indians of the Potomac*, developed for school groups touring Great Falls National Park (NPS 2015). This NPS program is split into three sections: *Living Off the Land*, *Artifact Analysis*, and *Making Camp*. *Living Off the Land* involves a short hike to an area around the Stout archaeological site and discussion on the importance of regional environmental resources (e.g., Potomac River, plants, and soils) to the region's first people.

The second segment of this program, *Artifact Analysis*, involves passing artifact replicas around to tour participants. This segment also consists of a conversation on what the artifacts reveal about human-environment relationships. The importance of artifacts in understanding archaeological sites is a central component of this dialogue (NPS 2015).

In the final stretch of this program, *Making Camp*, the group "makes camp" by settling around a picnic table area to rehash their tour experience. Tour participants are encouraged to act out scenarios the first people may have faced in the region. In this tour segment, the group also discusses preconceived stereotypes of American Indians, often acquired through the mainstream media (NPS 2015).

Riverbend's spin on this NPS program, titled *Indians of the Potomac*, focuses on educating primary school students. To fully understand Riverbend's Native American lifeways program, this researcher joined a Riverbend tour group to experience the program first-hand. Riverbend's tour is divided into three segments, similar to the NPS tour. Instead of making camp and handling artifact replicas, students complete a short trail hike to the park's yihakan and dugout canoes, shoot arrows with a bow, and sit through a brief presentation highlighting early Virginian lifeways inside Visitor's Center.

During the presentation, the program guide uses museum objects to educate the audience, including deer skins, nut grinding tools, and replicas of pieces on display in the museum. The focus of this tour is presenting lifeways associated with the Woodland Period. Tour participants are encouraged to explore the park's museum, investigating artifacts in the timeline exhibit and the environmental displays.

Riverbend's, *Indians of the Potomac,* and the NPS's, *Native Americans of the Potomac,* emphasize human-environment relationships. Though both programs highlight this important connection, there is minimal discussion of regional spatiotemporal changes. The Woodland Period is emphasized above other cultural periods in these tours, though indigenous people have inhabited the region for thousands of years.

Another factor emphasized in these tours is that Native Americans are still here. Riverbend Park is excellent at stressing this crucial point. The park's museum features the work of Rose Powhatan, a Tauxenent and Pamunkey elder, and artist, and highlights the importance of Virginia's tribes in their exhibit space. Additionally, the park hosts an annual Native American festival, inviting Virginia tribes to share their culture with the public.

The exhibit narrative pulled material from these two programs, data from Riverbend's museum, and information from the Clark's Branch report, VDHR, and other sources on Virginia's early lifeways. The narrative consisted of five short audio clips that played when the user virtually walked through the exhibit's portals. The narrative was kept as simple as possible, briefly describing the main features displayed in each cultural period. Audio clips were between 1.21 and 2.23 minutes long, and each clip contained under 230 words (Appendix B).

The Present Period's narrative welcomes the visitor to Riverbend's virtual Clark's Branch Site, then instructs the user on the correct methods for moving and interacting with exhibit objects. Each scene's narrative points to the period's important climate, fauna, flora, and cultural components. The final scene narration emphasizes the importance of remembering that, though many of the physical remnants of Native American sites have vanished, these sites and histories are essential components of Virginia's past, present, and future.

Fairfax County's archaeologists reviewed the narrative draft. The edits from this review were to ensure that there were no errors or misrepresentations. Members of this group suggested potential additions for future iterations of this exhibit during this review. The narrative was also reviewed by Rose Powhatan, who met with the researcher at Riverbend to discuss the application and content. Powhatan commented on the narrative draft and offered suggestions for further content to include in the exhibit. Powhatan brought an extensive knowledge base and essential perspective to this project. For example, she mentioned that the Potomac River in the region above Great Falls was known as *Cohonkarutan* in Algonquian. This name of the river was included in the narrative, with corresponding 3D models of *cohonks* (geese).

Also, a lifeways scene included in the Woodland Period was removed from the exhibit after this discussion with Rose and talks with other individuals at the Native American festival. The original narrative mentioned accounts from 17th-century sources that stated indigenous inhabitants danced day and night. Powhatan commented that it was hard to imagine and that it would be exhausting dancing day and night. A discussion of dancing was removed from the original narrative, and the dance scene was also removed. Dances are significant elements of Native American culture, passed down to descendants and laden with meaning. At Riverbend's Native American Festival, several different tribal groups share certain dances with the public. Following discussions with tribal members at Riverbend's Native American Festival about the meaning of several of the dances shared and experiencing these powerful moments, including a dance scene seemed to misrepresent these important traditions.

Powhatan also highlighted the importance of women and the matrilineal structure of Virginia's first communities. To highlight women in the exhibit and to indicate some of the gender roles associated with different tasks, two women characters were placed in the Woodland Period with the corn harvest. Among other crops, harvesting corn was one of the many responsibilities of Virginia's first women.

Traversing Time through Virtual Portals

Another goal of this research was to explore a new way to communicate temporal data in museum exhibits. In the IVR-based exhibit, visitors move through time by "walking" through virtual portals into different periods. Exhibit portals are shaped like rectangular doors, and moving through these doors transports the user to the next consecutive cultural period. Portals as transportation channels to different spaces and times are trendy in popular culture, particularly in science-fiction media (e.g., transportation portals in Marvel's blockbuster, *Dr. Strange* (Derrickson 2016)).

Portal popularity is evident in the gaming sector, and several options for adding and customizing portals are available in Unity. Several rounds of trial and error were necessary to identify the ideal portals for moving through time at virtual Clark's Branch.

Initially, the cultural periods were separated into four individual scenes. However, virtually moving between these scenes temporarily removed the user from the experience, with long periods where the user was stuck staring at a black screen. To remedy this issue, all the exhibit data was incorporated into one scene. Then, the four terrains were spread across the game's x-axis and linked together through corresponding portals. Users were transported to different terrains by moving through these portals. This method caused noticeable lag, distracting from the exhibit, and causing disorientation in the headset. Though this was not tested on users aside from the developer, the disconnection and lag could negatively impact the user's sense of presence and disrupt the learning process. Thus, this portal method was ruled out in initial development.

A successful portal traveling system was finally achieved by layering the terrains over one another. This development method relied on scripts from Unity's Pocket Portal VR asset. Pocket Portal VR is a free asset in Unity, with associated code and documentation provided in GitHub (Zimmer 2019). The Pocket Portal asset included multidimensional portals in prefab door shapes, providing developers with a solution for moving between different environments within one Unity scene. Instead of the user teleporting across different terrains, the terrain visibility is switched on and off. The exhibit user moves through the exhibit's portals, triggering the visibility of specific

GameObjects connected to specific terrains. The Pocket Portals VR asset refers to these GameObjects as *dimensions*.

All the data related to the four cultural periods was filed in one of four dimensions: Paleoindian, Archaic, Woodland, and Present. Each dimension contained a unique VR portal, used to transport the player to the next consecutive dimension (Figure 35). The four Clark's Branch terrains were placed in each of these dimensions, then stacked on top of each other. To ensure the four terrains were close to the same horizontal plane, the X, Y, and Z axes for these objects were centered out at zero in the scene's grid. When the exhibit begins, all the game data for each dimension loads at once, which means a longer loading time but overall less lag during runtime.

Figure 35 - The exhibit's four VR portals

The camera attached to the OVRPlayerController is an essential component in implementing these portals. When the OVRPlayerController goes through the portals, the player's camera triggers a plane embedded in the portal door, which triggers the Portal Dimension. When triggered, the Portal Dimension alerts the camera to render only the data in a specific dimension, using camera culling masks. For example, in the Present Period, the user can only see the Present Period data around them. Suppose the user looks through the Paleoindian portal door. In that case, they can catch a glimpse of the data in the Paleoindian Period, but only through the portal door. To enter and interact with data in another dimension, the user must trigger the Portal Dimension component by walking through the portal. This component, and other scripts in this asset package, were developed in the C# programming language.

The exhibit begins in the Present Period, with the visitor facing the Paleoindian Period portal. At this point in the exhibit, almost all of the application's data is already loaded. As the user moves through the portals, most of the data they experienced in the previous dimension is "destroyed." The destroyed information means that this data is removed from the running application.

There were two main reasons for destroying data users had already experienced. First, removing this data and associated portals ensured that the user moved into the next consecutive period. Second, there is a known rendering issue in Pocket Portals that causes substantial lag when the application contains more than one portal. To encourage the exhibit audience to move forward to the next dimension and alleviate lag issues, previously seen dimensions and data are destroyed using a DestroyObject action in *Playmaker*.

Playmaker is a Unity asset that uses functional state machines (FSM) to control events within games (e.g., switching scenes, animations, and physics) (Hutong Games 2019). Playmaker was used to add FSM's to objects to trigger events. Invisible barriers in the exhibit to keep users on, or close to, the trail are the only objects that are not loaded at the exhibit's start. These barriers are added when users walked through the portals using a Playmaker CreateObject action. Activating these invisible barriers does not have a noticeable impact on application lag.

The VR portals were used to create an exhibit that allows audiences to be in one time and look into another. For a brief moment moving through the portals, the visitor is immersed in two periods at once.

Navigating in Immersive Virtual Environments

During initial testing of the exhibit with the Oculus Rift system, testers indicated that navigating the exhibit was challenging. Testers felt lost in the periods and needed direction to maneuver through the immersive space successfully. To achieve successful navigation in the exhibit, users needed to understand and interact with the virtual space in a manner similar to how they would navigate real-world space.

In virtual and real-world spaces, navigation is a cognitive and physical process impacted by *locomotion* and *wayfinding*. Locomotion refers to how one physically moves from place to place. In real-world spaces, unaided by technology, humans are fixed to the earth, limited to terrestrial and aquatic environments. Technology can enhance human movement, allowing access to aerial arenas and other once unattainable spaces.

Immersive virtual technologies offer users several locomotion options. The four main IVR locomotion methods include teleportation, physically moving in place, physically moving through space, and virtual movement using a controller (Boletsis 2017). The IVR-based exhibit incorporated standard locomotion options used in Oculus systems. These systems typically offer two types of virtual locomotion: teleportation and joystick virtual movement. Teleportation involves selecting a specific spot in the game space using a controller, and when triggered by the controller, the user's immediate transportation to that spot. Teleportation offers rapid movement through the game space but can interfere with the user's sense of presence (Boletsis and Cedergren 2019). The Oculus's joystick option moves users through space when they push forward and backward on a small, plastic input device (i.e., the joystick) on the Oculus Touch Controllers. The Oculus Rift HMD tracks the user's head movements, so the user looks in the direction they want to travel to move forward.

Other types of IVR systems use physical movement through space and walking in place for user locomotion. For example, the HTC Vive uses sensors to track user movement through real-world space, so users' actual movements mirror their avatar's movements in the IVE. This is a holistic method of interacting with space but requires large, empty spaces for the user to walk around and some sensor setup. IVR locomotion experiences where the user physically walks through space often combine this locomotion technique with teleportation so users can travel over large areas of game space. This research avoided using teleportation locomotion to maintain user sense of presence and prevent potential motion sickness.

There is no space for an HTC Vive set up at Riverbend. The Oculus Rift system could fit on a small table, and the process for setting up the exhibit took under five minutes. However, exhibit users were not physically moving through the exhibit space. To effectively navigate the exhibit, it was necessary to teach users how to locomote in virtual space using the Oculus Touch Controller joystick.

First, exhibit users are seated on a swivel chair. Inside the Oculus Rift HMD, users can see their digital hand mirroring their right hand's actions. The digital hand is a solid grey color. The user does not have the option to change hand color. However, this could be a means of personalization in future applications that could further connect the user to their avatar.

To move through the exhibit, users manually operate the joystick using the right-hand Touch Controller. To move in the exhibit, users physically turn their heads (and bodies if it is more comfortable), looking in the desired direction of travel. Moving forward requires pushing the joystick away from their physical body, and moving backward involves pulling the joystick towards their person.

Location-tracking sensors, situated on small poles placed around the Rift HMD, follow the user's movements. These sensors track infrared LEDs (light-emitting diodes) located in the front and back of the Rift HMD. Touch Controllers track the user's hand movements using the same method; this tracking is referred to as *Constellation Tracking* (Melim 2019). When the user's virtual hand is placed on artifacts in the exhibit, the user can pick up artifacts by pressing the large input button on the Touch controller. The user is instructed on how to move in the virtual space and use their virtual hand from the introductory audio in the Present Period scene. Additionally, this researcher provides guidance on using this locomotion system before users began the exhibit.

When the user first begins the exhibit, they look into a black space that fades into the Present Period's rich green scenery. The user is fixed to the Present Period terrain by gravity modifiers and can only move across the X-axis by virtually walking. Jump function features were disabled on the Touch Controller, and the OVRPlayerController was set on a low acceleration speed to avoid simulator sickness. Simulator sickness (a.k.a. motion sickness) is a common complaint in IVR experiences, caused by a disconnect between the user's actions in the virtual system and the user's actions in the real world. This disconnect is caused when the user's eyes communicate to their brain that they are moving when their physical bodies are still.

The OVRPlayerController was tested at different acceleration speeds to determine an appropriate "walking" speed for the exhibit. This decision took into consideration speeds for successful wayfinding, time to examine features on the landscape, and simulator sickness. In a Unity desktop VE, standard FPS characters can move at a higher walking speed; this standard speed is set to 5 meters per second. The OVRPlayerController acceleration in the IVR-based exhibit is set considerably slower, with player acceleration set at 1 meter per second.

Teaching users how to locomote in virtual space was the first step in the exhibit's navigation system. Building a reliable wayfinding system for users was the second step in constructing a successfully navigable exhibit. Wayfinding refers to how people move through space following cognitive choices.

The IVR-based exhibit mimicked real-world space, with users controlling a virtual avatar moving horizontally across an X-axis. Because the exhibit mirrors real-world space and follows natural human locomotion, the navigation system was built following real-world wayfinding principles. The closer the IVE imitates the real environment, the easier it is for the user to navigate (Witmer and Singer 1998). Humans are used to navigating horizontally through space, firmly fixed to the ground below and the sky above. If users do not need to learn an entirely new means of maneuvering through an environment, they can focus their attention on learning new material presented in the IVE.

A trail (a feature from real-world Riverbend) was added to the IVR-based exhibit to improve user-wayfinding. Trails are international symbols of moving from one point to another. The exhibit's trail was modeled after segments of the Potomac Heritage Trail (PHT), a trail system that follows the Potomac River through the park and winds through the Clark's Branch Site. A wayfinding system was developed to keep exhibit users following this trail in the immersive space. This system followed seven of Foltz's (1998) eight wayfinding design principles to create a straightforward, user-friendly navigable space. These seven principles are: "make well-structured paths, limit user navigation choices, indicate what is ahead with sightlines, incorporate memorable landmarks for orientation, offer signs at decision points, create regions that vary visually, and give each location a unique identity (Foltz 1998:60)."

Make well-structured paths

Foltz defines "well-structured" paths as those that are "continuous" with "a clear beginning, middle, and end when viewed in each direction" (Foltz 1998: 62). The trail in this exhibit was both linear and cyclical. The trail took exhibit users on a loop. The user starts and finishes the exhibit in the Present Period, weaving through time at the Clark's Branch Site. Though the entire trail is not always visible, segments are ever-present, looping over the site's terrain.

In each period, the user starts at the beginning of a stretch of trail. Then, they move forward on the trail until they reach the portal. When they walk through the portal, the old stretch of trail disappears behind them, and they continue on to a new stretch. Depending on the user's location in the exhibit, the trail is covered in snow, peppered with acorns, or lined with lush, green ferns.

Indicate what is ahead with sightlines

Animations draw the audiences' attention and can be a component of wayfinding in IVE. The main sightlines for this exhibit are the portals, which contain animated models. Features such as the mammoths and canoe-builders catch the user's eye and offer a sneak peek into the next period. The portal sightlines also signify the end of the trail in that period. These portals serve as primary landmarks in the scene for users to understand their position in time, on the trail, and in the exhibit.

Limit user navigation choices

Users can not choose to go back to another period in the exhibit. Another limitation on user movement involves how far off the trail they can move. Foltz (1998) notes the best use of limiting users' navigation choices is when you want every navigator to absorb the same information. Every exhibit user needs to experience the main cultural and environmental features to grasp the period's key characteristics. Limiting the user to the trail and areas close to the trail improves users' chances of experiencing the main exhibit components.

Additionally, limiting the user to the trail keeps the user from falling through endless game space because the terrains in this exhibit are not limitless. Users straying too far from the trail could easily fall off the edge of the terrain. This problem is a common game design issue that developers solve with barriers, ensuring users stick to the terrain's navigable spaces.

The trail steers users through time and keeps them in maneuverable areas. However, as users progress through the exhibit, they are awarded freedoms to explore further off the trail. These freedoms offer users a more inquiry-based learning approach, where the user is encouraged to spend time investigating information interesting to them. Users were limited to a small segment of the trail in the Present Period scene, only permitted to move in the Paleoindian portal's direction. After correctly moving through the Paleoindian portal, the exhibit's invisible barriers are expanded, and users are rewarded with further range off-trail.

The idea behind this design was that the user's navigation skills would improve as the exhibit progressed. Successful navigators can then focus more on the exhibit material and less on figuring out how to move through the virtual space. In the exhibit's final scene, the first scene's tighter barriers are reinstated to signal the exhibit's end. Another indicator of the exhibit's close in this scene is placing the user off the trail.

Offer signs at decision points and incorporate memorable landmarks

In this exhibit, 3D models of bear footprints are used as directional signs. These footprints are oriented with the bear foot fixed on the trail, with toes facing the period's portal. A 3D bear footprint model was used instead of a 2D image because it appeared more pronounced on the trail. All periods, except the final Present Period, contain four bear footprint models. Excluding these footprints from the final scene and including a bear model signals to the visitor that their virtual hike, and the exhibit, are over.

The bear footprints, and trail, served as landmarks in the exhibit. If the user became disoriented or wandered too far from the trail, they could reestablish their position in space by returning to the trail and following the bear footprints. The trail and footprints were landmarks used throughout the exhibit, and users could see these features from any vantage point.

A bear footprint was selected as the main sign connecting the periods because of the continuous presence of bear species from the Paleoindian through the Present. The main exhibit focus was communicating environmental and cultural changes over time and highlighting connections between past and present periods. The bear footprints served as an environmental feature connecting the cultural periods. The trail functioned as the cultural component linking Riverbend's past and present people.

The artifact models were placed on tree stumps in each period, apart from the Present. In the Present Period, the user first learns how to engage with interactive exhibit models by picking up a large sphere on a stump. Users can recognize the stumps in each period as the locations with interactive artifacts. Text displayed on these stumps indicates the type of artifact and related cultural period.

Create regions that vary visually and give each location a unique identity

The four different exhibit periods serve as unique regions, breaking the deep map exhibit into manageable, recognizable segments (Figure 36). Foltz (1998) states that creating distinctive regional identities can help navigators reestablish their location and space orientation. Each region's identity assists exhibit users in understanding their spatiotemporal place in the exhibit.

Visual and auditory cues assist the user in understanding the unique periods. The period's overall environmental theme is the main factor in creating distinct periods. "Cold" is the Paleoindian Period's signature theme, conveyed through howling gusts of wind and falling white snow dominating the landscape. This cold theme contrasts with the colorful, cool fall scenery of the Archaic and the warm, summer haze of the Woodland. The two Present Period scenes act as neutral environments, where no climatic features are highlighted or exaggerated. The two Present Periods function as spaces to open and close the exhibit. These are not places where the user is meant to dwell, indicated through the limited range of user-motion and lack of enticing features.

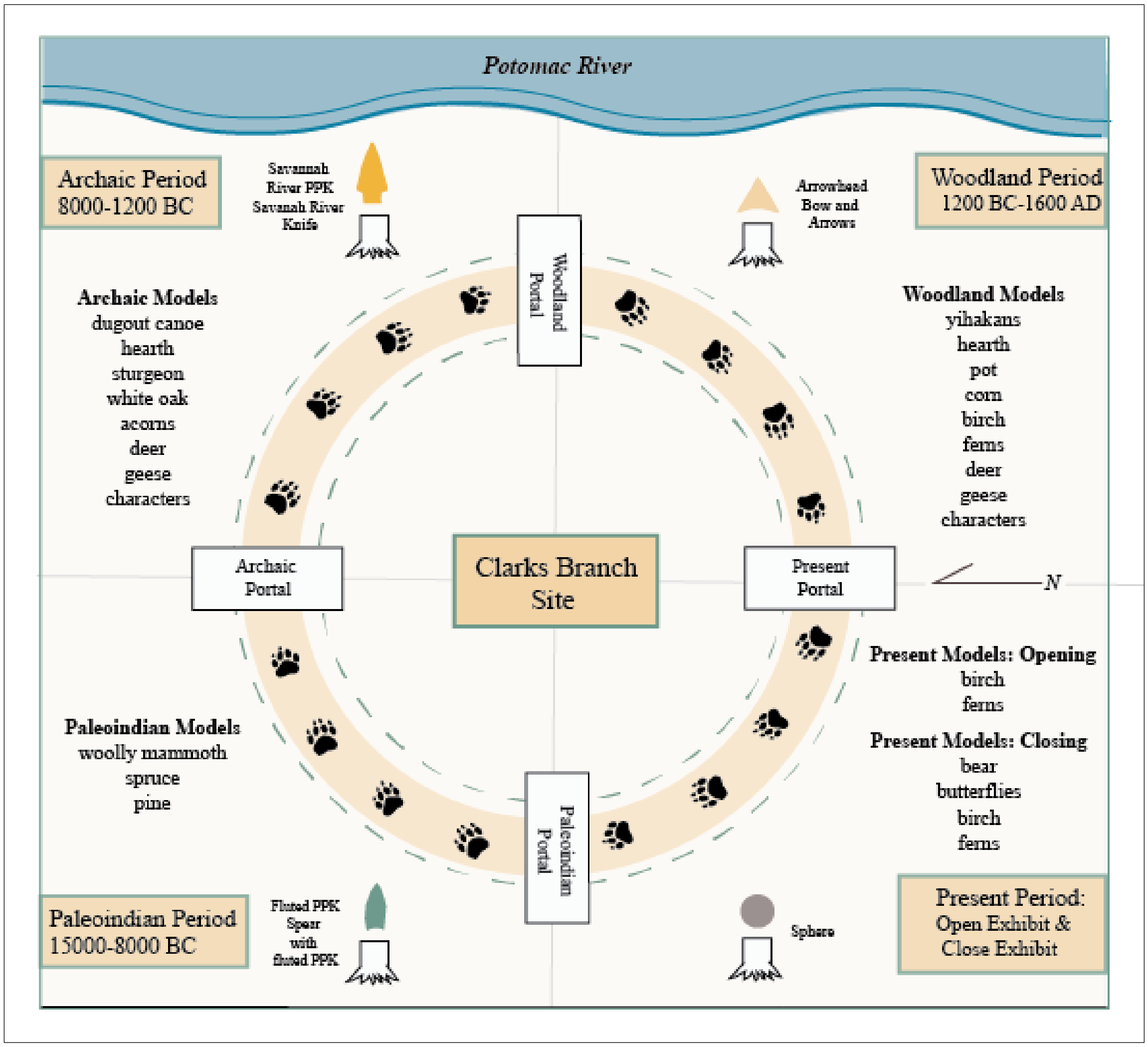


Figure 36 - Clark's Branch exhibit map

The Missing Principle - Providing Navigators with a Vista or Map

Foltz's eighth wayfinding principle is "use survey views (give navigators a vista or map) (Foltz 1998:60). Several attempts were made to add a reference map to this exhibit. First, a miniature map (a.k.a., a minimap) was placed in the computer screen's right-hand corner, displaying the entire trail and the user's position. Minimaps are used in gaming environments to help gamers orient themselves in space and decide on their next move. The minimap was successful in desktop development, but in the HMD, it was ineffective. The minimap remained fixed to the camera's right side, blocking out exhibit features and distracting the user.

A future solution to this issue could involve working with overlays to help orient the user. For this IVR-based exhibit, this additional guide was left out of development. In addition to the distraction issues associated with adding maps in the IVE, it was necessary to keep the exact location of the site private. For archaeological sites where confidentiality is less of an issue, future IVR research could investigate creating useful overview maps to help guide the immersive experience.

The final Clark’s Branch IVR-based exhibit was displayed using the Oculus Rift and Touch virtual reality system. The Oculus Rift system and exhibit ran on an MSI Stealth Pro laptop computer. For a computer to operate an Oculus Rift, specifications required an NVIDIA 1050Ti/AMD Radeon RX 470 graphics card or higher, Intel i3-61000/AMD Ryzen 3 1200, FX4350 or greater, at least 8GB+ RAM of memory, USB ports, Windows 10, and a DisplayPort 1.2/MiniDisplayPort (Facebook Technologies 2019a). The MSI Stealth Pro is a VR-ready laptop that exceeds minimum specifications. In total, the Stealth Pro and Oculus Rift weighs under six pounds and is highly portable.

CHAPTER FIVE -RESULTS

When the IVR-based Clark's Branch exhibit was completed, participants were invited to review the exhibit and answer a series of questions on their experience and knowledge of pre-Contact Virginia. Museums collect data concerning user experience and knowledge acquisition using mixed-methods approaches that involve qualitative methods (e.g., interviews, observations, and conversations) and quantitative methods (e.g., surveys, questionnaires, and comment boxes) (Nelson and Cohn 2015). This study also followed a mixed-methods approach, collecting data with pre-and post-IVR exhibit questionnaires and a focus group discussion.

Initially, the typical Riverbend visitor was the target population for this study, with the caveat that participants be at least 18 years of age. The age limit adhered to limitations outlined in the Oculus Health and Safety guidelines (Facebook Technologies 2019b). Following an outbreak of the SARS-CoV-2 virus in Northern Virginia, Riverbend Park and associated facilities were closed indefinitely. Thus, Riverbend's visitors were not available to participate in this research. To mitigate these issues, the study location was moved to George Mason University's (GMU) Exploratory Hall to ensure a controlled research environment. Also, the target population shifted to GMU Geography students.

Before the pandemic, Friends of Riverbend Park (FORB) members were invited to participate in a focus group discussion on the IVR-based exhibit. However, FORB canceled their participation following the closure of Riverbend Park. Instead, the focused discussion involved Fairfax County's Archaeology and Collections Branch (ACB) members, who had tested the IVR-based exhibit before the Sar-CoV-2 pandemic.

This study's results were collected from the focus group discussion and questionnaire data gathered from GMU student participants (Figure 37). Investigations followed all requirements outlined by GMU's Institutional Review Board (IRB). This study's IRB (1525051) was altered following the Sar-CoV-2 pandemic to account for the change of study location, participant group, and safety procedures. The new study procedures received approval from GMU's College of Science to continue investigations, following GMU's Return to Research Continuity and Safety Plan.

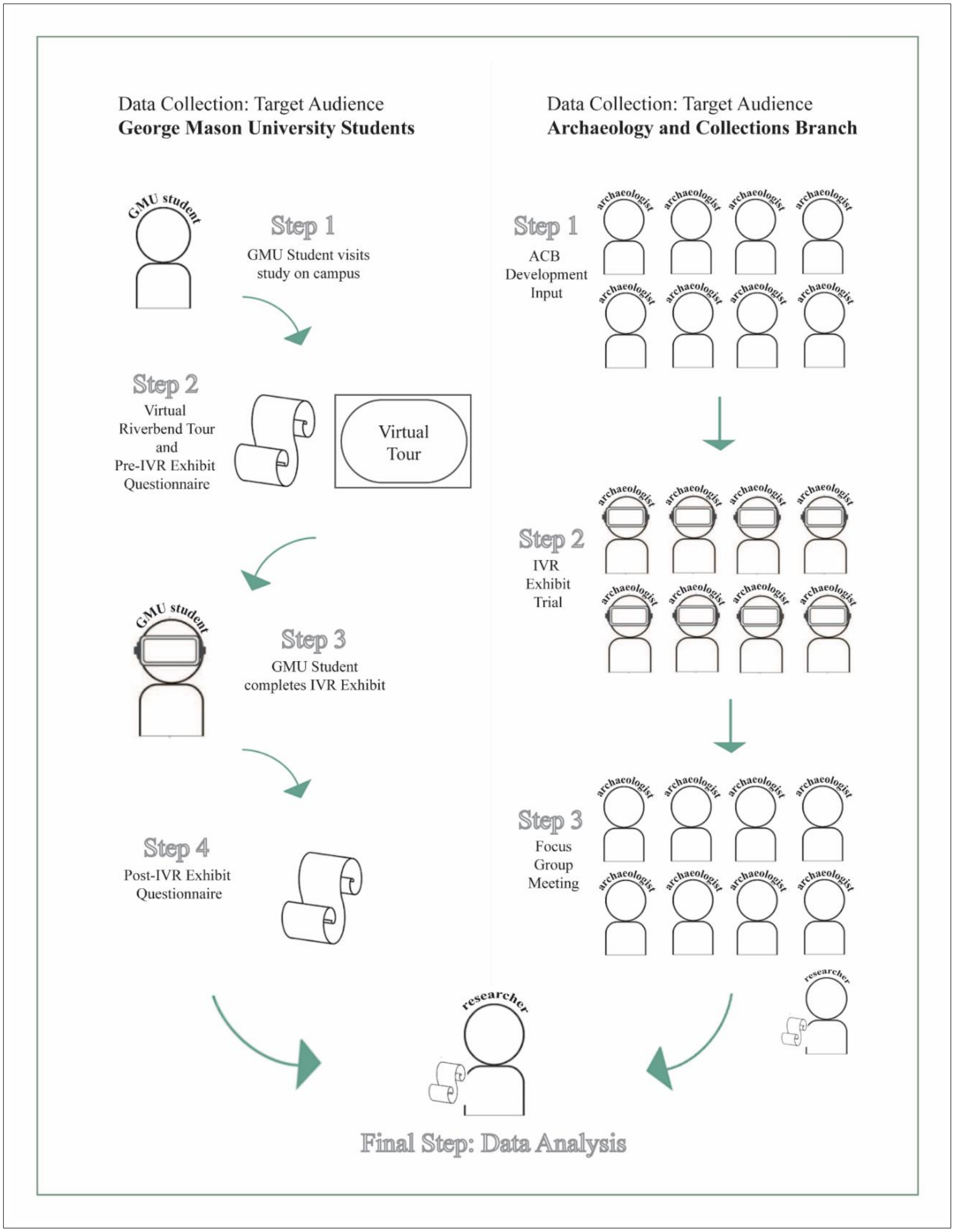


Figure 37 - Data collection process

Focus Group Discussion: Archaeology and Collections Branch

Before testing the IVR-based exhibit at Riverbend, the ACB was invited to review the exhibit and offer feedback on their experiences. The ACB archaeologists had actively participated in archaeological investigations at Riverbend Park before the study and were intimately acquainted with the subject material. This group evaluated the exhibit content and Oculus Rift system useability. This initial testing was completed to identify exhibit issues before public release.

The ACB was a suitable focus group for this study due to their collective expertise and desire to develop archaeology-and-history-focused public outreach programs. As commercial IVR systems (e.g., Oculus Rift) reach accessible price points, heritage sector workers at establishments like museums, cultural resource management firms, and universities have greater opportunities to work with IVR developers and to create custom exhibits. The main goals of conducting this focused discussion were to query the group's overall user experience and evaluate their views on IVR as an archaeology-focused educational tool. Focus group reactions to the IVR-based exhibit addressed the first research question posed by this study:

RQ1: What is the general user experience of an IVR-based exhibit? Specifically,

a. are users generally receptive to IVR-based educational tools?

b. do users feel the deep map IVR-based exhibit improved their understanding of the multidimensional nature of archaeological sites?

On October 5, 2020, five ACB members participated in a guided discussion. The focus group lasted 68 minutes and was conducted virtually over Zoom, a video communications platform. Participants answered seven questions querying their experiences in the exhibit (Appendix C). To maintain participant privacy in this small group, gender associations and age groups for participants remained confidential and were not a part of this analysis.

Before this guided discussion, participants watched a brief, two-minute walk-through of the exhibit in a virtual-tour format to refresh their memories of the Clark's Branch IVR-based exhibit (Figure 38). This virtual tour was shared over the moderator's screen.

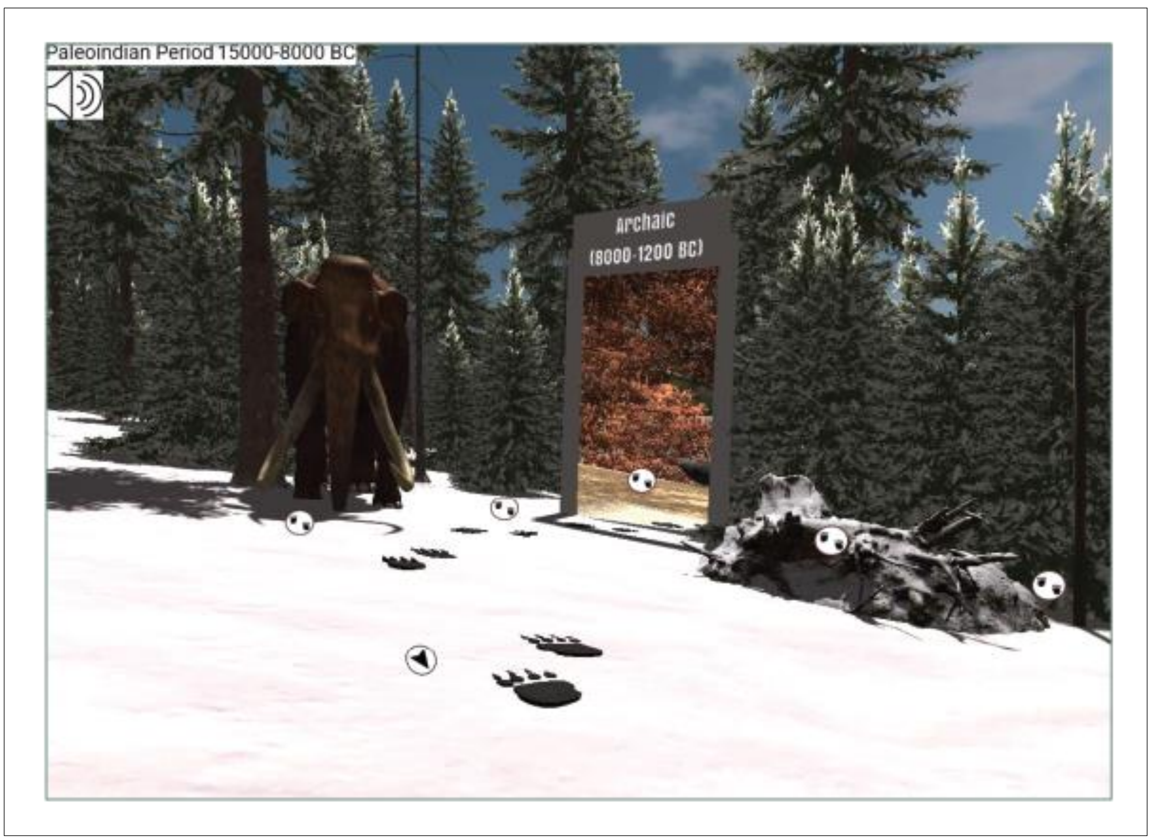


Figure 38 - Image of the virtual tour shown to focus group

Organizing, categorizing, summarizing, and analyzing data gathered from the focus group discussion followed methods rooted in *grounded theory,* a qualitative analysis framework first introduced by Glasner and Strauss and (1967). Grounded theory promotes systematic data dissection, categorization, and summation, to reveal new theories rooted in data. This process involves meticulous *coding*, defined in this framework as a word or phrase that captures the data's meaning. Saldana (2016) groups six grounded, theory-coding methods under *first* and *second* cycles. First-cycle coding involves *in vivo, process, and initial* coding, in which the raw data is organized in manageable segments. Second-cycle coding groups *focused, axial* and *theoretical* methods. This second stage of coding involves analyzing initial codes and memos and summarizing ideas into core concepts that support a theory. Data from this study's focus group discussion was analyzed using first and second cycle methods. Atlasti software, a computer-aided qualitative data analysis software (CAQDAS), was used to search for patterns, develop codes and memos, and organize core concepts

Following the focus group discussion, the discussion transcript was uploaded to Atlasti, and study participants were assigned a unique identifier (1-5). The first coding of this document relied on *initial* and *in vivo* coding techniques. Initial coding (a.k.a., open-coding) involves a meticulous line-by-line review of the data, assigning a word or phrase code to the information that summarizes what was said. The in vivo coding process is part of this initial process, using codes from the participant's exact phrases and words.

The transcript was reviewed four times in the first-cycle coding process. This coding stage involved in vivo coding using codes from the transcript words (e.g., Archaic, 2D, and immersive) and initial coding, creating codes from overall themes (e.g., limited IVR experience). Forty codes were assigned during this stage of analysis.

Analyzing word-frequency queries was a first-cycle coding method used to identify key concepts in the transcript. Atlasti's *word typewriter* and *word list* frequency queries were used during this stage. The word-typewriter tool ordered words by count, from most frequent to least frequent (Figure 39). The word-list tool organized words by count, frequency of code, assigned code group, and quotation.

Figure 39 - Focus group data in the word-typewriter tool

Memo writing occurred simultaneously with recoding and grouping codes. Memos consisted of short phrases and thoughts that emerged from analyzing the transcript and first-cycle codes. These passages included changes in participant mood, emerging themes, and key assertions. These ideas were organized in the Atlasti memo manager.

The second coding cycle centered on narrowing the extensive list of codes down into groups and identifying key categories. This process involved analyzing the original codes, recoding, and organizing the information into groups. Constant comparison was used to assess emerging ideas and codes against already identified thoughts and themes.

Overall, focus group participants felt the IVR exhibit enhanced their understanding of artifact context, environment, and temporal shifts at Clark's Branch. Additionally, the group believed the sensory immersion contributed to the learning experience and that IVR was a promising public outreach tool. The forty codes related to these perceptions were organized under five main code groups: sensory immersion, artifact context, environment, temporal, and public outreach. This data was reviewed to identify the core reason why the group believed the experience enhanced their understanding of the Clark's Branch Site.

Focus Group Analysis

The focus group discussion's key assertion is that the immersive exhibit's embodied component enhanced the learning experience. The group discussed three main factors connected to this improved embodied learning approach: the sensation of "being" in another environment (a.k.a. sense of presence), the ability to interact with the virtual spaces, and the novel visual immersion. The ACB participants felt the experience was an effective means of communicating complex information (e.g., topography, artifact context, and climatic changes), challenging to convey through traditional public outreach approaches (e.g., showing timelines and aerial photography). Throughout the discussion, this group noted the difficulties of asking public audiences to use their imaginations to envision archaeological information and changes at sites over time. The consensus was that the embodied experience improved the learning environment by encouraging the exploration of virtual knowledge representations on the user's terms.

The Sensation of "Being" Somewhere Else

The ACB archaeologists felt they were transported to Clark's Branch in the IVR-based exhibit, and participants experienced a sense of presence. The group noted that this sensation of "being" at virtual Clark's Branch could not be achieved in traditional museum exhibits. All focus-group participants had experienced IVR in HMDs, but none where they interacted with the environments by moving through the virtual space. Thus, the perception that they were in control was a new IVR experience. Participant 1 aptly described the immersion sensation experienced in virtual Clark's Branch.

> The way you could turn your head and see the animals, it is just, I am used to playing video games and used to moving controllers to move my head one way and joystick another. In the headset (the Oculus Rift HMD) you just reach out for it and it will be there. (Participant 1)

The group pointed out that the virtual portals enhanced their overall sense of presence. Participant 3 stated this succinctly: "The portals added to the sense of presence." The portals were also connected to sense of place, mentioned by Participant 3, who said, "There was your sense of place again, when you went through the portals, you took it in all over again. It was fresh and new and you felt like you were somewhere different." Participant 2 echoed a similar sensation of feeling immersed again when they traveled through the exhibit portals.

The focus group agreed that experiencing this sense of presence improved their understanding of the Clark's Branch Site, in particular the environmental elements. Participants commented that virtually walking over the real-world terrain models provided a new means of exploring topographical data. One participant noted they felt the embodied immersive approach helped them better understand this type of information.

> Topographic data is not the sexiest data type to read. You look at a map and you know how to read it but having that (the digital elevation models), that's where I like the computational work you did with the Lidar. It helps you see how high up are you from tributary. It's easier to understand it in this way. (Participant 1)

One participant had worked on data from the site, and was familiar with the site's topography, but had never physically visited Riverbend. This participant noted that their virtual walk over the digital Clark's Branch terrain was "…useful for someone like me that has never been there. I feel like I could walk to the actual hearth because you used the lay of the land" (Participant 2). One participant was unsure of the necessity of real-world elevations in the exhibit, commenting that including this data "likely depends on the audience" and that it was "questionable" if general audiences would "pick up the nuances" (Participant 5).

Overall, the group felt that walking through the virtual interpretations of the past environment, and seeing the evolving flora, fauna, and cultural components enhanced their understanding of regional prehistory. Participant 5 remembered a visit to another prehistoric site and commented on the difficulties of imagining this site's multifaceted evolution.

> One time years and years ago I was at Theodore Roosevelt island with a geomorphologist and we were talking about different prehistoric periods and how things would have looked differently. It’s one thing to imagine it in your head, but to actually have the different types of trees and animals kind of brings it to life. (Participant 5)

In addition to enhancing their personal understanding of prehistory in the region, participants noted how the sensory experience could improve the way archaeologists and museum specialists educate public audiences. Participant 3 summarized this sentiment by saying, “It’s so different when you are telling someone about a prehistoric environment instead of seeing it.”

The group commented on methods they had previously used to show site changes and reflected on the difficulties of communicating sensory information through static visuals, like aerial imagery. Participant 1 remarked that “People’s eyes light up when they see those aerial photographs.” This participant also added that “You can’t use an aerial photo to show all this. You would have to use technology such as this (IVR).” This participant also remarked on the difficulties of describing archaeological features to the public.

> These funny brown stains or this little hole in the ground is what it means to us (the archaeologists). It means hearth, longhouse, and fish cleaning. What did it look like to them (indigenous people)? It is putting meat on the bones. (Participant 1)

Participant 5 agreed that the experience went beyond what a static image could convey, saying, “It’s not like you are looking at a snapshot of somewhere. You are in their world.”

Interactive and Animated spaces

The interactive elements were another component of the embodied experience that enhanced the learning process for the ACB archaeologists. Interactive and animated exhibit models caught the participants’ attention, pointed to as the participants’ favorite part of the experience. In particular, the group remarked on the exhibit’s fauna and character models' movements, continually referencing the animated woolly mammoth.

Though depictions of woolly mammoths are often shown in museums (including at Riverbend), walking up to a woolly mammoth is not a common experience. Getting to move across an animated Paleoindian scene, with falling snow and a moving mammoth, offered participants a comprehensive perspective on this early period. Participant 3 stated they thought the mammoth was “so cool” and that the Paleoindian scene's elements really “solidified the idea” of the prehistoric environment.

The group also recalled seeing the movements associated with the exhibit's characters, especially those in the Archaic scene. Participant 4 specifically remembered the characters and movements involved in building the dugout canoe. Participant 3 remarked that they too liked seeing the action in the Archaic scene and that "The canoe and smoking fish gave more like a temporary camp feel, seeing the resource usage." Participant 1 commented that the scene's features revealed some of the background behind the laborious tasks depicted.

> It made me think, yeah, that's what they were fishing for. They really needed to spend time processing. Big effort. They are nasty fish. They bite and they are horrible. Seeing how they are processed, that is something that would have to be taken back and worked on. (Participant 1)

This comment implies that Participant 1 connected with the characters in the scene. The IVR experience helped the participant better understand hard tasks associated with the scene's activities and relate to the Archaic people. This suggests that IVR-based GIS offers a phenomenological approach, linking quantitative environmental data typically shown in GIS with social components. This finding suggests that IVR is a potential answer to the heavy critique of positivism and environmental determinism in GIS.

In a continuation of the discussion on the work of the Archaic people, the ACB archaeologists agreed more animated features (like the Archaic characters) would improve the exhibit. They noted that the movements drew their attention to certain content. Participant 2 remembered the Native American characters most from their experience, commenting that the "Things that weren't standing still caught my eye. Just being able to see what was going on at that time." Also, participants wanted further detail in the exhibit. Participant 1 commented that they wished to see "…more animated humans. Put little outfits on them. The personal items."

Of the exhibit features, the group best remembered the animated and interactive models. Participant 4 commented that "I remember the artifacts the most. I spent so long just picking them up and turning them around." Participant 3 echoed this sentiment, saying being "able to pick everything up, that was really cool for me." In addition to being drawn to the animated and interactive components, the ACB archaeologists felt the dynamic and interactive exhibit components would connect with the public and help audiences better understand the site. Participant 5 noted they believed the experience would be a useful educational tool because "It gives you a feeling you were really there, a lot more than looking at a flat, static exhibit with objects and pictures." Participant 3 remembered a favorite museum exhibit from youth where "You got to touch everything and experience things" and that "People love to stop and interact with exhibits."

Participants also highlighted the importance of offering interactive museum experiences for younger audiences. Participant 5 remarked that the IVR-based exhibit would most appeal to generations familiar with technology-based learning. "The younger folks that would be into that kind of thing, also being able to pick up the artifact or do the different things would engage them" (Participant 5). Participant 3 remarked that more interactive objects in the scenes would be a good addition to the experience, suggesting that future users "stir the pot or (flint) knapp (stone)."

Visuals over Imagination

The interactive artifacts were important exhibit features, but the visual immersion was unquestionably the highlight of the archaeologists' IVR experience. This is likely because visuals are essential to creating an embodied experience and sense of presence. So much information in IVR applications is taken in through the users' eyes (Witmer and Singer 1998). The group indicated that seeing the past interpretations, instead of imagining complex, multidimensional information, was key to better understanding the scene. Participant 2 remarked early in the discussion that the experience "Offered a better impression of the environment than I would have necessarily come up with in my own head." Participant 1 summarized the group's overall response to the visuals in the exhibit, stating:

> It doesn't seem to matter what I've read. My ability to understand a prehistoric site is probably better having seen some of the exhibit's things. The smoking fish and the growing of the corn. To see the things visually together and cement them in my mind. It's easier to put sites together when there is a visual. (Participant 1)

Focus-group participants also remarked that they often relied on visuals, including photographs and copies of primary source drawings, to help the public visualize different periods at sites. This process often involves relying on public audiences' imaginations, asking them to envision complex environmental information (e.g., topographical and hydrological changes).

Also, archaeology-focused outreach programs and museum displays are often artifact-centric, and other types of information (e.g., climate, flora, and fauna) are usually omitted. In particular, participants noted the difficulties of describing prehistoric landscapes that cannot be shown through visuals like aerial imagery. The group pointed out that the visuals in the exhibit helped to connect different cultural and environmental components. Participant 1 described their experience seeing the evolution of the prehistoric landscape in the exhibit.

> Having the trees was helpful. It's not something that we think about. We all put the information in our reports, but to see the Paleoenvironment. We don't talk about it a lot. The land was so much clearer in the Woodland Period, and seeing how the landscape opened up gave a sense of how they (indigenous people) were using the river different. We can see corn. We can see the campsites. (Participant 1)

Participants concurred that this technology's primary benefit was the ability to show the public a virtual knowledge representation instead of verbally describing how sites had changed. The ACB archaeologists also commented on the importance of incorporating regional specialists to help construct models to serve as scientific knowledge representations in virtual exhibits. Participant 1 remarked that mainstream media portrayal of Native American culture often "mix their time periods and their places up." The group agreed they were tired of seeing incorrect features such as "Plains Indian headdresses" (Participant 1) and "totem poles" (Participant 5) in Virginia pre-Contact interpretations.

Misrepresentation of cultures is an issue, and museums misrepresent culture when parts of the historical narrative are omitted. The ACB archaeologists liked that the

Clark’s Branch immersive exhibit showed the site’s lesser-known histories. Participant 3 remarked that they enjoyed the Archaic scene in the IVR-based exhibit because it presented a period at the site which visitors don’t typically learn about in pre-Contact Virginia history. The participant summarized this sentiment well. “I thought that was cool to exhibit to the public. The temporary camps are glazed over, but they are important (Participant 3).”

Conclusions

The ACB archaeologists responded positively to the immersive exhibit and felt the technology offered great promise in educating the public on the complexities and changes connected to archaeological sites. The archaeologists often mentioned the challenges of explaining changes over time, primarily environmental and climatic shifts, in traditional programs relying on visuals such as aerial images and the audiences’ imaginations. The group noted that the immersive exhibit's inquiry-based approach was an improved method for teaching public audiences about sites. Participant 1 summarized this sentiment well, stating, “Anytime you let the user guide their own experience over throwing information at them, it makes for a more enriching experience.”

The group felt they were transported to Clark’s Branch, experiencing a sense of presence. Participant 1 succinctly expressed this sensation, saying, “When I was in the headset, it was unsettling. There was such a sense of presence that I felt like I was at Clark’s Branch.” The group felt they were in control of the experience, moving across the site and interacting with artifacts at their own speed. The exhibit’s animated models caught the groups’ attention, and the visuals presented a comprehensive picture of past landscapes.

The exhibit’s deep-mapping framework also resonated with the archaeologists. Throughout the discussion, the topic continually shifted back to other sites that would benefit from showing cultural and environmental changes over time. Participants reminisced about sites they had personally worked at. The discussants' moods shifted from serious to excited as they elaborated on the sites they wanted to see interpreted in an immersive exhibit. Well-known sites and sites with long-running archaeological programs (e.g., Jamestown, St. Mary’s City, and Williamsburg) were mentioned in addition to lesser-known sites (e.g., Whitehurst Freeway Site and Mt. Air). Each time participants mentioned a new site, the discussion centered on the participant’s interest in seeing these sites' cultural and environmental evolution.

The embodied experience of the novel immersion brought the site to life, but the deep mapping framework, presenting the “clear separation of time periods (Participant 4)” is what these archaeologists want to see in future exhibits. The group also agreed that the deep mapping format (i.e., linking different 3D and 2D environmental and cultural information) could also assist archaeologists in training and analysis. Additionally, they noted IVR-based exhibits could be used for archaeological laboratory technicians who rarely have the opportunity to visit sites and project directors to advise field archaeologists from afar.

In addition to using the deep mapping framework for archaeologists, participants mentioned tying in other scientists' work, such as naturalists and astronomists, to build even more comprehensive exhibits. Participant 1 summarized the range of experiences that IVR-deep maps could offer users well.

> There is no reason why if you are trying to be a holistic museum not to get the naturalists onboard. There's no reason you couldn't show special places or put them (IVR users) in a virtual exhibit and explain why they are in danger and explain the habitat. It doesn't have to be archaeology; it could be comprehensive. Show flooding hurting the river and any number of things. Make it show what the night sky looked like at different times. The sky is the limit. (Participant 1)

The ACB archaeologists expressed excitement thinking about the immersive deep mapping possibilities for recreating and presenting archaeological information. Participants indicated that they wanted more from their immersive experience and perceived that the immersive platform could be used to explore diverse data from multidisciplinary perspectives. The groups' inclination towards building more comprehensive exhibits reflects an overall sentiment that deep map exhibits are an enhanced method of presenting multilayered and complex archaeological-and historical information.

Questionnaire Results - GMU Geography Students

To assess the user experience, learning acquisition, and concepts of sense of presence and place attachment, GMU Geography students were invited to experience the IVR-based exhibit and participate in this study. Students were recruited through email (Appendix D) and selected a suitable appointment slot to complete the study on a project-specific Google calendar. The selected time slot was only visible to the researcher to maintain participant confidentiality. Time slots were spaced at two-hour intervals to allow for the necessary Sars-CoV-2 cleaning of the space and equipment. Once the study time was confirmed, an email from the researcher provided further instruction on accessing the study space. Eight GMU students completed this study. Demographic data collected from this group included age and gender information. Student participants selected one from six generation choices: Greatest Generation (born 1910-1927), Silent Generation (1928-1945), Baby Boomer (born 1946-1964), Generation X (born 1965-1980), Millennials (born 1981-1996), and Generation Z (born 1997-). For gender identity, participants were asked to select one or more from seven choices: Male/Man, Female/Woman, TransMale/TransMan, TransFemale/TransWoman, Genderqueer/Gender nonconforming, Something Else and Decline to Answer. From the student participants, five students identified as Generation Z Females/Women, one identified as a Millennial Female/Woman, one identified as a Generation Z Male/Man, and one identified as a Millennial Male/Man. Figure 40 illustrates the generation and gender of each participant.

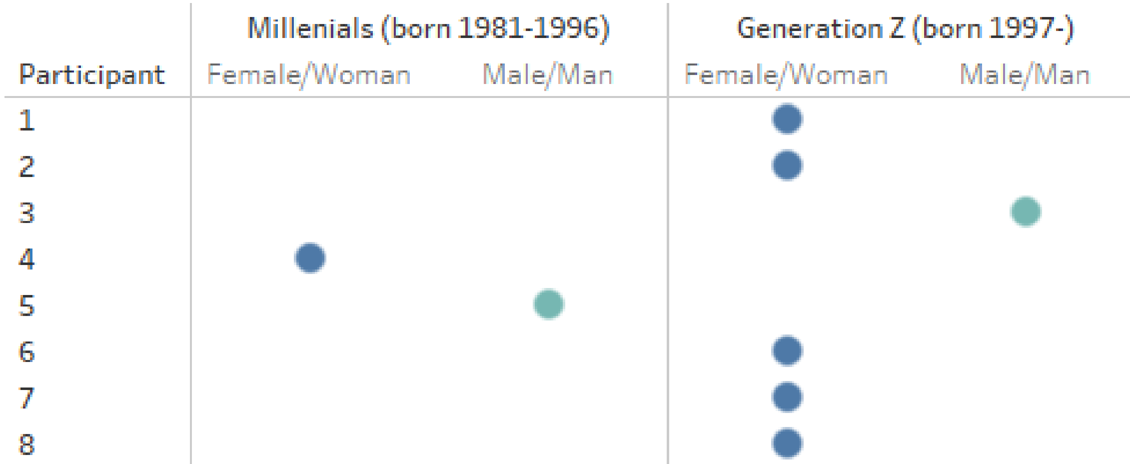


Figure 40 - Study participant generation and gender

This research was conducted in a private office in a locked corridor in the Geography and Geoinformation Science wing of GMU's Exploratory Hall. Students were permitted to enter this corridor 10 minutes before the study started, following signs to a private office space. Once participants were in this office, the researcher guided the student through the study procedures (Appendix E) via an iPad in compliance with this study's Sar-CoV-2 no person-to-person protocol.

Students completed four steps in this study. First, students read and signed a consent form and were asked to review the Oculus Rift Health and Safety Warnings. These warnings were provided on a computer monitor in the office and in laminated print form. Following their review of these warnings, students were then asked to look over a Riverbend Story Map displayed on a second computer monitor in the study space (Figure 41). The Riverbend Story Map contained a virtual tour of Riverbend and the study's pre-and-post IVR questionnaires (Appendix F). These questionnaires were developed using ESRI's Survey123 application.

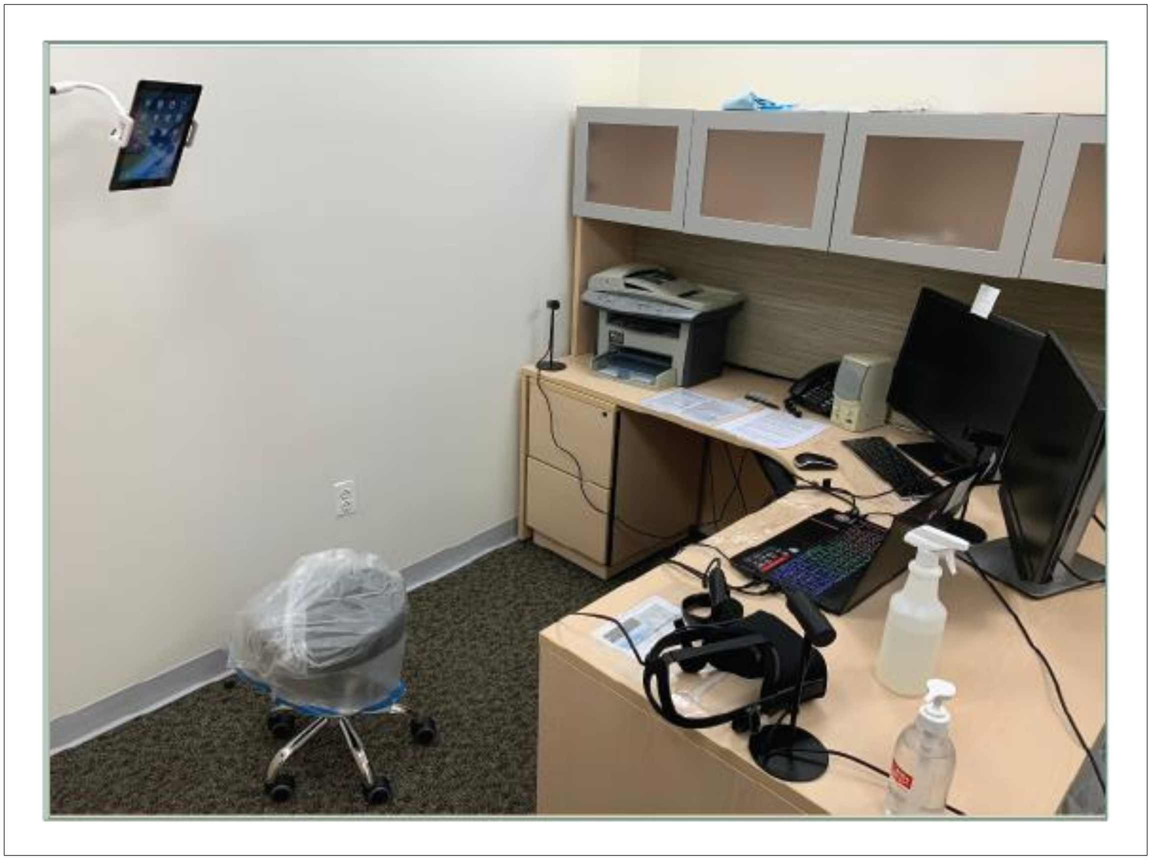


Figure 41 - Study area at George Mason University (GMU)

The Riverbend Story Map's virtual tour contained a series of Riverbend museum photographs, these taken before the Sar-CoV-2 outbreak. These images were linked together using the Kuula Virtual Tour Professional platform. Kuula is a program for creating tours using 360-degree and 2D images (Kuula 2020). Kuula's virtual tours are composed of linked images the user explores using forward and backward buttons embedded in the tour photographs. Virtual tours have become an increasingly popular means for users to explore different areas of the globe, including exhibits in internationally renowned institutions (e.g., the Louvre (Louvre 2020) and Smithsonian museums (Solly 2020)).

The Riverbend Story Map's virtual tour began with an image of the Visitor's Center from Riverbend's main parking lot, where most visitors would typically start their Riverbend trip. From this point, the user could click on a bear footprint icon embedded in this image to move forward in the tour and enter the museum. A red arrow-button icon moved the user back to the previous image. Study participants navigated the virtual tour using the bear footprint and red arrow icons. The virtual tour consisted primarily of photographs of Riverbend's early Native American lifeways exhibit. The exhibit images included a closeup of Riverbend's linear timeline display.

Also included in the Riverbend Story Map was a brief introduction to Riverbend Park. This description provided basic information on the park and a map indicating the park's location in relation to Washington D.C (Figure 42).

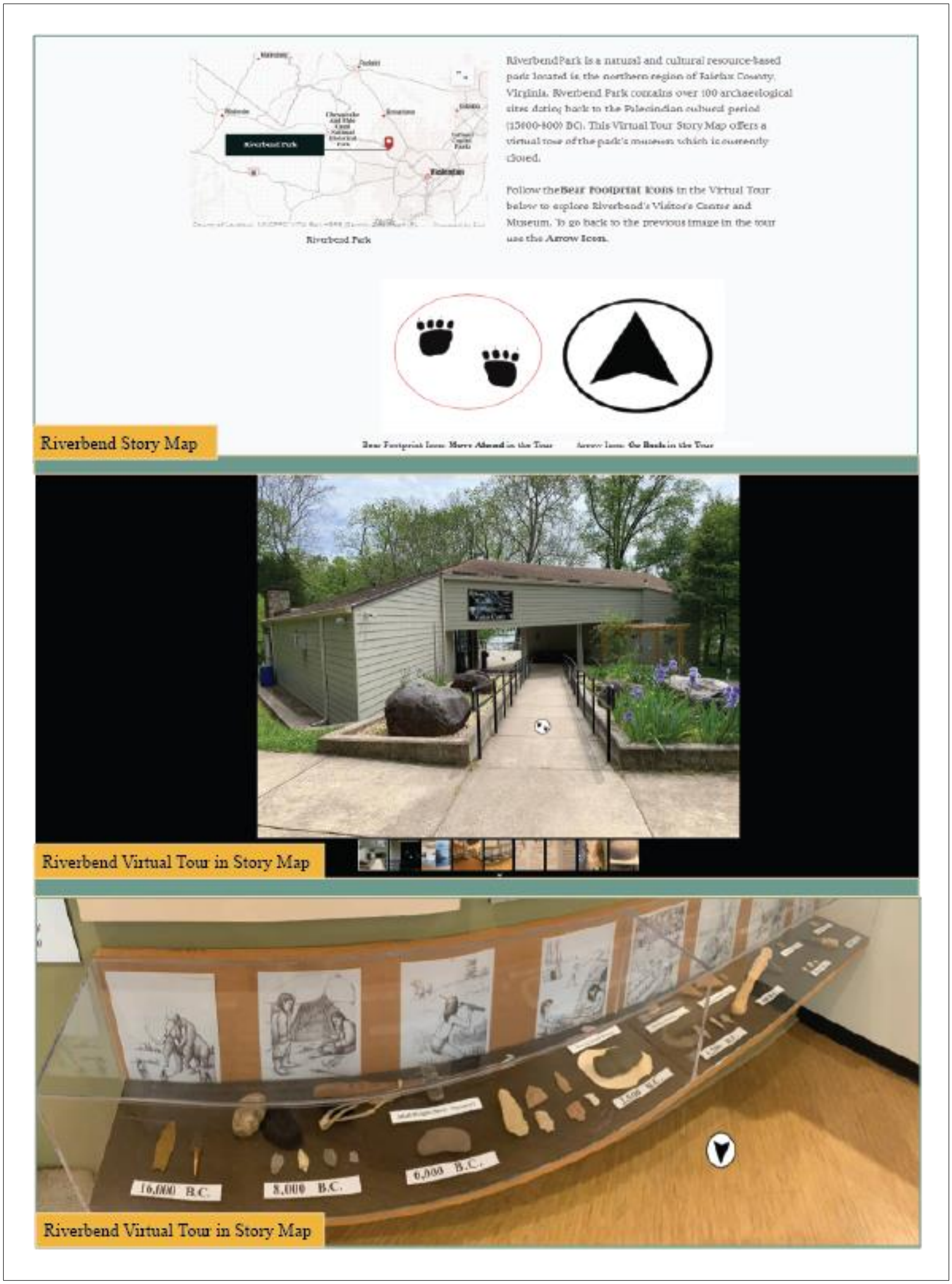


Figure 42 - Riverbend virtual tour in the study's story map

Participants reviewed the virtual tour, then completed the pre-IVR questionnaire in the Story Map. When these activities were finished, they proceeded to the study's IVR-based exhibit. At Riverbend Park, the researcher had the opportunity to help participants comfortably fit the Oculus HMD to their heads and ensure users did not get tangled in the system's cords. At Riverbend, the researcher could also physically show participants the Oculus Touch joystick and buttons needed to maneuver through the exhibit successfully. The modified study at GMU did not permit person-to-person contact, which made communication challenging. The researcher could not start the exhibit, stop the exhibit, or help the participant operate the technology, except through directions transmitted through an iPad. To alleviate some of these communication issues, the researcher read a script over the iPad detailing how to use the equipment before the participant donned the Oculus HMD. After finishing the IVR exhibit, users proceeded to the fourth and final step in this process, completing the post-IVR questionnaire in the Riverbend Story Map. When the study was finished, the room and study equipment were thoroughly sanitized to prepare for the next participant.

Multiple-choice questionnaires were used to investigate this thesis's research questions. Gathering data with questionnaires is a well-established tradition in social science research, considered essential for accurate and reliable data collection (Alzua-Sorzabal et al. 2005). In addition to assessing learning outcomes, questionnaires collected information to evaluate the participants' experiences, sense of presence, and place attachment.

Questions were structured following guidance in *Evaluation Toolkit for Museum Practitioners* to “use simple language, ensure questions are not ambiguous, ask one question at a time, test questions on others before the study, and don’t ask questions you don’t need answers to” (Foster 2008: 29-30).

Questionnaire Results - User Experience and Deep Mapping Concept

Evaluating the user experience in the IVR-based exhibit was a primary research focus of this thesis. The ACB focus group discussion provided insight into how this specialized group felt about the exhibit and its use as a public outreach tool. Additionally, this study queried student participants on their user experience and opinions on IVR as a deep mapping educational platform. Student participants answered several questions on the pre-and-post-IVR exhibit questionnaires to address the first research question posed in this thesis:

RQ1: What is the general user experience of an IVR-based exhibit? Specifically,

a. do users feel the deep map IVR-based exhibit improved their understanding of the multidimensional nature of archaeological sites
b. are users generally receptive towards IVR-based educational tools?

Three items on the study’s post-IVR exhibit questionnaire investigated this research question. Two of these questions evaluated if users perceived the IVR-based exhibit enhanced their understanding of the complex spatiotemporal human-environmental shifts at Clark’s Branch. One question queried the user’s overall perception of the exhibit. A five-item Likert scale was used to evaluate participant responses, ordered from *Strongly disagree* to *Strongly agree*. Data was entered into the

International Business Machines Corporation's (IBM) Statistical Product and Service Solutions (SPSS). The Likert scale questions were assigned a specific weight in SPSS. For Questions 9, 13, and 15, the weights were assigned as follows: *Strongly disagree* = 1, *Disagree*= 2, *Neutra*l = 3, *Agree* = 4 and *Strongly agree* = 5. For the three user experience questions, participants were asked to select one option from these five choices.

The three items on the post-IVR exhibit questionnaire querying student participant's user experience were:

Q13. I enjoyed learning about the Clark's Branch archaeological site through the immersive virtual reality exhibit (Overall User Experience)

Q9: The IVR exhibit helped me better understand cultural and environmental changes over time at Riverbend Park (Deep Mapping Concept)

Q14. After completing this experience, I can better place different environmental (plants, animals, climate) and cultural (artifacts, lifeways) information in specific cultural periods (Deep Mapping Concept)

Overall, student participants indicated they enjoyed learning about Clark's Branch in the IVR-based exhibit. For Question 13, inquiring if students enjoyed their experience, the average weight from all participants was 4.88, between *Agree* and *Strongly agree*. The average weight for Question 13 from the six female participants was 4.83 between *Agree* and *Strongly agree.* The two male participants both strongly agreed they enjoyed the experience, with an average weight of 5. The average weight for Question 13 from the six Generation Z participants was 4.83, between *Agree* and *Strongly agree.* The two

Millennial participants both selected *Strongly agree* for Question 13 with an average weight of 5.

In Question 9, students indicated they believed the IVR-based exhibit helped them better understand spatiotemporal human-environmental shifts at Riverbend. The average weight for Question 9 was 4.5, between *Agree* and *Strongly agree*. The average weight for Question 9 from the six female participants was 4.5 between *Agree* and *Strongly agree*. The average weight from the two male participants was also 4.5, between *Agree* and *Strongly agree*. The average weight for Question 9 from the six Generation Z participants was 4.67, between *Agree* and *Strongly agree*. The two Millennial participants both selected *Agree* for Question 13 with an average weight of 4.

Question 14 also queried the participants' perception of the educational deep mapping component. Question 14 asked the students if they believed the IVR experience assisted them in better placing environmental and cultural features in Virginia's pre-Contact cultural periods. The average student participants' response was *Agree* for Question 14, with a weight of 4. The average weight for Question 14 from the six female participants was 3.83 between *Neutral* and *Agree*. The average weight from the two male participants was 4.5, between *Agree* and *Strongly agree*. The average weight for Question 14 from the six Generation Z participants was 4, the youngest generation agreeing the experience enhanced their ability to place cultural and environmental information into specific cultural periods. The average weight for Question 14 from the two Millennial participants was 4 (*Agree*). The results of Question 9, 13, and 14 are illustrated in Figure 43.

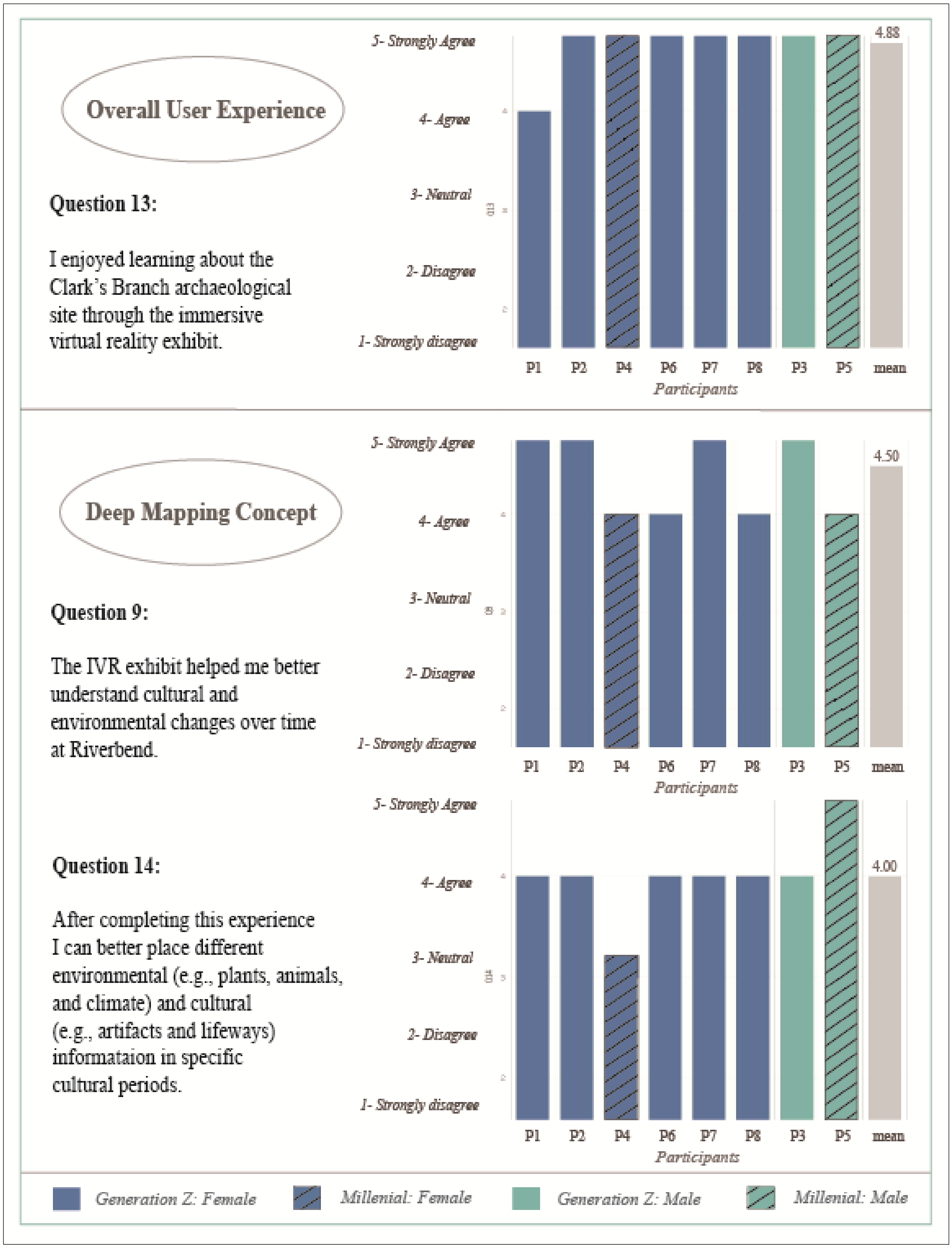


Figure 43 - Questionnaire Results: User experience

Questionnaire Results - Knowledge Acquisition

The user experience and user perception of IVR-based exhibits as effective educational tools was another focus of this research. To evaluate if student participants experienced learning gains following their IVR experience, participants completed pre-and-post exhibit questionnaires. The results of these questionnaires were evaluated to determine if there was a significant difference between the pre-and-post item answers.

The first seven questions on the questionnaires queried participant knowledge of artifact context and cultural and environmental hallmarks of Virginia's three main pre-Contact cultural periods. These seven questions were identical on the pre-and-post questionnaires.

These questions focused on the *remembering* and *understanding* levels of Bloom's taxonomy. Bloom's taxonomy is a learning framework often presented in a pyramid graphic displaying six tiers of the learning process: *Remembering, Understanding, Applying, Analyzing, Evaluating*, and *Creating* (Persaud 2018). This exhibit aimed to educate users on the bottom two tiers of this pyramid, to recognize and understand the material, realizing that the subject matter was unfamiliar to many participants. Five questions focused on Bloom's taxonomy's base tier: *remembering*. These questions tested the participants' ability to recognize and recall information from the exhibit. Two of the seven questions queried the second tier of Bloom's taxonomy: *understanding*. These questions assessed if participants could apply knowledge learned in the exhibit to new situations. Further research is necessary for the cultural heritage gaming sphere to assess how best to target higher cognitive tiers in Bloom's framework (Mortara et al. 2014).

Questionnaire Results: Knowledge Acquisition on Artifact Context

Items were included in the questionnaires to evaluate if participants remembered contextual information related to artifacts following the IVR-based exhibit. These questions addressed the second research question posed in this thesis:

> RQ2: Do IVR-based exhibits enable users to develop a broader understanding of artifacts? Specifically, will study participants better understand artifacts contextualized in a virtual interpretation vs. displayed in a museum case?

Riverbend's museum displays PPKs from each major pre-Contact cultural period and Woodland Period pottery fragments. The IVR-based exhibit presents three PPKs from Clark's Branch and a Potomac Creek Pot replica. The three PPKs shown in the IVR-based exhibit were presented in two formats to communicate context as a) as the artifact model and b) the artifact model attached to a tool (e.g., hafted to a knife, spear, and arrow). Three items on the study questionnaires (Question 1, Question 2, and Question 7) sought to identify if study participants better understood contextual information connected to the PPKS and pottery after viewing and interacting with these artifacts' virtual interpretations. These three questionnaire items focused on Bloom's taxonomy's base tier: *remembering*. Participants selected one answer from four choices in a multiple-choice format.

The three artifact context questions querying participants' ability to remember information:

Q1. Broadspears, such as the stemmed Savannah River shown below, are associated with the ___________cultural period.

- Paleoindian (15000-8000 BC)
- Archaic (8000-1200 BC)
- Woodland (1200 BC-1600 AD)
- Don’t Know

Q2. Pottery was introduced to the region during the ______________________ cultural period.

- Paleoindian (15000-8000 BC)
- Archaic (8000-1200 BC)
- Woodland (1200 BC-1600 AD)
- Don’t Know

Q7. Fluted points were likely attached to a _____________________.

- Spear
- Arrow
- Net
- Don’t know

Participants selected one answer from four choices for these questions. The correct choice earned the participant a mark of 100 on the question. Incorrect selections received a mark of 0. Students did not learn on either questionnaire if they had selected correct/incorrect answers to questionnaire items.

For Question 1, participants were asked to place Broadspears in the correct cultural period. In the IVR-based exhibit, two Savannah River Broadspears were shown in the Archaic Period scene, In this scene, one Savannah River Broadspear artifact was presented by itself, and one was hafted to a knife. The correct answer for Question 1 was Archaic (8000-1200 BC).

In the pre-exhibit questionnaire, the average participant score for Question 1 was 12.5 out of a possible 100 points. Post-exhibit, the average participant score increased to 75.00 out of a 100-point scale. The average pre-exhibit participant score for Question 1 from the study's six female participants was 16.67 out of a possible 100 points. Post-exhibit, this average increased to 66.67 on a 100-point scale. The average pre-exhibit score from the two male participants on Question 1 was 0 from a possible 100 points. Post-exhibit, the male average score increased to 100. The pre-exhibit Question 1 average for the Generation Z participants was 16.67 on a 100-point scale. Following the exhibit, this average increased to 83.33. The average score from the Millennial participants on Question 1 was 0 from a possible 100 points. Post-exhibit, this average score increased to 50 on a 100-point scale.

Question 2 asked participants to select the correct period in which ceramic technology was introduced to the region. Pottery was a main feature in the exhibit's Woodland Period scene. A complete Potomac Creek pot model was presented in this scene over a hearth. The correct answer for Question 14 querying when pottery was introduced to the region was the Woodland Period (1200 BC-1600 AD). In the pre-exhibit questionnaire, the average participant score for Question 2 was 12.50 out of possible 100 points. In the post-exhibit, the overall average participant score increased to 62.5 out of a possible 100 points. The average participant score for Question 2 from the study's six female participants was 16.67 out of a possible 100 points. Post-exhibit, the female's average participant score increased to 66.67 on a 100-point scale. The average pre-exhibit score from the male participants for Question 2 was 0 from a possible 100 points. Post-exhibit, the male average score increased to 50 on a 100-point scale. The pre-exhibit Question 2 average for the Generation Z participants was 16.67 on a 100-point scale. Following the exhibit, this average increased to 66.67. The average score from the Millennial participants on Question 2 was 0 from a possible 100 points. Post-exhibit, this average score increased to 50 on a 100-point scale.

Question 7 went beyond placing the artifacts in the correct cultural period and queried the participants' knowledge of the type of tool a fluted point might have been attached to. The average score for Question 7 was 75.00 out of a possible 100 points on the pre-exhibit questionnaire. Post-exhibit, all participants selected the correct answer, receiving 100 points. The average pre-exhibit participant score for Question 7 from the study's six female participants was 83.33 out of a possible 100 points. The average pre-exhibit score from the two male participants on Question 7 was 50 from a possible 100 points. The pre-exhibit Question 7 average for the Generation Z participants was 83.33 on a 100-point scale. The average pre-exhibit score from the Millennial participants on Question 7 was 50 from a possible 100 points.

Overall, the participant's scores on the three questions related to artifact context increased from an average pre-exhibit score of 33.33 to a post-exhibit average score of 79.17 on a 100-point scale. The overall participants' results for these three items are illustrated in Figure 44.

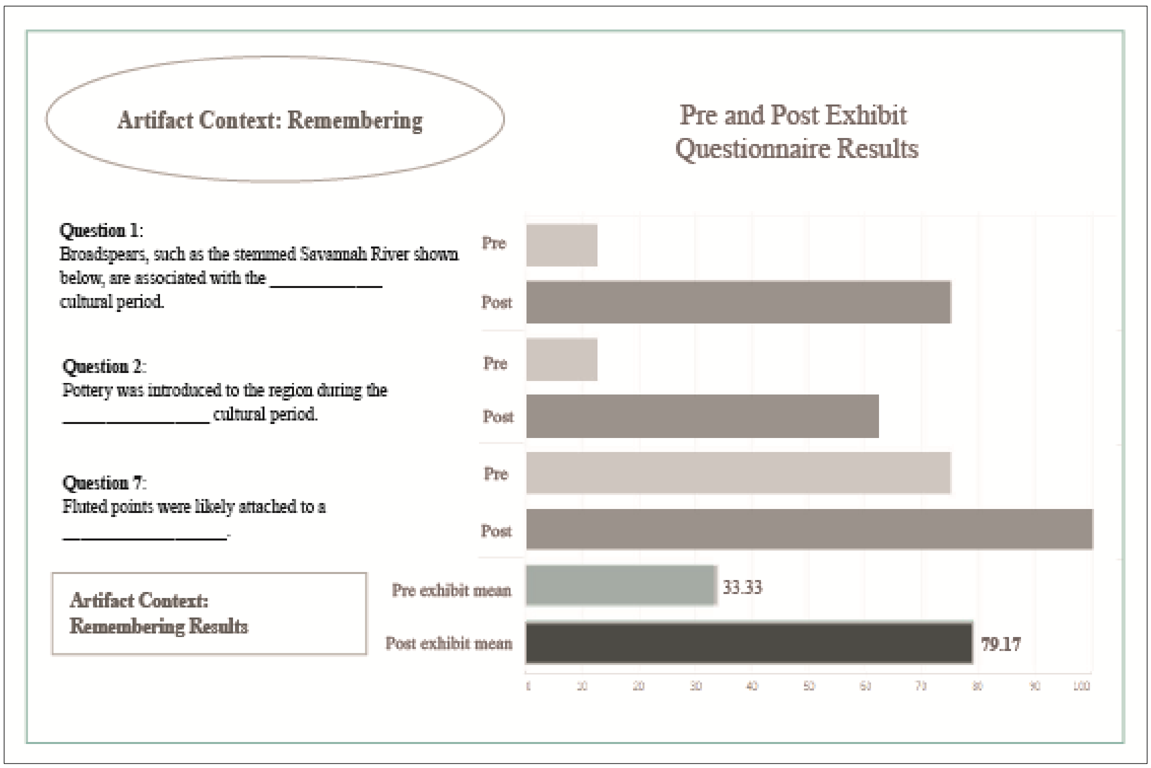


Figure 44 - Questionnaire Results: Artifact context

The average female participant pre-exhibit score on the artifact context questions was 38.89 out of a possible 100 points. Post-exhibit, the female's average participant score increased to 77.78. The average pre-exhibit score from the two male participants was 16.67. Post-exhibit, this average score increased to 83.33. The pre-exhibit average score concerning questions related to artifact context for the Generation Z participants was 38.89 on a 100-point scale. Following the exhibit, this average increased to 83.34. The average score from the Millennial participants increased from 16.67 in the pre-exhibit artifact context average to a post-exhibit average of 66.67 on a 100-point scale. The participant pre-and-post exhibit average scores related to remembering artifact context (Questions 1, 2, and 7) are illustrated in Figure 45.

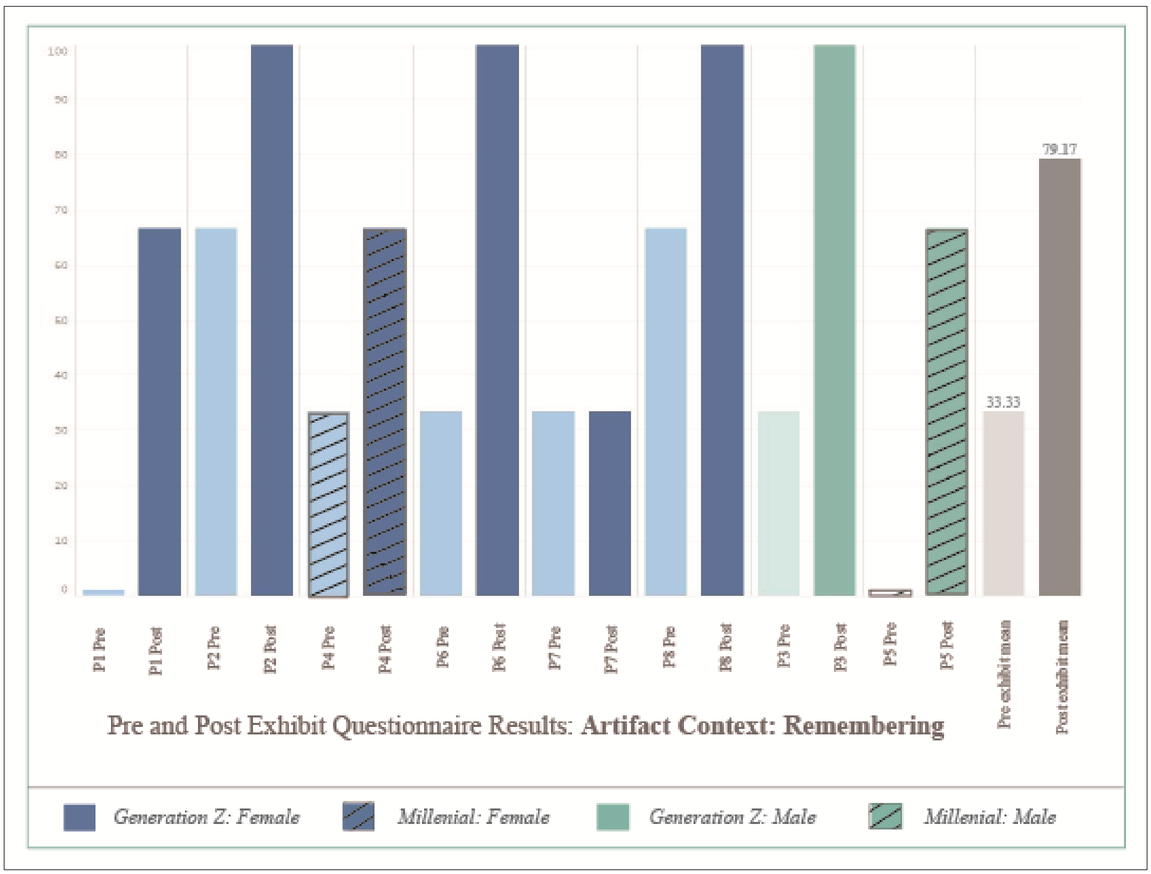


Figure 45 - Questionnaire Results: Artifact context with demographic data

These findings suggest that participants remembered contextual information on artifacts following the IVR-based exhibit. Evaluating if the difference in the pre-and-post questionnaires' scores was statistically significant was not feasible due to the low number of study participants. Additionally, the low number of participants makes it unfeasible to identify significant correlations between the results and demographic information. Future work to determine statistical significance will incorporate further study participants, a paired t-test analysis evaluated in SPSS, and correlation analysis.

Questionnaire Results: Knowledge Acquisition on Spatiotemporal Human-Environment Relationships

Four items on this study's pre-and-post questionnaires assessed if participants experienced learning gains on spatiotemporal human-environment relationships at the Clark's Branch Site. These questions focused on this thesis's third research question:

> RQ3: Will deep map IVR-based exhibits improve users' knowledge of time, space, and human-environment relationships at archaeological sites? Specifically,
>
> a. major environmental shifts during the Paleoindian through Woodland cultural periods and how these impacted indigenous people's subsistence strategies in Northern Virginia, and
>
> b. social and cultural changes in Northern Virginia over time.

Two questions evaluated if participants *remembered* exhibit content related to presented spatiotemporal human-environment relationships. Participants selected one answer from four items. Correct answers received a mark of 100, and incorrect answers received a mark of 0.

Q3. A hunting party in the Paleoindian cultural period likely used ________ to hunt, while a hunting party in the Woodland cultural period likely used bows and arrows.

- Spears with fluted points
- Broadspears
- Guns
- Don’t know

Q4. Corn was an important food source for people living during the ________________ cultural period.

- Paleoindian (15000-8000 BC)
- Archaic (8000-1200 BC)
- Woodland (1200 BC-1600 AD)
- Don’t Know

For Question 3, participants were asked to identify what tool Paleoindian hunters would use compared with Woodland Period hunters. This information was both shown in the IVR-based exhibit and communicated through the exhibit’s narrative. This question asked participants to associate different hunting apparatuses with specific cultural periods. The correct answer for Question 3: Spears with fluted points. In the pre-exhibit questionnaire, the average participant score for Question 3 was 62.5 from a possible 100 points. On the post-exhibit questionnaire, the average score increased to 87.5 on a 100-

point scale. The average pre-exhibit participant score for Question 3 from the study’s six female participants was 66.67 out of a possible 100 points. Post-exhibit, the female's average participant score increased to 83.33 on a 100-point scale. The average pre-exhibit score from the male participants on Question 3 was 50 from a possible 100 points. Post-exhibit, the male participants selected the correct answer and received the full 100 points. The pre-exhibit Question 3 average for the Generation Z participants was 66.67 on a 100-point scale. Following the exhibit, this average increased to 83.33. The average score from the Millennial participants on Question 3 was 50 from a possible 100 points. Post-exhibit, the Millennials correctly answered the question, and the average score increased to 100.

Question 4 asked participants to remember which cultural period the IVR-based exhibit associated with corn. Corn was a main agricultural feature highlighted in the Woodland Period scene and narrative. The correct answer for Question 4 was the Woodland Period (1200 BC- 1600 AD). In the pre-exhibit questionnaire, the average participant score for Question 4 was 50.00 on a 100-point scale. Post-exhibit, all participants selected the correct answer, the average participant score increasing to 100.00 on a 100-point scale. The average pre-exhibit participant score for Question 4 from the study’s six female participants was 66.67 on a 100-point scale. The average pre-exhibit score of the male participants on Question 4 was 50 from a possible 100 points. The average pre-exhibit score on Question 4 for the Generation Z participants was 66.67 on a 100-point scale. The average pre-exhibit score from Millennial participants was 0.

The second two questions on spatiotemporal human-environment relationships evaluated if participants *understood* exhibit materials, the second tier on Bloom's taxonomy. These questions assessed if participants could apply knowledge learned in the exhibit to new situations.

In the Archaic Period scene in the exhibit, acorn models cover the trail, and the narrative describes how nuts and seeds were an important food source for people living during this period. Question 5 queried if participants could connect the Archaic acorns, they had learned about in the narrative to grinding implements like mortar and pestles. The correct answer for Question 5 was Archaic (8000-1200 BC).

Q5. Using mortars and pestles to crush nuts and seeds likely began in this cultural period.

- Paleoindian (15000-8000 BC)
- Archaic (8000-1200 BC)
- Woodland (1200 BC-1600 AD)
- Don't Know

In the pre-exhibit questionnaire, the average participant score for Question 5 was 50.00 from a possible 100 points. On the post-exhibit questionnaire, the average participant score increased to 62.50 on a 100-point scale. The average pre-exhibit participant score for Question 5 from the study's six female participants was 50 out of a possible 100 points. Post-exhibit, the female's average participant score remained the same at 50. The average pre-exhibit score from the male participants on Question 5 was also 50. Post-exhibit, both males selected the correct answer and the average score increased to 100. The pre-exhibit Question 5 average for the Generation Z participants was 50 on a 100-point scale. Following the exhibit, this average increased to 66.67. The average score from the Millennial participants on Question 5 was 50 from a possible 100 points. Post-exhibit, this average remained at 50 out of a 100-point scale.

Question 6 sought to identify if participants understood exhibit content and could apply knowledge to a new scenario. Question 6 introduced participants to new information, the saber-toothed cat, Smilodon. In the exhibit, participants learned about Paleoindian megafauna, like the woolly mammoth. This question sought to evaluate if participants understood megafauna were connected to the Paleoindian Period. The correct answer to Question 6 was Paleoindian (15000-8000 BC).

Q6. Megafauna, such as the saber-toothed cat, Smilodon, could have lived around the site during this period.

- Paleoindian (15000-8000 BC)
- Archaic (8000-1200 BC)
- Woodland (1200 BC-1600 AD)
- Don’t Know

In the pre-exhibit questionnaire, the average participant score for Question 6 was 75.00 on a 100-point scale. In the post-exhibit questionnaire, all participants selected the correct answer and received 100 points for correctly selecting Paleoindian (15000-8000 BC). The average pre-exhibit participant score for Question 6 from the study’s six female participants was 66.67 out of a possible 100 points. The average pre-exhibit score from the male participants on Question 6 was 100 from a possible 100 points. The pre-exhibit Question 6 average for the Generation Z participants was 66.67 on a 100-point scale. The Millennial participants both selected the correct answer for Question 6 on the pre-exhibit questionnaire, with an average score of 100.

Overall, the participants' scores on the four questions related to spatiotemporal human-environment relationships improved in the remembering and understanding tiers of Bloom's taxonomy. For questions evaluating the remembering tier, the pre-exhibit average score improved from 56.25 to a post-exhibit average score of 93.75 on a 100-point scale. In the understanding tier, scores improved from a pre-exhibit average questionnaire score of 62.5 to a post-exhibit average score of 81.25 on a 100-point scale. Overall, participants' knowledge of the spatiotemporal human-environment relationship increased from a pre-exhibit average score of 59.38 to a post-exhibit average score of 87.5 on a 100-point scale. These results are illustrated in Figure 46. These findings suggest that overall, participants' knowledge of regional pre-Contact spatiotemporal human-environment relationships improved following the IVR-based exhibit.

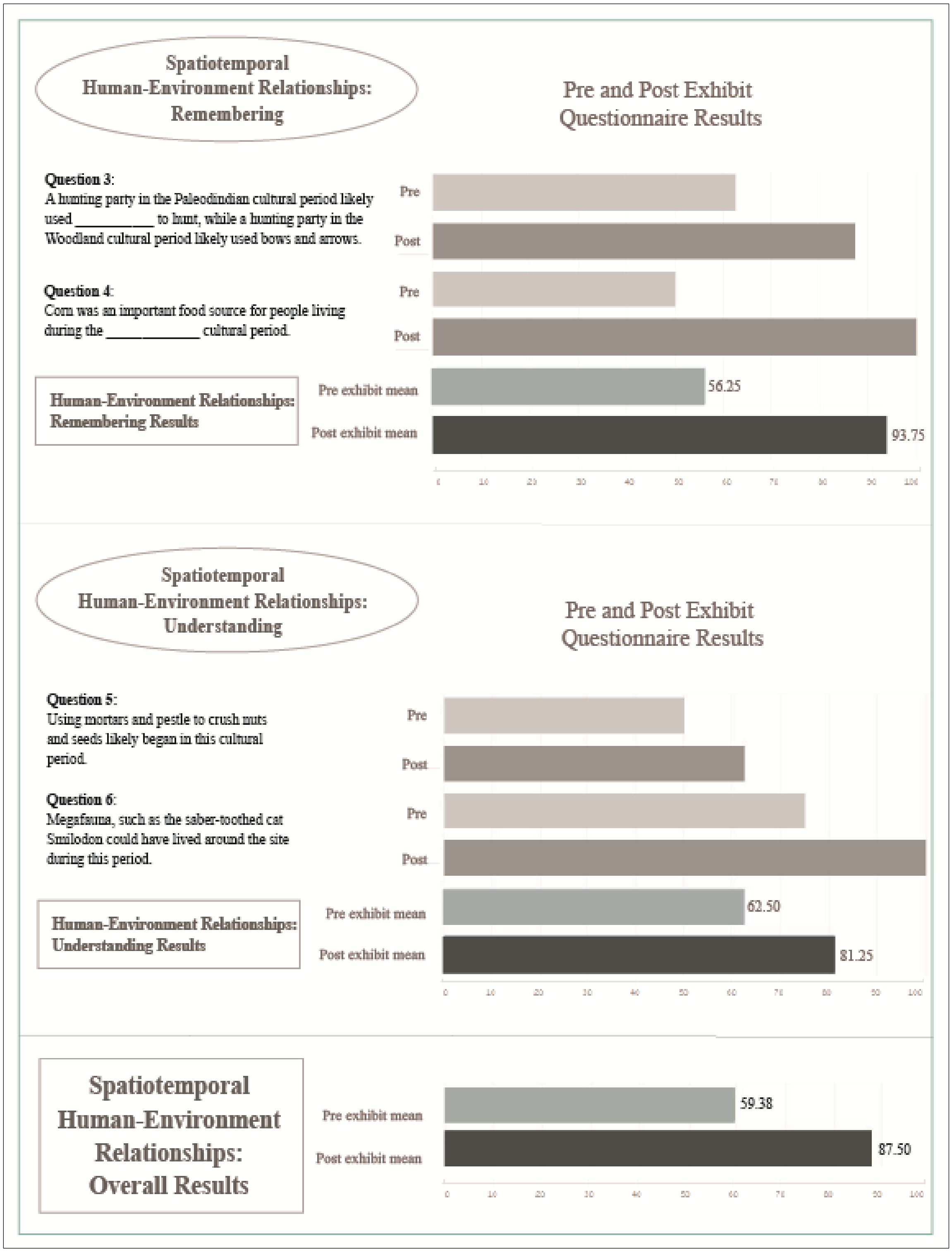


Figure 46 - Questionnaire Results: Spatiotemporal human-environment relationships

The average pre-exhibit score on the spatiotemporal human-environment relationship questions from the study’s six female participants was 62.51 out of a possible 100 points. Post-exhibit, the female's average participant score increased to 83.33. The average pre-exhibit score from the two male participants was 62.5. Post-exhibit, this average score increased to 100. The pre-exhibit average score concerning questions related to artifact context for the Generation Z participants was 62.51 on a 100-point scale. Following the exhibit, this average increased to 87.50. The average score from the Millennial participants increased from 50 in the pre-exhibit average, to a post-exhibit average of 87.50 on a 100-point scale. The participants’ individual pre-and-post exhibit average scores related to spatiotemporal human-environment relationship questions are illustrated in Figure 47.

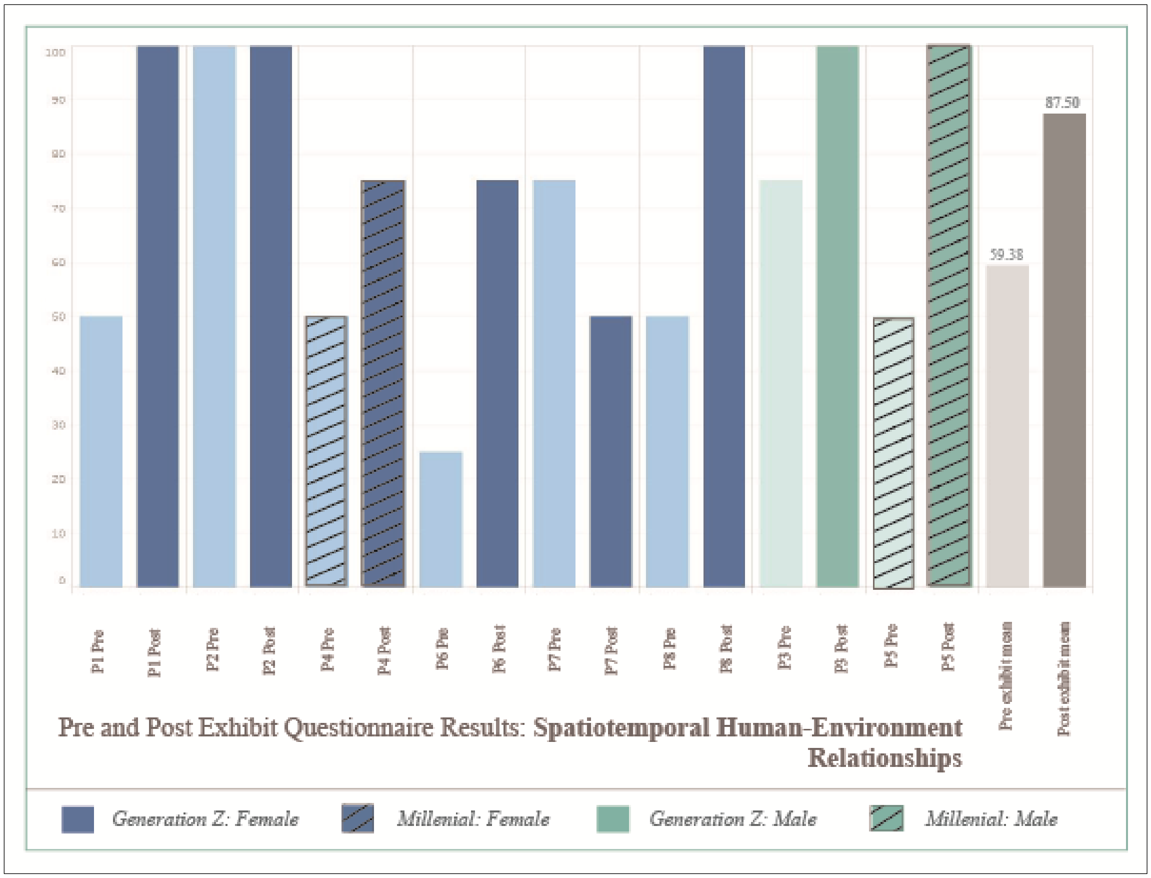


Figure 47 - Questionnaire Results: Spatiotemporal human-environment relationships with demographic data

Evaluating if the difference in the pre-and-post- exhibit questionnaires scores was statistically significant was not feasible due to the low number of study participants. Analyzing relationships between demographic data and study findings is also unfeasible due to this low number. Future work to determine statistical significance will incorporate a paired t-test analysis, evaluated in SPSS, and correlation analysis.

Questions one-seven on the pre-and-post questionnaires assessed participant learning gains following the IVR-based exhibit. Study results suggest that each participant experienced learning gains on the subject matter following the IVR experience. The average participant score increased from a pre-exhibit average of 48.21 to a post-exhibit average of 75 on a 100-point scale (Figure 48). Figure 49 illustrates the individual participant's pre-and-post questionnaire results.

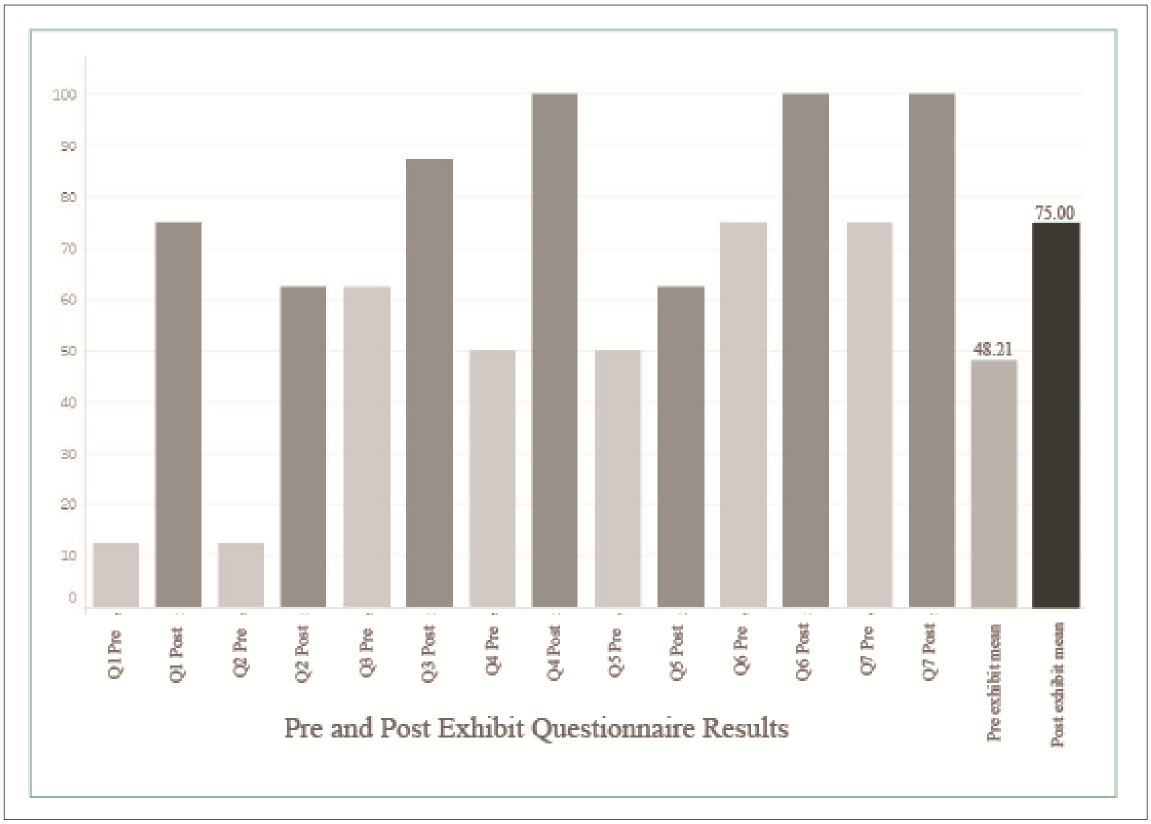


Figure 48 - Questionnaire Results: Questions 1-7 average participant results

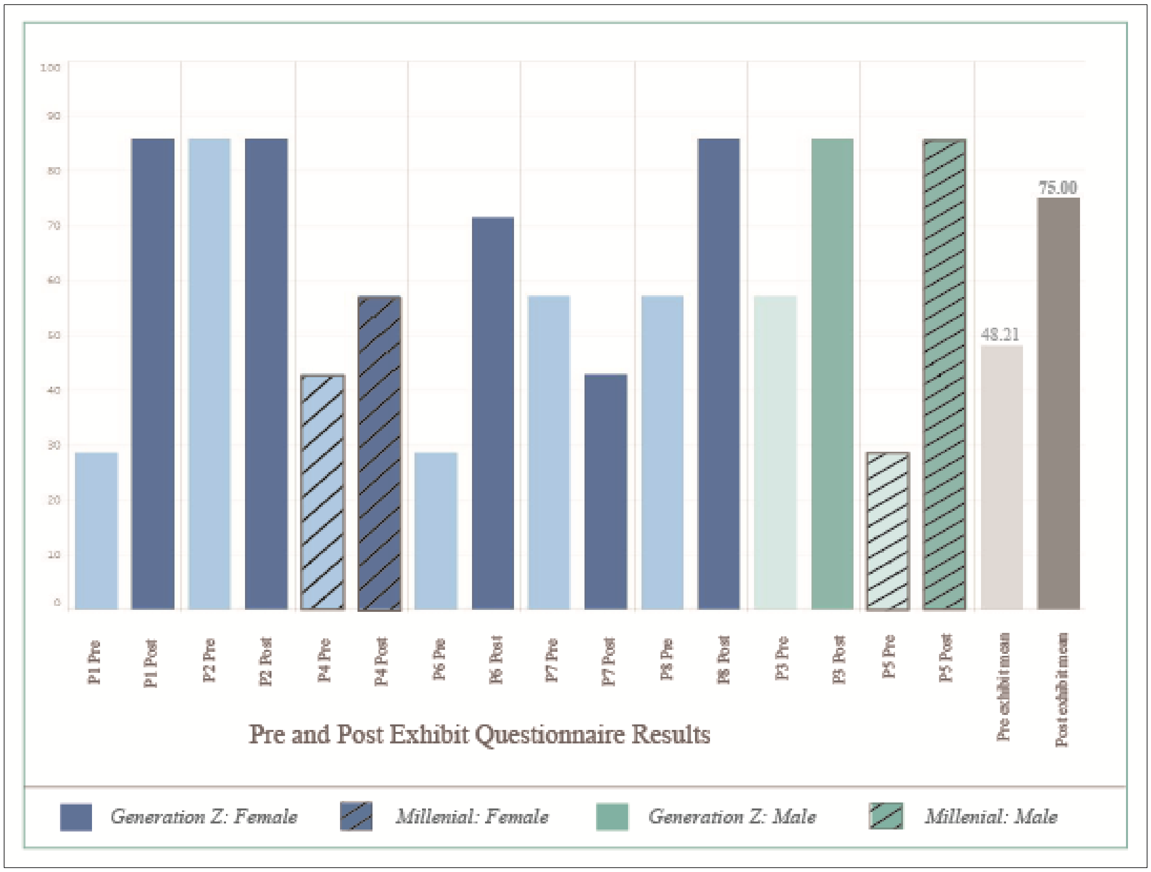


Figure 49 - Questionnaire Results: Overall participant results

Questionnaire Results - Sense of Presence

Four questions were included in this study's post-IVR questionnaire to evaluate if users experienced a sense of presence in the exhibit. These questions were included to address the fourth research question investigated in this research:

> RQ4: Will users experience a sense of presence in the IVR-based exhibit? If experienced, is a sense of place related to users' learning achievements?

These four questions were modeled after questions from Witmer and Singer's (1998) presence questionnaire and addressed four presence factors: control, distraction, sensory, and realism. Igroup Presence Questionnaire (IPQ 2016) items were also considered when structuring the post-exhibit questionnaire. For each question, participants chose a selection on a Likert scale. The Likert scale questions were assigned a specific weight in SPSS. For Questions 8, 10, and 12 the weights were ordered as follows: *Strongly disagree* = 1, *Disagree*= 2, *Neutra*l = 3, *Agree* = 4 and *Strongly agree* = 5. These questions assessed control, sensory, and realism presence factors. For Question 11, these weights were reversed, with *Strongly agree* = 1, *Agree* = 2, *Neutral* = 3, *Disagree* = 4, and *Strongly disagree* = 5. Question 11 evaluated the perception of real-world distractions experienced by the participant.

Questions to assess participants' sense of presence in the IVR exhibit on the post-IVR questionnaire:

Question 8. I felt as if I was controlling the virtual experience from inside the space (IPQ 2016; Witmer and Singer 1998: Sense of Presence Control Factor)

Question 10. I felt a sense of being in the virtual environment (IPQ 2016: Sense of Presence Sensory Factor)

Question 11. I was aware of real-world events occurring around me (Witmer and Singer 1998: Sense of Presence Distraction Factor)

Question 12. The virtual environment seemed real (IPQ 2016: Sense of Presence Realism Factor)

Out of the four sense of presence factors investigated in this research, participants perceived the sensory factor the most, with a weight of 4.25 between *Agree* and *Strongly agree*. The average weight for Question 10, evaluating the sensory factor for the six female participants was 4.17 between *Agree* and *Strongly agree.* The average weight from the two male participants was 4.5, between *Agree* and *Strongly agree*. The average weight for Question 10 from the six Generation Z participants was 4.33, between *Agree* and *Strongly agree.* The two Millennial participants both agreed they felt a sense of being in the virtual environment with an average weight of 4.

The average participant weight for the control factor, evaluated in Question 8, was 4.13, between *Agree* and *Strongly agree*, indicating participants felt they were in control of their actions in the exhibit. The average weight for Question 8, from the six female participants, was 4.17 between *Agree* and *Strongly agree.* The average weight from the two male participants was 4 (*Agree*). The average weight for Question 8 from the six Generation Z participants was 4.5, between *Agree* and *Strongly agree.* The two Millennial participants both selected Neutral for Question 8 with a weight of 3.

On ranking the level of distraction experienced, the participant average was 3.38, between *Neutral* and *Disagree.* The participants' distraction level was evaluated in Question 11 and assessed how much the participants noticed the real-world activities outside the exhibit. The average weight for Question 11, evaluating the distraction factor from the six female participants was 4 (*Disagree*). The average weight from the two male participants was 1.5, between *Agree* and *Strongly agree*. The average weight for Question 11 from the six Generation Z participants was 3.66, between *Neutral* and *Disagree.* The average weight for this question from the two Millennial participants was 2.5, between *Agree* and *Neutral*.

Participants ranked the exhibit's level of realism at 3.25, between *Neutral* and *Agree*. The average weight for Question 12, evaluating the female participants' assessment of how real the exhibit seemed was 3.17 between *Neutral* and *Agree.* The average weight from the two male participants was 3.5, between *Neutral* and *Agree*. The average weight for Question 12 from the six Generation Z participants was 3.5, midway between *Neutral* and *Agree.* The two Millennial participants' average weight for Question 12 was 2.5, between *Disagree* and *Neutral*. The results of the four presence questions assessed in this study are illustrated in Figure 50.

The average participant scores of the four sense-of-presence factors were combined to assess the users' average overall sense of presence. The average weight for the users' perceived sense of presence in the exhibit was 3.75, between *Neutral* and *Agree*. The average weight of presence experienced by female participants was 3.88 between *Neutral* and *Agree*. The average weight of presence experienced by the study's male participants was 3.38, also between *Neutral* and *Agree*. Generation Z participant's average weight for presence was 3.99, between *Neutral* and *Agree.* The average weight of presence experienced by the study's Millennial participants was 3 (*Neutral*).

Figure 50 - Questionnaire Results: Sense of presence

Overall, these results suggest users did experience sense of presence factors in the IVR-based exhibit. The second part of Research Question 4 sought to identify a relationship between a sense of presence and learning gains. The low number of data impacted the ability to sufficiently complete this test. Additionally, the low number of participants made it unfeasible to identify relationships between demographic information and study findings. Correlation analysis will be conducted in future work to assess potential relationships in questionnaire results.

Questionnaire Results - Place Attachment

The final research question investigated in this thesis examined place attachment. This question evaluated if users experienced place attachment following the immersive exhibit. Additionally, this study examined if place attachment is related to the study participants' desire to visit the park in the future.

RQ5: Will users experience place attachment towards Riverbend Park following the IVR-based exhibit? If experienced, is place attachment related to users' interest in visiting the park?

Two questions were included in the post-exhibit questionnaire to evaluate if users experienced place attachment. These questions were developed from William's (2000) place attachment scale. A five-item Likert scale was used to gauge participant's responses from *Strongly disagree* to *Strongly agree.*

Q16. I feel that Riverbend Park is a part of who I am (Williams 2000 Place Attachment)

Q18. I feel attached to Riverbend Park (Williams 2000 Place Attachment)

For these two questions, participants chose a selection on the Likert scale. The Likert scale questions were assigned a specific weight in SPSS. Question 16 and 17 weights were assigned as follows: *Strongly disagree* = 1, *Disagree*= 2, *Neutra*l = 3, *Agree* = 4, and *Strongly agree* = 5.

Question 16 asked participants if they felt Riverbend was a part of who they were. The participant average for this place attachment question was 2 (*Disagree*). The average score for Question 16 across all four demographic groups examined in this study (i.e., Generation Z Females, Generation Z Males, Millennial Females, and Millennial Males) was 2 (*Disagree*).

Question 18 inquired if participants felt attached to Riverbend. The average answer for this question was 2.63, between *Disagree* and *Neutral*. The average weight for Question 18, from the six female participants, was 2.5 between *Disagree* and *Neutral.* The average weight from the two male participants was 3 (*Neutral*). The average weight for the six Generation Z participants was 2.67, between *Disagree* and *Neutral.* The average weight for Question 18 from the two Millennial participants was 2.5, between *Disagree* and *Neutral.*

Overall, the average place attachment experienced by participants was 2.32, between *Disagree* and *Neutral*. The average place attachment score for females was 2.25. The male's average place attachment score was 2.5. The average for Generation Z participants concerning their level of place attachment was 2.34, and for Millennials, it was 2.25. These results suggest that, overall, the students did not feel an attachment to Riverbend Park.

The place-attachment questions were part of the original study, which ran at Riverbend Park. Question 15 queried how many times visitors had frequented the park, with the number of visits starting at 1. Only one participant (Participant 7) had been to the park. This participant had also only visited once.

Q15. How many times have you visited Riverbend Park?

- I have never visited Riverbend Park
- 1-3 visits a year
- 4-10 visits a year
- More than 10 visits a year

When the study shifted to George Mason University, Question 15 was altered to reflect that participants may have never visited Riverbend. Question 15 queried how many trips to Riverbend participants had completed. The results of Questions 15, 16, and 18 are illustrated in Figure 51.

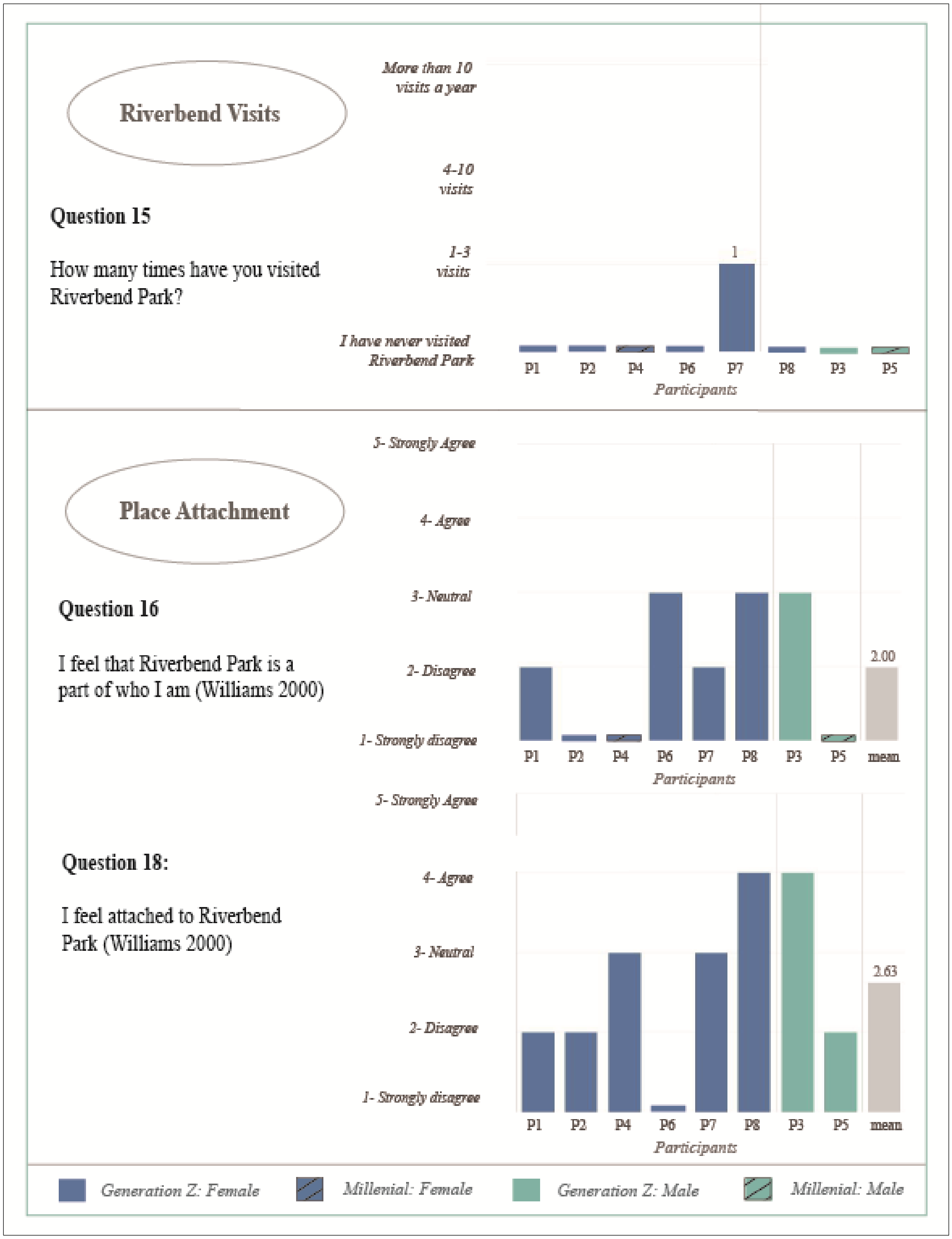


Figure 51 - Questionnaire Results: Place attachment

An additional question was included to assess if participants who had not visited the park were interested in visiting following their IVR experience. A five-item Likert scale was used to gauge participant's responses from *Strongly disagree* to *Strongly agree*. Weights for answers to this question were assigned as follows in SPSS: *Strongly disagree* = 1, *Disagree*= 2, *Neutra*l = 3, *Agree* = 4 and *Strongly agree* = 5.

Q17. Are you interested in visiting Riverbend Park after completing this virtual experience (answer Not Applicable if you have already visited Riverbend Park)?

Only one participant, a Generation Z female, had visited Riverbend before completing the study, and this participant (Participant 7) answered not applicable on the following question inquiring if participants wanted to visit following the IVR experience. Overall, the average participant score for Question 17 was 4.75, between *Agree* and *Strongly Agree*. The average weight for Question 17 querying a desire to visit the park from five female participants was 4.8 between *Agree* and *Strongly agree.* The average weight from the two male participants was 4 (*Agree*). The average weight of the Generation Z participants was 4 (*Agree).* The average weight for Question 17 from the two Millennial participants was 5, indicating they had a strong interest in visiting Riverbend after completing the exhibit. These results are illustrated in Figure 52.

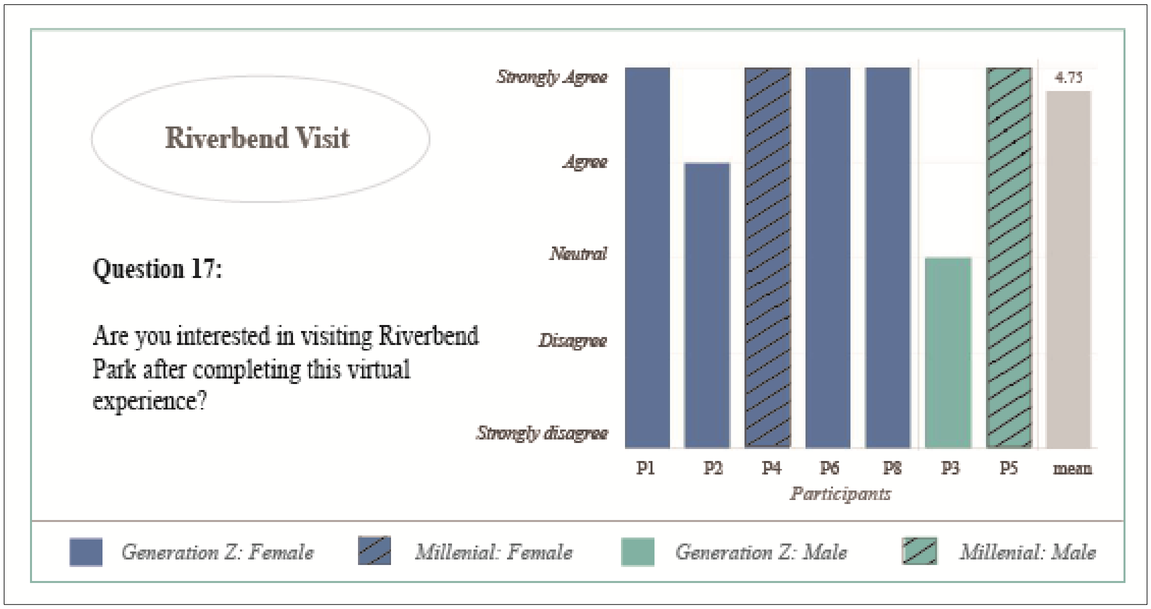


Figure 52 - Questionnaire Results: Study participant level of interest in visiting Riverbend Park

Overall, the results of this study suggest that participants did not experience high levels of place attachment to Riverbend from the IVR-based exhibit. However, these initial results show that low attachment to the park did not impact users' interest in visiting Riverbend in the future. Participants did want to visit the park after the study, implying that the exhibit piqued their interest in Riverbend and connecting further with the park in person. Future research with higher numbers and a more diverse group of participants, will investigate relationships between demographics, place attachment, and park visitation.

CHAPTER SIX - SUMMARY AND CONCLUSIONS

This research produced an IVR-based deep map exhibit highlighting spatiotemporal human-environment relationships at Virginia's Clark's Branch archaeological site. This exhibit's primary purpose was to present different, multidimensional data layers to educate exhibit users on this site's temporal, environmental, and cultural evolution. Traditional museum exhibits focus on specific events, people, or objects and often neglect to show the wide range of information connected to historically significant places. Diverse, Digital-Age audiences require more from their museum experiences, requesting personal, interactive, technology-based exhibits. The Clark's Branch IVR-based exhibit provides users with an interactive and immersive holistic experience encouraging users to explore sites from inquiry-based, embodied approaches. This exhibit's deep mapping framework links layers of data and presents users with a more comprehensive and inclusive view of archaeological sites and history.

The Clark's Branch IVR-based exhibit was tested on GMU Geography students to evaluate the user experience and assess if the exhibit improved users' knowledge of contextual information related to artifacts and regional changes over time. Additionally, this work evaluated if exhibit users experienced a sense of presence and, if experienced, if this sense of presence was related to users' knowledge acquisition. Exhibit users' place attachment to Riverbend Park was also investigated to identify if place attachment is related to the users' interest in visiting the site. Five research questions helped guide these investigations.

GMU students completed pre-and-post exhibit questionnaires assessing the students' knowledge of artifacts and regional changes in pre-Contact Virginia. The results of these questionnaires were analyzed to address this study's research questions. Additionally, members of the FCPA ACB, a specialized group of archaeologists, participated in a focused group discussion, answering a series of questions on the exhibit to identify their overall user experience and opinions towards IVR-based exhibits as educational tools.

User Experience - Research Question 1

Assessing exhibit users' overall user experience and sentiment towards educational IVR-based exhibits was a primary research focus in this study. Research Question 1 focused on identifying the users' experience, evaluating if users were a) receptive towards IVR-based educational tools and b) felt the IVR-based exhibit improved their knowledge of the multidimensional character of archaeological sites.

Are users receptive to IVR-based educational tools?

Focus Group Discussion - ACB Archaeologists

The ACB archaeologists responded positively to the IVR-based exhibit and indicated they felt the experience was an excellent approach to engaging with the public. This group continually noted the difficulties in explaining changes over time at sites, particularly environmental and climatic shifts. Overall, they believed the immersive exhibit offered a solution to showing spatiotemporal environmental and cultural site information that improved on traditional outreach tactics (e.g., displaying aerial images or copies of primary documents). The archaeologists felt that the IVR system's embodied experience offered a holistic perspective and inquiry-based learning approach to exploring the site, one that would appeal to the public audiences. Additionally, the group agreed that seeing the different temporal, environmental, and cultural data layers helped them build a comprehensive idea of the site over different periods.

The experience sparked the archaeologists' imaginations, and the group envisioned what other sites might look like in an immersive deep map. Though the group felt the novel, embodied experience was the main feature the public would enjoy, the core of the focus-group conversation centered on the immersive deep map framework. The ACB archaeologists mentioned several sites that would benefit from highlighting different spatiotemporal changes and remarked that the deep mapping framework could expand to encompass data from other disciplines. The archaeologists recognized that the framework could serve as a cohesive container for different scientific data, presented in an engaging, holistic format appealing to scientists and non-specialists.

GMU Student Participants

The GMU student user experience was also addressed in this research. One question on the post-exhibit questionnaire focused specifically on assessing the overall user experience. On a ranked Likert scale (Strongly Disagree=1 to Strongly Agree=5), most users selected that they strongly agreed they enjoyed the exhibit with a user average of 4.88 (between Agree and Strongly Agree). The study's male participants and all but one female participant selected that they strongly agreed they enjoyed the experience.

One Generation Z female participant selected that they agreed they enjoyed the exhibit. This positive sentiment aligns with other IVR studies' findings querying user experience in immersive educational environments (Carrozzino and Bergamsco 2010). It could be that positive reactions to the IVR experience are related to these exhibits' novel nature. Though these systems are becoming more financially feasible, IVR-based exhibits are still rare in museums.

Do users feel the IVR-based exhibit enhanced their understanding of the multidimensional nature of archaeological sites?

Focus Group Findings

The ACB archaeologists indicated they believed the IVR-based exhibit improved their knowledge of temporal, environmental, and cultural layers at Clark’s Branch. Several participants mentioned that the presentation of the different periods helped them better grasp the greater picture of cultural landscape evolution. The sensory immersion dominated the focus group discussion and was noted as a key factor in enhancing the learning experience. Participants felt the immersive, interactive elements (e.g., walking across the terrain and picking up the artifacts) offered a more natural way to engage with archaeological information.

Additionally, the archaeologists highlighted the portals as important exhibit components for improving their knowledge of period-specific environmental and cultural features. They noted that the portals’ clear separation of time and ideas helped to organize the different layers of complex information. Also, several participants commented on the portals as contributors to the overall sense of presence. One participant noted that when they stepped through the portals, they experienced the sense of presence experienced at the beginning of the exhibit all over again. Another participant expressed this feeling as well, noting they felt as if they had entered a new environment when they moved through a new exhibit portal. This finding suggests that portals may be an important game component in accessing a deeper sense of presence for the user; this topic should be explored in future research.

Student Participant Findings

Two questions queried if the study's student participants believed the exhibit's deep map framework contributed to their understanding of regional spatiotemporal human-environmental relationships. On a ranked Likert scale (Strongly Disagree =1 to Strongly Agree=5), users fell midway between Agree and Strongly Agree (average score of 4.5) that the IVR-based exhibit enhanced their understanding of these relationships. The averages for male and female participants were both 4.5 for this question. Generation Z students' average rank was 4.67 and the Millennials' average rank was 4.

Students also indicated the exhibit improved their ability to associate different environmental and cultural features with specific cultural periods. On a ranked Likert scale (Strongly Disagree =1 to Strongly Agree=5) users agreed that the immersive experience improved their ability to place information with the correct cultural period, with an average rating of 4 (Agree). The female participants ranked their perceived ability to place information with specific cultural periods lower, at 3.83, than the study's male participants who agreed they felt they could place information with an average score of 4.5. Both Generation Z and Millennials had an average score of 4 for this question.

These findings suggest that though student participants agreed they had learned about different spatiotemporal environmental and cultural information, they were less confident they could correctly place what they had learned into content. Though no statistical significance can be identified from analyzing the demographic information, males were more confident than females they could correctly associate information with temporal periods. This finding aligns with research focused on confidence discrepancies between genders (Sarsons and Xu 2015).

Knowledge Acquisition - Research Questions 2 and 3

To test if students could correctly place information into cultural context and evaluate if participants learned about other exhibited subject matter, participants completed pre-and-post-exhibit questionnaires. Results of these questionnaires were compared to determine if a significant difference existed between pre-and-post questionnaire item answers.

Two research questions guided these investigations. Research Question 2 assessed if users better understood contextual information related to artifacts following the immersive exhibit. Research Question 3 evaluated if users better understood complex spatiotemporal human-environment relationships after the immersive experience. Seven questions on the pre-and-post-exhibit questionnaires tested the users' knowledge of artifact context and regional spatiotemporal human-environment relationships.

Artifact Context - Research Question 2

Museums typically pedestal artifacts behind glass displays, and the public has limited interaction with these materials. This thesis sought to identify if reattaching artifacts with contextual information through virtual interactive interpretations could better interpret these materials for public audiences. This study's second research question assessed whether a significant difference existed between users' artifact context knowledge before and after completing the IVR-based exhibit. Two questionnaire items evaluated the users' ability to place artifacts with the associated cultural period. One questionnaire item assessed the users' ability to connect an artifact to associated hunting apparatus. These three questions evaluated if users were able to remember artifact context information presented in the exhibit.

The findings of this study suggest user knowledge on artifact context improved following the IVR-based exhibit. The users' ability to place broadspears in the Archaic Period improved an average of 62.5 points, increasing from an average pre-exhibit score of 12.5 to a post-exhibit score of 75 on a 100-point scale. The users' ability to place pottery correctly in the Woodland Period also improved, increasing 62.5 points, from an average pre-exhibit score of 12.5 to a post-exhibit average score of 75 out of a 100-point scale.

The questionnaires also assessed the users' ability to connect artifacts to associated hunting apparatus. One question asked users to select the correct hunting implement for a fluted PPK. The average pre-exhibit score for connecting the fluted PPK to a spear was 75 points. After the exhibit, all participants associated the fluted PPK to a spear, achieving 100 out of a 100-point scale.

Overall, the users' ability to remember contextual information related to exhibited artifacts increased by 45.84 points. The average pre-exhibit artifact context score of 33.33 increased to an average post-exhibit artifact context score of 79.17. On these questions, female participants' scores increased an average of 38.9 points, and the male participant scores increased an average of 50 points. The Generation Z average scores increased 44.45 points, and Millennial average scores increased 33.33 points. Though statistical significance cannot be proved due to limited study participants, these findings suggest the IVR-based exhibit improved all users' understanding of the artifacts' contextual information.

Riverbend's museum displays broadspears, fluted PPKs, and pottery, but museum visitors cannot interact with these materials. In the IVR-based exhibit, users were encouraged to pick up the artifacts and visualize them in an appropriate period and use context. Also, presenting interpretations of the implements associated with the artifacts (e.g., spear connected to fluted PPK) helps users visualize how artifacts were used. Attaching artifacts to associated tools in virtual interpretations reconnects artifacts with their human component. Permitting audiences to physically connect (even in a virtual space) with artifacts is a way to emphasize connections between past peoples and contemporary museum visitors. Virtual interpretation helps users build a deeper knowledge of artifactual information, and the immersive component enhances this interpretation through interactive and personal experiences with artifacts.

Spatiotemporal Human-Environment Relationships - Research Question 3

This research also evaluated if users' learning gains on spatiotemporal human-environment relationships improved following the IVR-based exhibit. Research Question 3 assessed if the IVR -based exhibit improved users' knowledge of a) major environmental shifts and b) sociocultural changes over pre-Contact cultural periods in Northern Virginia.

Major Environmental Shifts

Two questions queried users' abilities to remember and understand environmental shifts. Question 4 assessed exhibit users' knowledge of the introduction of corn and shift from foraging to farming, a major Woodland Period hallmark. Users' ability to connect corn to the Woodland Period improved 50 points following the IVR-based exhibit from a pre-exhibit average score of 50 to a post-exhibit score of 100 on a 100-point scale.

The second environment-focused question queried the users' understanding of exhibited content. This question introduced new information to assess if users could apply what they learned in the exhibit to a new scenario. Users were asked to place unexhibited megafauna, the Smilodon, in the correct cultural period. The users' ability to place the Smilodon in the correct cultural period improved 25 points, from a pre-exhibit score of 75 to a post-exhibit score of 100.

Sociocultural Changes

Two items were included on the questionnaires to evaluate users' abilities to remember and understand exhibited regional sociocultural shifts. Participants were asked to recall the tool type a Paleoindian hunter would use compared with Woodland hunters' bows and arrows. Following the IVR-based exhibit, all users could associate spears with the Paleoindian Period. The users' ability to remember the Paleoindian spear improved by 37.5 points, the average pre-exhibit score increasing from 62.5 to 100 points on a 100-point scale.

Study participants were also asked to place unexhibited mortars and pestles into the associated cultural period to assess the users' association of nuts with the Archaic Period. The users' ability to connect the Archaic Period's displayed nuts with the new information, the mortar and pestle, improved by 12.5 points following the IVR-based exhibit from an average pre-exhibit score of 50 to a post-exhibit average score of 62.5 out of 100 on a 100-point scale.

Overall, this study's results indicate users' experienced learning gains on spatiotemporal human-environment relationships at pre-Contact Clark's Branch by 28.12 points. Participants' scores increased from an average pre-exhibit score of 59.38 to an average post exhibit score of 87.5 on a 100-point scale. The average female participant score increase following the exhibit was 29.17 points. Male participants' average scores increased by 37.5 points. Generation Z participants' average scores increased by 29.17 points, and Millennials' average scores increased by 37.5 points.

The findings on users' knowledge acquisition concerning spatiotemporal human-environmental relationships suggest that the IVR-based exhibit improved all users' ability to remember and understand these complex layers of information. It is difficult for traditional museum displays to display multifaceted data connected to archaeological sites in a cohesive application. Often, the environmental information is omitted in site presentation, or visitors are asked to rely on their imaginations to fill in the gaps. The Clark’s Branch IVR-based exhibit's deep mapping framework connects the environmental information with temporal data, artifacts, and lifeways interpretations. These different elements are all displayed in Riverbend's museum, but they are scattered around the museum space. Though statistical significance cannot be proved due to limited study participants, this study’s findings suggest that deep mapping immersive exhibits can improve users’ learning achievements on the complex, multidimensional layers of archaeological sites.

Sense of Presence - Research Question 4

This research also investigated sense of presence, defined in this thesis as the sensation of being in a different space. Sense of presence is a phenomenon sometimes experienced in immersive environments. This study’s fourth research question evaluated if a) users experienced sense of presence and b) if experienced, if sense of presence was related to users’ learning achievements. Participants were asked four questions following the IVR-based exhibit to assess their sense of presence. Following Witmer and Singer's (1998) and IPQ’s (2016) presence questionnaires, four questions assessing presence were added to the post-exhibit questionnaire. The four questions evaluated the user’s perception of four presence factors: control, realism, distraction, and sensory.

For the questions on their perception of these factors, users selected one answer on a weighted five-item Likert scale from Strongly disagree = 1 to Strongly agree = 5. Of the four factors, the average realism factor was 3.25, between Neutral and Agree. The average control factor rank was 4.13, between Agree and Strongly agree. For believing they were “in” the virtual environment (sensory factor), the user average rank was between Agree and Strongly Agree with an average rank of 4.25. The average rank for the distraction factor was 3.38, between Neutral and Disagree.

The results of the four sense of presence factors were combined to assess the users’ overall sense of presence. The average weight for the users’ perceived sense of presence was 3.75. This average places the users between Neutral and Agree, closer to agreeing on questions querying sense of presence factors.

The study’s female participants' sense of presence average rank was 3.88 between *Neutral* and *Agree*. The male participants' average rank was 3.38, also between *Neutral* and *Agree*. Generation Z participants’ average presence rank was 3.99, and Millennial participants’ presence rank was 3.

The realism and distraction factors negatively impacted the users’ overall sense of presence. The question on realism asked participants if they believed the virtual environment was real. Though much of the exhibit data was created using real-world information (e.g., artifact scans, images of plants, and elevation models), the exhibit content still looked like a game environment. Future research could evaluate if the environment needs to closely mirror real-world spaces, like the visuals a 360-degree video would offer, to achieve a higher sense of presence. This question also could be altered to reflect if users believed that they were real in the space. What defines “realness” and how to achieve this in an IVE could be an important future focus in sense of presence studies.

The distraction factor also impacted the users' sense of presence in this study. In the closed study environment at GMU, the environment was already less distracting than conventional museum settings and certainly less distracting than Riverbend Park. No other people were in the study's office space. The only other person nearby was the researcher in another closed office in a separate section of the corridor. The primary real-world distraction factor was the researcher, observing the study from an iPad situated on a wall behind the participant. The male participants in this study indicated they were more aware of real-world distractions than the female participants. It is unfeasible to identify a significant connection between gender and distraction levels in this study due to low participation, but future research could investigate relationships between gender and the ability to block out distractions in IVR systems.

Even though findings indicated that distractions impacted users' presence in this study, the study's sense of presence assessment suggests users experienced heightened presence factors (particularly sensory and control) in the exhibit. It is unfeasible to address if this sense of presence is correlated to learning achievements due to the limited number of study participants. Future research into this topic could be conducted to investigate if this potential relationship.

Future work could also examine if a specific sense of presence factor (i.e., distraction, sensory, realism, and control) impacts learning gains over another. Museums interested in installing IVR-based exhibits may not have quiet, private rooms to completely block out real-world distractions, but perhaps users do not need to be separated entirely from the real world to be invested in the virtual space. A primary benefit of immersive exhibits is removing the user from the real world. Still, full cognizant separation from reality may not be possible, and also, the user might not want to feel completely removed from the real world. Institutions interested in using immersive technologies should consider some of these factors when developing and implementing IVR-based experiences.

Place Attachment - Research Question 5

The last concept investigated in this research was place attachment, a contributing factor to the sense-of-place concept. The place attachment factor in the sense-of-place construct is of central interest to park managers, as this concept is connected to park visitors' interest in park protection and preservation. The place attachment factor was examined in this research, investigating if the IVR-based exhibit contributed to users' place attachment and, if so, whether place attachment is related to an interest in visiting Riverbend Park.

Two questions on the post-exhibit questionnaire assessed the users' level of place attachment to the park. These questions were created following William's (2000) place attachment questionnaire. For these place-attachment questions, users selected one answer on a weighted five-item Likert scale from Strongly disagree = 1 to Strongly agree = 5. The participant average was 2 (*Disagree*) for the place attachment question evaluating if they felt Riverbend was a part of who they were. Participants were also asked if they felt attached to Riverbend. The average for this question was 2.63, between *Disagree* and *Neutral*.

Overall, the average place attachment experienced by participants was 2.32, between *Disagree* and *Neutral*. The female participants' average place attachment rank of 2.25, and the male participants' average place attachment rank was 2.5. The average place attachment rank for Generation Z participants was 2.34, and for Millennials, it was 2.25. These findings suggest that, overall, the students did not feel an attachment to Riverbend Park

The second part of Research Question 5 evaluated if the users' place attachment to the park was related to an interest in visiting the park. A statistical correlation analysis between place attachment and interest to visit Riverbend was not possible due to the limited number of study participants. The available data suggests that though participant placement attachment was low, the students showed an interest in visiting the park. All participants who had not visited the park (seven out of eight users) ranked their level of interest in visiting on the post-exhibit questionnaire. Users selected their level of interest on a weighted five-item Likert scale (Strongly disagree = 1 to Strongly agree = 5). The average for this question was 4.75, between Agree and Strongly Agree, indicating student participants were interested in visiting Riverbend

The results of this study imply that users did not experience place attachment in the IVR-based exhibit. However, users that had never been to the park indicated an interest in visiting the park after the study. These findings suggest that IVR-based exhibits, like movies and literature, can spark an interest in visiting parks containing archaeological sites. This counters the notion that archaeology-focused virtual exhibits might keep visitors from traveling to the actual sites.

Future Directions and Conclusions

This research suggests that deep map history-focused IVR exhibits improve users' understanding of the multidimensional nature of archaeological sites. Study participants indicated they enjoyed the immersive educational experience and believed they gained a greater understanding of spatiotemporal human-environment shifts at the Clark's Branch Site. In addition to believing they better understood these relationships, test results from this research suggest that participants experienced learning gains on exhibited materials following the IVR-based exhibit. Findings also suggested that users experienced sense of presence factors (particularly sensory and control factors) related to the sensation of "being" somewhere else, in the exhibit. Digital Age museum visitors want novel technology-based personal experiences, and IVR, accessing a user's sense of presence, is the type of inquiry-based approach to learning visitors want.

Museums seeking to create novel experiences to educate public audiences on the many histories tied to sites can benefit from incorporating IVR technologies in their displays. This study found that IVR users enjoy the new technologies and want more IVR-based exhibits at museums and archaeological sites. In particular, this study found users were especially interested in seeing sites' environmental and cultural evolution. These findings indicate that users want to know more about archaeological sites; exhibits that incorporate deep mapping frameworks are one approach to fulfilling this visitor requirement.

The deep map exhibit framework successfully links and presents different environmental, temporal, and cultural data layers. This framework serves as an important and much-needed repository, able to incorporate diverse data, new narratives, and multidisciplinary research (e.g., information from naturalists and astronomists). Future work with this deep mapping framework could also explore the traditional timeline from different directions, entering the story from different periods instead of moving from earlier to later times. The flexible deep map framework, built in the Unity game engine, allows easy alteration to the exhibit for future iterations of this application, with scenes added and deleted as necessary. Flexible exhibits that can be readily modified could alleviate issues with out-of-date displays that do not reflect current national thought. Exhibits and public displays (e.g., statues) should educate audiences on history, serving as comprehensive and inclusive societal foundations.

A comprehensive Riverbend Park history exhibit could build on the Clark's Branch exhibit's deep mapping framework. For example, a future Riverbend IVR-based exhibit could add narratives like that of Ellick's, an enslaved man who once lived in the park. It could also tell James Madison's story, the president who spent the night at Riverbend when he fled the White House following a British attack. Many meaningful stories are tied to significant places, and exhibits developed with immersive deep map frameworks offer an engaging and novel approach to sharing hidden histories with the public.

This study took place during the Sar-CoV-2 global pandemic. Many museums, including the museum in Riverbend's Visitor Center, closed their doors during this period. Some institutions adapted to these physical closures by developing virtual experiences to connect their audiences to the museum's collections. For museums lacking the resources to create and operate virtual platforms, temporarily, the public cannot access these spaces. Without admission to the collections and exhibits, there might be no publically accessible information on associated archaeological sites and histories.

One of the questions investigated in this thesis was if users can experience place attachment in IVR-based exhibits. The findings suggest that overall, users did not feel attached to Riverbend following the IVR-based exhibit. However, after the IVR experience, study participants indicated an interest in visiting the park. Even if they travel to the park, almost a year into the pandemic, they still do not have access to Riverbend's museum. Large institutions shifted to virtual platforms to share collections with the public, but regional museums like Riverbend do not have the resources to go virtual. That does not mean Riverbend's narratives and artifacts are less important than those connected to larger institutions

As the international community faces unprecedented challenges fighting Sar-CoV-2, museums are more of an afterthought than ever. If people do not know about sites, they cannot form attachments potentially essential to preserving sites. Identifying platforms that can share collections with the public should be a priority, not a postscript. The public has a right to access and learn about archaeological collections as these belong to all of us and convey our shared history. It is unlikely museums will use IVR-based exhibits in museum spaces in the near future, as most interactive displays are closed due to Sar-CoV-2 . Additionally, the post- Sar-CoV-2 public will likely avoid displays involving placing an object over their nose and eyes.

However, the benefit of the deep mapping exhibit framework created in this work is that it does not have to be shared through a museum's immersive system. The framework can be shared on personal IVR systems (e.g., Oculus Rift), desktops, and mobile devices. Museums hoping to share collections virtually can start with smaller digitally-focused exhibits, adding different technologies and narratives as necessary to tell these important stories. Currently, the Clark's Branch IVR-based exhibit is being modified for desktop computers to be part of Riverbend's new virtual *Indians of the Potomac* program. Visitors will be able to safely explore the deep map exhibit from a distance to learn about the layers of history hidden beneath Riverbend's surface.

Additionally, the deep map framework is being expanded to reach specialist audiences. Recently, ESRI released a Unity software development kit (SDK) that can readily connect specialists' spatially related information to the deep map framework developed in this research. This connection will improve archaeologists' understanding of Clark's Branch with additional layers of data (i.e., artifacts quantities and microtopography).

This framework's ability to accommodate and share diverse data appeals both to specialists and public audiences. It offers access to different information that helps build more comprehensive and inclusive understandings of history and place. To better understand ourselves, we need to identify approaches to making the past accessible (Tuan 2011: 187). This research's deep map exhibit framework is one approach to making inclusive pasts accessible and sharing multidimensional information. Developers continue to build and invest in the Unity game engine, adding to developers options for readily adding different types of information. These enhancements can improve on the deep mapping framework, opening up new directions for what an immersive deep map can do. One of this study's focus group participants summarized the many possibilities and promise of the immersive deep map framework produced in this research best, stating, “The sky's the limit!

APPENDIX

Appendix A - Exhibit Demo

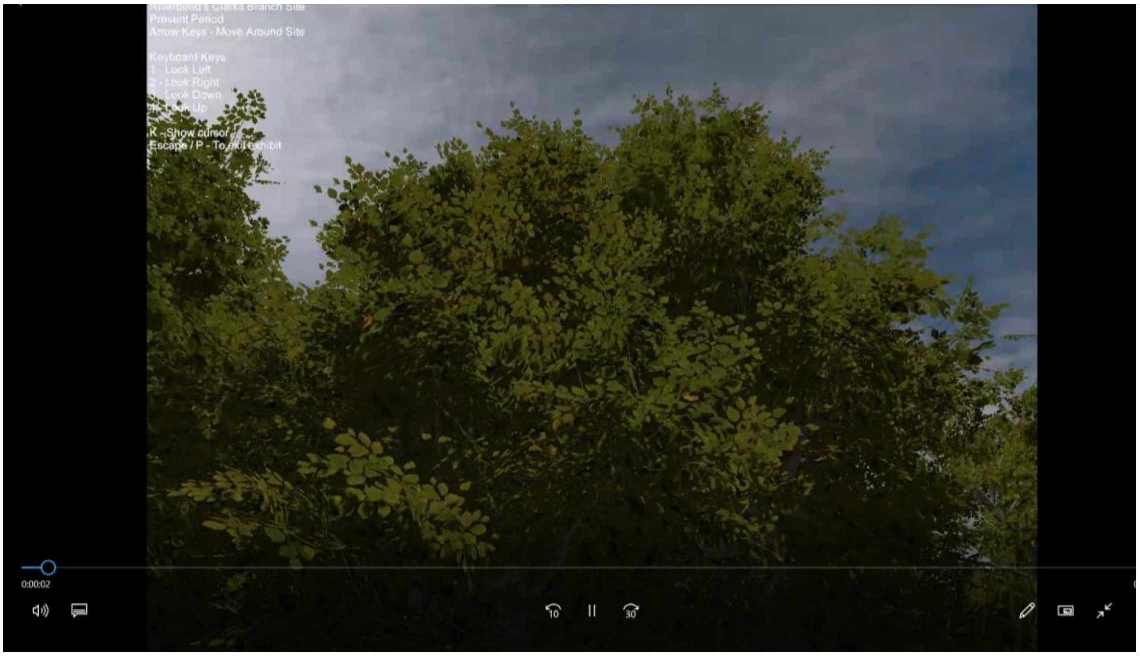


Figure 53 - Clark's Branch Exhibit demo

Use the link below to view a demo of the Clark’s Deep Map Branch Exhibit

https://drive.google.com/file/d/1U5RdZAOvIveNbz4GStsBcdu3FnDmv8Zg/view?usp=sharing

Appendix B - IVR Exhibit Narrative

First Scene: Present

Welcome to Riverbend's Clark's Branch archaeological site. To move through this virtual exhibit, press forward on the oculus touch joystick and move along the trail following the bear footprints. Practice walking by following the footprints to the tree stump ahead on your right.

Trigger

Practice picking up the sphere on the stump using the oculus touch controller. Put your hand on the sphere and press the button under your middle finger to pick up the sphere, making a fist with your hand. To let go of the sphere, let go of the button under your middle finger and relax your fist.

This virtual exhibit contains three scenes showing cultural and environmental changes over time at Clark's Branch. Each scene shows artifacts, animals, plants, and climatic changes. Each scene contains a tree stump with different Clark's Branch artifacts to pick up, representing each cultural period. When you are finished looking at the artifacts put them down. You should never take artifacts from an archaeological site.

To travel through time to different cultural periods, move through the virtual time portals in each scene. For the best experience, follow the trail and bear footprints through the time portals, pick up the artifacts on the stump, and when the audio in the scene has ended, move through the next portal.

When you are ready, move through the Paleoindian portal just ahead.

Second Scene: Paleoindian

During the Paleoindian period, the region's oldest cultural period, the climate was colder, and wetter, with tundra-like grasslands and coniferous forests containing spruce trees, like those around you. The regions first people may have hunted megafauna, such as the woolly mammoth, using fluted projectile points made of fine stone. These fluted points have a characteristic groove, or flute, on the base. This groove would have helped attach the fluted point, to a spear.

Pick up the fluted point discovered at Clark's Branch in three pieces and look at the groove, also known as a flute, on the base of the point. You can also pick up the spear with the point attached. When you are finished, move through the portal to the warmer, drier climate of the Archaic period.

Third Scene: Archaic.

During the Archaic, populations in this region increased, and people began to settle along rivers, like the Potomac, which offered transportation and sustenance, like the Sturgeon fish, shown here smoking over a fire

To travel on rivers such as the Potomac, the first people made dugout canoes, like the men are building in this scene. To build these canoes, the first people burned logs and scraped out the insides.

The climate became warmer, and drier, in the Archaic period. Spruce were replaced by deciduous, nut-bearing trees, such as the white oak surrounding you

In the Archaic, the first people stopped using fluted points. People living in the archaic made large, broadspear points from coarse stone, such as the Savannah river point, shown on the knife in this scene. These large points may have been used to process resources such as Sturgeon fish.

To continue traveling through time at Clark's Branch, follow the bear footprints through the woodland portal.

Fourth Scene: Woodland

During the Woodland period, the region's first people became more sedentary, living in small hamlets and villages in structures called yihakans. Look towards the Potomac to see yihakans and notice the smoke rising from the structures. The fires inside the yihakans were kept burning at all times.

In the woodland period, bow and arrow technology was introduced to the region. The stone tips on these arrows are often called arrowheads. They are typically much smaller than the points we have seen from the previous periods. Look at the triangle arrowhead, from the Clark's Branch site, on the stump in this scene. Bow and arrow technology helped the first people hunt deer, an important source of food, clothing, and tribute.

Also during the woodland period, corn was introduced to the region. The first people cooked corn in clay pots, such as the pot on the hearth in this scene. Women were responsible for planting and harvesting corn. Pottery was another technology introduced in the woodland period. Remains of a woodland hearth were discovered during excavations here at Clark's Branch containing fragments of pottery.

The areas first people called the Potomac River above great falls, *Cohonkarutan* or goose river, for the many geese that visited the river during the winter. Geese still frequent the river and Riverbend park today.

Walk through the portal to return to the Modern-day Clark's Branch site.

Fifth Scene: Present Scene

Now you are back in the present period at the Clark's Branch site. It is important to remember that though many of the physical remnants of archaeological sites have vanished from the landscape these sites, and the history of the region's first people should be respected. The descendants of Virginia's first peoples are still here, and members of Virginia's tribes share their heritage with the public through events and outreach, including an annual Native American festival held at Riverbend Park each September.

We hope you enjoyed your tour and learned about how this site, and the park, have changed over time from the Paleoindian period to the present. Thank you for experiencing Clark's Branch site exhibit. When you are finished, please remove the Oculus headset.

Appendix C - Focus Group Questionnaire

Study Title: Immersive Virtual Reality at Riverbend Park
Focus Group: Fairfax County Archaeology and Collections Branch (approximately 70 minutes)

Focus Group Procedures

1. Ask participants to sign consent forms electronically prior to the meeting. Collect these electronically prior to participation in the focus group meeting.
2. Introductions: the researchers involved in the study and the goal of the study to educate and engage on one of Riverbend's archaeological sites.
3. What is expected of the focus group participants (answering questions through the hour concerning the immersive virtual reality experience at Riverbend Park)
4. Conduct the main discussion covering the key focus group questions. An opening question and then 6 main focus group questions will be asked with each discussion lasting no more than 10 minutes.
5. Summarize the main points of view gathered from participants and ask them if this is an accurate summary from their feedback.
6. Ask for further comments/questions from the participant group.
7. Thank the participant group for their feedback/support.

Focus Group Structured Questions
Focus Group: Friends of Riverbend Park (3-7 participants)

1. Was your experience in the Clark's Branch IVR exhibit positive, negative, or neutral and why do you feel this way?

2. Do you feel the IVR experience helped you better understand cultural (e.g., lifeways, artifacts) and environmental (e.g., climate, animals, plants) changes over time at the Clark's Branch site and, if so, why do you feel this way?

3. In the Clark's Branch IVR exhibit did you experience a sense of presence i.e., a sense of "being" in the virtual environment?

4. If you experienced a sense of presence do you feel that this sense of presence helped you learn about environmental and cultural changes over time at the Clark's Branch site?
5. What content do you remember most from this IVR exhibit?

6. Do you feel that the IVR experience helped place different layers of information i.e. artifacts, lifeways representations, flora, fauna, and terrain, into context?

7. Do you feel the Clark's Branch IVR exhibit is a good educational tool for museums? Why or why not? Do you think this is an experience that should be included in future developments for Riverbend Park? What would you change from this experience?

Appendix D - Student Recruitment Letter

Dear Student,
I am a doctoral candidate in George Mason University's, Geography and Geoinformation Science Department, researching the use of immersive virtual reality (IVR) exhibits as educational tools for archaeological sites and museums. I have developed an IVR exhibit on an archaeological site in Fairfax County's, Riverbend Park, and would like to invite you to take part in a study assessing the educational effectivity of this exhibit.

The study lasts approximately 14 to 32 minutes and involves two quick questionnaires, examining a Story Map on Riverbend Park, and experiencing an IVR exhibit through an Oculus Rift headset. The study will be conducted in a closed office in GMU's Exploratory Hall and will not involve person-to-person contact. If you are willing to participate in this study, you will receive a $50 Amazon gift card and a 2-hour parking pass for GMU's Shenandoah Parking Deck (next to Exploratory Hall).

Please note that you should not participate in this study if you have a history of seizures, are pregnant, suffer from heart conditions, suffer pre-existing binocular vision abnormalities, are ill with cold, flu, headaches, migraines, or earaches, preexisting nausea, dizziness, fear of heights, or have medical devices that might interfere with the Oculus.

If you would like to take part in this study, please let me know. I can be reached by email at **apettitt@masonlive.gmu.edu**. The Institutional Review Board (IRB) Net reference number for this study is 1525051 and questions regarding the IRB process can be answered by George Mason University's Institutional Review Board at (703) 993-4121.
Best Regards,
Alisa Pettitt

<u>Appendix E - IVR Exhibit Instructions for Student Participants</u>

Directions for How to Complete Immersive Virtual Reality (IVR) Riverbend Exhibit

Riverbend IVR Exhibit

Welcome to the Riverbend IVR study. Please have a seat and remain seated for the entire study.

This immersive virtual reality exhibit shows changes over time at an archaeological site in Fairfax County's, Riverbend Park, displayed in an Oculus Rift headset.

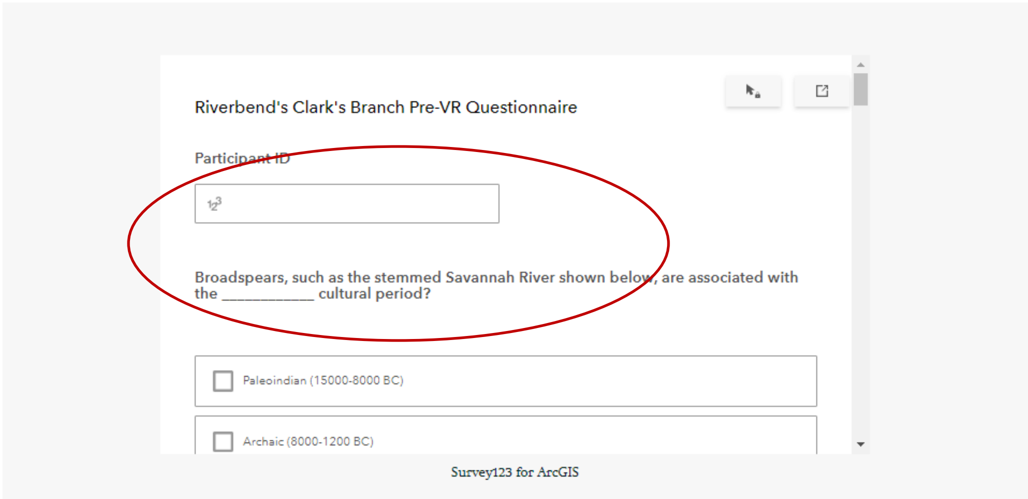
This study will last approximately 14 to 32 minutes and for completing the study you will receive an Amazon gift card. I will guide you through this process virtually.

Before beginning this study please read and sign the consent form in front of you. Second, please read the Oculus Safety Guidelines on the computer screen. When you are finished close the Oculus Safety Guidelines document.

There are **4 parts** to this study:

1) Please review the **Story Map** on the screen in front of you and follow the directions included in the story map. Virtually walk through Riverbend Park's Visitor Center Virtual Tour embedded in the Story Map.

2) Complete and submit the **Pre-IVR questionnaire** included on the Story Map webpage. Fill in the Participant ID number assigned to you under Participant ID. When you are finished with the questionnaire click the **Submit** button. **Do not close the Story Map Window.**



3) You will experience the Oculus Rift IVR Exhibit through the Oculus Rift and Oculus Touch Controllers connected to the computer in this room

Oculus Touch hand controllers' instructions

To move in this exhibit, you will use the Oculus Touch hand controllers. When you are wearing the Oculus Rift headset, look in the direction you want to see by physically moving your head, then virtually move in the direction you want to go using the joystick on the touch controller. To operate the controller, you push forward on the joystick to move forward and backward on the joystick to move backward in the exhibit. To move left or right, look in the direction you want to go and move the joystick.

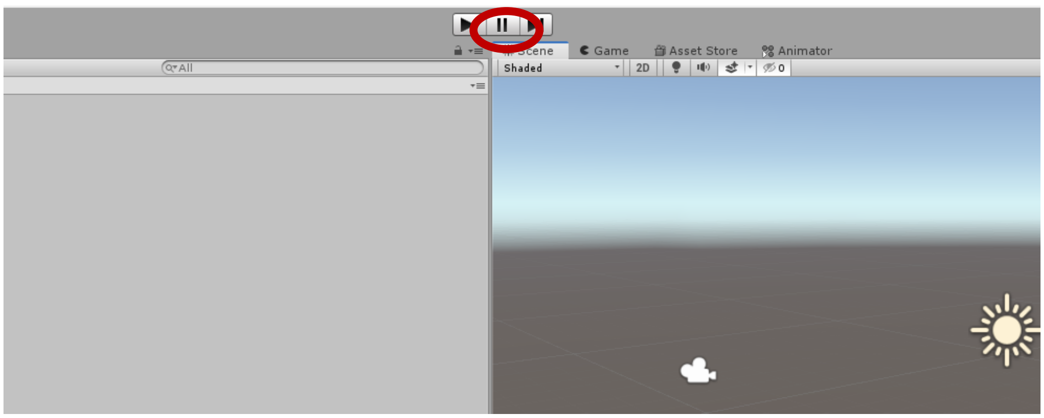
In the Oculus Rift headset, you will see your virtual hands.

To pick up digital artifacts place your virtual hand on the artifact and push your middle finger down on the controller button like you are making a grip. When you want to release the artifact, let go of your grip and you will let go of the digital artifact.

Oculus Rift Headset instructions

When you are in the exhibit follow the audio instructions. The audio instructions will indicate when the exhibit is completed. When you have finished the exhibit, please put down the hand controllers and remove the Rift headset.

4) When you are ready to begin, maximize the **Unity Riverbend IVR Exhibit** window on the computer.
   Press the "Play" button on the Exhibit Screen in front of you and place the Oculus Rift over your eyes. The exhibit will start, and audio will guide you.



If at any time you feel dizzy, nauseous, or sick **please remove the headset**.

5) When you are finished with the exhibit close the **Unity Riverbend IVR Exhibit** window. Return to the Story Map and complete the **Post-IVR Questionnaire** at the bottom of the Story Map**.** Use the same Participant ID. Select Submit.

Thanks for your participation in this study!

Appendix F - Post-IVR Questionnaire : Survey 123 Format

Riverbend's Clark's Branch Post-IVR Questionnaire

Participant ID ☐

Broadspears, such as the stemmed Savannah River shown below, are associated with the ____________ cultural period?

☐ Paleoindian (15000-8000 BC) ☐ Archaic (8000-1200 BC) ☐ Woodland (1200 BC-1600 AD) ☐ Don't Know

Pottery was introduced to the region during the ________ cultural period.

☐ Paleoindian (15000-8000 BC) ☐ Archaic (8000-1200 BC) ☐ Woodland (1200 BC-1600 AD) ☐ Don't Know

A hunting party in the Paleoindian cultural period likely used _______ to hunt, while a hunting party in the Woodland cultural period likely used bows and arrows.

☐ Spears with fluted points ☐ Broadspears ☐ Guns ☐ Don't Know

Fluted spear point | Stemmed broadspear projectile point/knife | Arrowhead

Corn was an important food source for people living during the____________ cultural period.

☐ Paleoindian (15000-8000 BC) ☐ Archaic (8000-1200 BC) ☐ Woodland (1200 BC-1600 AD) ☐ Don't know

Using mortars and pestles to crush nuts and seeds likely began in this cultural period.

☐ Paleoindian (15000-8000 BC) ☐ Archaic (8000-1200 BC) ☐ Woodland (1200 BC-1600 AD) ☐ Don't Know

Megafauna such as the saber-toothed cat, Smilodon, could have lived around the site during this period.

☐ Paleoindian (15000-8000 BC) ☐ Archaic (8000-1200 BC) ☐ Woodland (1200 BC-1600 AD) ☐ Don't Know

Fluted points were likely attached to a ________________.

☐ Spear ☐ Arrow ☐ Net ☐ Don't Know

I felt that seeing the artifacts in context helped me better understand how they were used.

○ Strongly disagree ○ ○ Neutral ○ Agree ○ Strongly agree

I felt I was controlling the immersive virtual exhibit from inside the virtual space instead of controlling the exhibit from the outside.

○ Strongly disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly agree

I felt a sense of "being" in the virtual space.

○ Strongly disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly agree

I was aware of real-world events occurring around me while in the IVR exhibit.

○ Strongly disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly agree

The immersive virtual environment seemed real.

○ Strongly disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly agree

I enjoyed learning about the Clark's Branch archaeological site through the immersive virtual reality exhibit

○ Strongly disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly agree

After completing this experience, I can better place different environmental (e.g. plants, animals, climate) and cultural (e.g. artifacts, lifeways) in specific cultural periods.

○ Strongly disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly agree

How many times have you visited Riverbend Park?

○ I have never visited Riverbend Park ○ 1-3 visits a year ○ 4-10 visits a year ○ More than 10 visits a year

Are you interested in visiting Riverbend Park after completing this virtual experience? (answer Not Applicable if you have already visited Riverbend).

○ Strongly disagree ● Disagree ○ Neutral ○ Agree ○ Strongly agree ○ Not Applicable

l feel attached to Riverbend Park.

○ Strongly disagree Disagree ○ Neutral ○ Agree ○ Strongly agree

Which generation do you belong to?

☐ Greatest Generation (born 1910-1927) ☐ Silent Generation (born 1928-1945) ☐ Baby Boomer (born 1946-1964) ☐ Generation X (born 1965-1980) ☐ Millennials (born 1981-1996) ☐ Generation Z (born 1997-)

Gender Identity

☐ Male/Man ☐ Female/Woman ☐ TransMale/TransMan ☐ TransFemale/TransWoman ☐ Genderqueer/ Gender nonconforming ☐ Something Else ☐ Decline to Answer

Date and Time

REFERENCES

Acevedo, D., E. Vote, D.H. Laidlaw, and M.S. Joukowsky. 2001. "Archaeological Data Visualization in VR: Analysis of Lamp Finds at the Great Temple of Petra, a Case Study." In *Proceedings Visualization, 2001. VIS '01.*, San Diego, CA, USA: IEEE, 493–597. http://ieeexplore.ieee.org/document/964560/ (August 18, 2019).

Adobe. 2019. "Adobe Creative Cloud | Software and Services for Creative Professionals." https://www.adobe.com/creativecloud.html?promoid=ZP46FD38&mv=other (February 28, 2019).

Agapiou, A., and V. Lysandrou. 2015. "Remote Sensing Archaeology: Tracking and Mapping Evolution in European Scientific Literature from 1999 to 2015." *Journal of Archaeological Science: Reports* 4: 192–200.

Alzua-Sorzabal, A. et al. 2005. "Interface Evaluation for Cultural Heritage Applications: The Case of FERRUM Exhibition." http://diglib.eg.org/handle/10.2312/VAST.VAST05.121-128 (August 15, 2019).

Ascher, R. 1961. "Experimental Archeology." *American Anthropologist* 63(4): 793–816.

Bailey, G. 2008. "Time Perspectivism: Origins and Consequences." In *Time in Archaeology: Time Perspectivism Revisited*, Utah University Press, 13–30.

Bauer, A.C.M., and G. Andringa. 2020. "The Potential of Immersive Virtual Reality for Cognitive Training in Elderly." *Gerontology* 66(6): 614–23.

Benko, H., E.W. Ishak, and S. Feiner. 2004. "VITA: Visual Interaction Tool for Archaeology (Demo)." In *Proceedings of the 2004 ACM SIGMM Workshop on Effective Telepresence - ETP '04*, New York, NY, USA: ACM Press, 48. http://portal.acm.org/citation.cfm?doid=1026776.1026789 (August 18, 2019).

Beverley, R., S. S. Atias, H.C. Roundtree, and S. Parrish. 1947. *The History and Present State of Virginia (A New Edition).*

Bjorkli, B., S. Ledas, G. Liestol, T. Stenarson, and E. Uleberg. 2018. "Archaeology and Augmented Reality: Visualizing Stone Age Sea Level on Location." In *Computer Applications and Quantitative Methods in Archaeology*, Oxford, England: Archaeopress.

Blender. 2019. "Blender.Org - Home of the Blender Project - Free and Open 3D Creation Software." *blender.org*. https://www.blender.org/ (February 28, 2019).

Bodenhamer, D.J., T.M. Harris, and J. Corrigan. 2013. "Deep Mapping and the Spatial Humanities." *International Journal of Humanities and Arts Computing* 7(1–2): 170–75.

Boletsis, C. 2017. "The New Era of Virtual Reality Locomotion: A Systematic Literature Review of Techniques and a Proposed Typology." *Multimodal Technologies and Interaction* 1(4): 24.

Boletsis, C., and J.E. Cedergren. 2019. "VR Locomotion in the New Era of Virtual Reality: An Empirical Comparison of Prevalent Techniques." *Advances in Human-Computer Interaction* 2019: 1–15.

Borrego, A., J. Latorre, M. Alcañiz, and R. Llorens. 2019. "Embodiment and Presence in Virtual Reality After Stroke. A Comparative Study With Healthy Subjects." *Frontiers in Neurology* 10: 1061.

Braudel, F. 1972. *The Mediterranean and the Mediterranean World in the Age of Philip II*. 1st U.S. ed. New York: Harper & Row.

British Museum. 2020. "John White, The Manner of Their Fishing." *drawing*. https://www.britishmuseum.org/collection/object/P_1906-0509-1-6 (September 12, 2020).

Bruno, F., S. Bruno, G. De Sensi, M.L. Luchi, S. Mancuso, and M. Muzzupappa. 2010. "From 3D Reconstruction to Virtual Reality: A Complete Methodology for Digital Archaeological Exhibition." *Journal of Cultural Heritage* 11(1): 42–49.

Chang, K.E, C.T. Change, H.T. Hou, Y.T. Sung, H.L. Chao, and C.M. Lee 2014. "Development and Behavioral Pattern Analysis of a Mobile Guide System with Augmented Reality for Painting Appreciation Instruction in an Art Museum." *Computers & Education* 71: 185–97.

Cignoni, P., and A. Montoni. 2020. "Meshlab." *Meshlab*. https://www.meshlab.net/.

Cranmer, E., T. Jung, M.C. Dieck, and A. Miller. 2016. "Understanding the Acceptance of Augmented Reality at an Organizational Level: The Case of Geevor Tin Mine Museum." In *Information and Communication Technologies in Tourism 2016*, eds. Alessandro Inversini and Roland Schegg. Cham: Springer International Publishing, 637–50. http://link.springer.com/10.1007/978-3-319-28231-2_46 (August 18, 2019).

Custer, J. 1991. "Notes of Broadspear Functions." *Archaeology of Eastern North America* 19(1): 51–74.

De Reu, J., P. De Smedt, D. Herremans, D. Van Meirvenne, P. Laloo, W. De Clercq. et al. 2014. “On Introducing an Image-Based 3D Reconstruction Method in Archaeological Excavation Practice.” *Journal of Archaeological Science* 41: 251–62.

Derrickson, S. 2016. *Dr. Strange*. Marvel.

Ebert, D. 2004. “Applications of Archaeological GIS.” *Canadian Journal of Archaeology* 28(2): 319–41.

ECAI. 2001. “TimeMap.” *TimeMap*. http://www.ecai.org/Tech/Timemap.html (March 12, 2019).

Egloff, K., and D. Woodward. 2006. *First People: The Early Indians of Virginia*. 2nd ed. Charlottesville: University of Virginia Press in association with the Virginia Dept. of Historic Resources.

Ekelund, B., and M. DeMarsche. 2018. “Outdated Rules Are Killing Museums—Here’s How Things Can Change.” *Artsy*. https://www.artsy.net/article/artsy-editorial-outdated-rules-killing-museums-things-change (August 15, 2019).

Erickson, M. St. J. 2013. “Decoding the Mystery of the Jamestown Sturgeon.” *Daily Press*. https://historicjamestowne.org/visit/plan-your-visit/wildlife/sturgeon/ (March 12, 2020).

Eve, S. 2014. *Dead Men’s Eyes: Embodied GIS, Mixed Reality and Landscape Archaeology*. Oxford: Archaeopress.

Facebook Technologies, LLC. 2019a. “Oculus Device Specifications.” file:///D:/Oculus-RiftS-Warnings-English-052119.pdf (February 23, 2019).

———. 2019b. “Oculus-Rift-Warnings.” file:///D:/Oculus-RiftS-Warnings-English-052119.pdf (February 23, 2019).

Fischer, H.A., and E.A. Wentz. 2020. “Place Attachment and Learning Outcomes among Tourists Who Volunteer for a U.S. National Park Science Volunteer Program.” *Applied Environmental Education & Communication*: 1–16.

Foltz, M.A. 1998. “Designing Navigable Information Spaces.” Massachusetts Institute of Technology.

Forte, M. et al. 2012. “3D Archaeology at Çatalhöyük.” *International Journal of Heritage in the Digital Era* 1(3): 351–78.

Fortes, D. “Unity AR + GPS Location.” *AR + GPS Location*. https://docs.unity-ar-gps-location.com/guide/#ar-foundation (November 22, 2019).

Foster, H. 2008. "Evaluation Toolkit for Museum Practitioners." Renaissance East of England. http://visitors.org.uk/wp-content/uploads/2014/08/ShareSE_Evaltoolkit.pdf

Fresa, A. 2013. "A Data Infrastructure for Digital Cultural Heritage: Characteristics, Requirements and Priority Services." *International Journal of Humanities and Arts Computing* 7(supplement): 29–46.

Friends of Riverbend Park (FORB). n.d. "Friends of Riverbend Park - Home." http://www.forb.wildapricot.org/ (August 15, 2019).

Gabellone, F., A. Lanorte, N. Masini, and R. Lasaponara. 2017. "From Remote Sensing to a Serious Game: Digital Reconstruction of an Abandoned Medieval Village in Southern Italy." *Journal of Cultural Heritage* 23: 63–70.

Galeazzi, F. 2016. "Towards the Definition of Best 3D Practices in Archaeology: Assessing 3D Documentation Techniques for Intra-Site Data Recording." *Journal of Cultural Heritage* 17: 159–69.

Gillings, M. 2017. "Mapping Liminality: Critical Frameworks for the GIS-Based Modelling of Visibility." *Journal of Archaeological Science* 84: 121–28.

Glaser, B.G., and A.L. Strauss. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. 4. paperback printing. New Brunswick: Aldine.

Griggs, M. 2019. "Adobe Fuse: What It Is and How to Use It to Create 3D Characters | Creative Bloq." https://www.creativebloq.com/features/adobe-fuse-what-it-is-and-how-to-use-it-to-create-3d-characters (June 22, 2019).

Groshong, L., S.W. Stanis, M. Morgan, and C.J Li. 2020. "Place Attachment, Climate Friendly Behavior, and Support for Climate Friendly Management Action among State Park Visitors." *Environmental Management* 65(1): 98–110.

Gutierrez-Maldonado, J., A. Andres-Pueyo, A. Jarne, A. Talarn, M. Ferrer, and J. Achotegui. 2017. "Virtual Reality for Training Diagnostic Skills in Anorexia Nervosa: A Usability Assessment." In *Virtual, Augmented and Mixed Reality*, eds. Stephanie Lackey and Jessie Chen. Cham: Springer International Publishing, 239–47. http://link.springer.com/10.1007/978-3-319-57987-0_19 (February 6, 2021).

Hall, S. 2014. "Civil War Battlefields for Future Generations: The Relationship between Battlefield Preservation and Popular Culture." In *The Civil War in Popular Culture: Memory and Meaning*, University Press of Kentucky.

Halpenny, E.A. 2010. "Pro-Environmental Behaviors and Park Visitors: The Effect of

Place Attachment." *Journal of Environmental Psychology* 30(4): 409–21.

Harriot, T. 1972. *A Briefe and True Report of the New Found Land of Virginia (The Complete 1590 Theodor de Bry Edition)*. Dover Publi.

Harvard College, President and Fellows. 2020a. "Theodor de Bry after John White, The Broiling of their Fish over the Flame." *drawing*. https://harvardartmuseums.org/collections/object/275738 (September 12, 2020).

Harvard College, President and Fellows. 2020b. "Theodor de Bry after John White, The Seething of Their Meat in Earthen Pots." *drawing*. https://harvardartmuseums.org/collections/object/275738 (September 12, 2020).

Harvard College, President and Fellows. 2020c. "Theodor de Bry after John White, The Manner of Makinge Their Boates." *drawing*. https://harvardartmuseums.org/collections/object/275920?position=9 (September 12, 2020).

Hernández, B., A.M. Martín, C. Ruiz, and M.C. Hidalgo. 2010. "The Role of Place Identity and Place Attachment in Breaking Environmental Protection Laws." *Journal of Environmental Psychology* 30(3): 281–88.

Historic England. 2017. *Historic England: Research Agenda*. Swindon.

Holdaway, S., and L. Wandsnider, eds. 2008. *Time in Archaeology: Time Perspectivism Revisited*. Salt Lake City: University of Utah Press.

Howey, M.C.L., and M. Brouwer Burg. 2017. "Assessing the State of Archaeological GIS Research: Unbinding Analyses of Past Landscapes." *Journal of Archaeological Science* 84: 1–9.

Huang, H., and S.E. Chang. 2017. "Place-Based Learning and Change of Sense of Place: Educational Program in a Historic Town." *Environment-Behavior Proceedings Journal* 2(6): 363.

Hussein, M. and Natterdal, C. 2015. "The Benefits of Virtual Reality in Education." Goteborg, Sweden.

Hutong Games. 2019. "Playmaker." *Playmaker: Make World*. https://hutonggames.com/ (September 16, 2019).

Igroup. 2016. "IGroup Presence Questionnaire." http://www.igroup.org/pq/ipq/items.php (July 20, 2019).

Inashima, P. 2012. *Phase III Investigations at Clark's Branch (44FX3226)*. Fairfax, Virginia: Fairfax County Park Authority.

Infinity Code. 2019. “Real World Terrain.” *Real-World Terrain: Version 4.5*. https://infinity-code.com/documentation/real-world-terrain.pdf (November 2, 2019).

Johnson, M. 1986. “The Prehistory of Fairfax County: An Overview.”

Johnson-Glenberg, M.C. 2018. “Immersive VR and Education: Embodied Design Principles That Include Gesture and Hand Controls.” *Frontiers in Robotics and AI* 5: 81.

Jorgensen, B.S., and R.C. Stedman. 2001. “Sense of Place as an Attitude: Lakeshore Owners Attitudes toward their Properties.” *Journal Of Environmental Psychology* 21(3): 233–48.

Jung, T., M.C.T. Dieck, H. Lee, and N. Chung. 2016. “Effects of Virtual Reality and Augmented Reality on Visitor Experiences in Museum.” In *Information and Communication Technologies in Tourism 2016*, eds. Alessandro Inversini and Roland Schegg. Cham: Springer International Publishing, 621–35. http://link.springer.com/10.1007/978-3-319-28231-2_45 (August 18, 2019).

Kanter, J. 2000. “Realism vs. Reality: Creating Virtual Reconstructions of Prehistoric Architecture.” In *Virtual Reality in Archaeology*, 47–52.

Karasik, A., and U. Smilansky. 2008. “3D Scanning Technology as a Standard Archaeological Tool for Pottery Analysis: Practice and Theory.” *Journal of Archaeological Science* 35(5): 1148–68.

Kinsey, W. 1972. “Archaeology in the Upper Delaware Valley.” *Pennsylvania Historical and Museum Commission Anthropological Series* 2.

Knabb, K.A. et al. 2014. “Scientific Visualization, 3D Immersive Virtual Reality Environments, and Archaeology in Jordan and the Near East.” *Near Eastern Archaeology* 77(3): 228.

Knapp, A.B., ed. 1992. *Archaeology, Annales, and Ethnohistory*. Cambridge: Cambridge University Press. http://ebooks.cambridge.org/ref/id/CBO9780511759949 (August 4, 2019).

Kowlessar, J., J. Benjamin, I. Moffat, and W.V. Duivenvoorde. 2019. “Multi-Scaler 3D Modelling to Reconstruct an Experiential Landscape: An Example from a Worker’s Cottage at Mount Dutton Bay, South Australia.” *Journal of Archaeological Science: Reports* 23: 478–89.

Kuula. 2020. “About Kuula.” *About Kuula*. https://kuula.co/about (April 20, 2020).

Lepouras, G., and C. Vassilakis. 2004. “Virtual Museums for All: Employing Game Technology for Edutainment.” *Virtual Reality* 8(2): 96–106.

Lercari, N. 2017. “3D Visualization and Reflexive Archaeology: A Virtual Reconstruction of Çatalhöyük History Houses.” *Digital Applications in Archaeology and Cultural Heritage* 6: 10–17.

Lerma, J.L., S. Navarro, M. Cabrelles, and V. Villaverde. 2010. “Terrestrial Laser Scanning and Close Range Photogrammetry for 3D Archaeological Documentation: The Upper Paleolithic Cave of Parpalló as a Case Study.” *Journal of Archaeological Science* 37(3): 499–507.

Louvre. 2020. “Collection and Louvre Palace: Online Tours.” *Online Tours*. https://www.louvre.fr/en/visites-en-ligne (July 15, 2020).

Lubar, S. 2013. “Timelines in Exhibitions.” *Curator: The Museum Journal* 56(2): 169–88.

Luo, L., X. Wang, C. Liu, H. Gui, and X. Du. 2014. “Integrated RS, GIS, and GPS Approaches to Archaeological Prospecting in the Hexi Corridor, NW China: A Case Study of the Royal Road to Ancient Dunhuang.” *Journal of Archaeological Science* 50: 178–90.

Makransky, G., T.S. Terkildsen, and R.E. Mayer. 2019. “Adding Immersive Virtual Reality to a Science Lab Simulation Causes More Presence but Less Learning.” *Learning and Instruction* 60: 225–36.

Markowitz, D.M. et al. 2018. “Immersive Virtual Reality Field Trips Facilitate Learning About Climate Change.” *Frontiers in Psychology* 9. https://www.frontiersin.org/article/10.3389/fpsyg.2018.02364/full (August 17, 2019).

Marty, P.F., and K.B. Jones, eds. 2008. *Museum Informatics: People, Information, and Technology in Museums*. New York: Routledge.

Means. 2019. *Personal Communication with Bernard Means*. Richmond, Virginia.

Means, B. K. 2015. “Promoting a More Interactive Public Archaeology.” *Advances in Archaeological Practice* 3(03): 235–48.

Means, B. K., A. McCuistion, and C. Bowles. 2013. “Virtual Artifact Curation of the Historical Past and the NextEngine Desktop 3D Scanner.” *Technical Briefs in Historical Archaeology* 6: 1–12.

Melim, A. 2019. “Increasing Fidelity with Constellation-Tracked Controllers.” *Oculus*

Developers. https://developer.oculus.com/blog/increasing-fidelity-with-constellation-tracked-controllers/ (October 3, 2020).

Metashape. 2019. "Agisoft Metashape." https://www.agisoft.com/ (February 28, 2019).

Minocha, S., A.D. Tudo, and S. Tilling. 2017. "Affordances of Mobile Virtual Reality and Their Role in Learning and Teaching." *University of Sunderland's St. Peter's Campus*.

Mixamo. 2019. "Mixamo." https://www.mixamo.com/#/ (February 28, 2019).

Mortara, M., C.E. Catalano, F. Bellotti, G. Fiucci, M. Houry-Panchetti, and P. Petridis. 2014. "Learning Cultural Heritage by Serious Games." *Journal of Cultural Heritage* 15(3): 318–25.

National Park Service (NPS). 2015. "Native Americans of the Potomac." Native American Indians of the Potomac - National Park Service https://www.nps.gov/.../American%20Indian%20PAC%20park%20visit.do...

Nelson, A. and S. Cohn. 2015. "Data Collection Methods for Evaluating Museum Programs and Exhibitions." *Journal of Museum Education* 40(1): 27–36.

North, M., and S. North. 2016. "A Comparative Study of Sense of Presence of Traditional Virtual Reality and Immersive Environments." *Australian Journal of Information Systems* 20.

O'Driscoll, J. 2018. "Landscape Applications of Photogrammetry Using Unmanned Aerial Vehicles." *Journal of Archaeological Science: Reports* 22: 32–44.

Osgood, C. E. 1952. "The Nature and Measurement of Meaning." *Psychological Bulletin* 49(3): 197–237.

Parcak, S. H. 2009. *Satellite Remote Sensing for Archaeology*. London ; New York: Routledge.

Perot Museum. "Perot Museum of Nature and Science." *Dinaledi Chamber VR Experience | Perot Museum of Nature and Science*. http://www.perotmuseum.org/dinaledivr/index.html (August 15, 2019).

Persaud, C. 2018. "Bloom's Taxonomy, the Ultimate Guide." https://tophat.com/blog/blooms-taxonomy-ultimate-guide/.

Pickford, J. 2018. "Museums Hit by 'Stratospheric' Art Prices and Funding Cuts." *Financial Times*. https://www.ft.com/content/e1b325ce-122f-11e8-940e-08320fc2a277 (August 16, 2019).

Pitas, N. A., A. J. Mowen, A .R. Graefe, and G. T. Kyle. 2018. "Place Attachment and Spending Preferences in a Local Public Park System: The Case of Corporate Sponsorship." *Journal of Leisure Research* 49(2): 71–90.

Potter, B. A., Baichtal, J. F., Beaudoin, A. B., Fehren-Schmitz, L., Haynes, C. V., Holliday, V. T., Holmes, C. E., Ives, J. W., Kelly, R. L., Llamas, B., Malhi, R. S., Miller, D. S., Reich, D., Reuther, J. D., Schiffels, S., & Surovell, T. A. 2018. "Current evidence allows multiple models for the peopling of the Americas." *Science Advances, 4*(8), eaat5473. https://doi.org/10.1126/sciadv.aat5473

Povroznik, N. 2018. "Towards a Global Infrastructure for Digital Cultural Heritage." In *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection*, eds. Marinos Ioannides et al. Cham: Springer International Publishing, 607–15. http://link.springer.com/10.1007/978-3-030-01762-0_53 (December 1, 2018).

Pujol, L. 2004. "Archaeology, Museums and Virtual Reality." *Digithum* 0(6). http://digithum.uoc.edu/article/10.7238/d.v0i6.542/ (February 26, 2021).

Rae, J., and L. Edwards. "Virtual Reality at the British Museum: What Is the Value of Virtual Reality Environments for Learning by Children and Young People, Schools, and Families? | MW2016: Museums and the Web 2016." https://mw2016.museumsandtheweb.com/paper/virtual-reality-at-the-british-museum-what-is-the-value-of-virtual-reality-environments-for-learning-by-children-and-young-people-schools-and-families/ (August 15, 2019).

Ramkissoon, H., B. Weiler, and L. D. G. Smith. 2012. "Place Attachment and Pro-Environmental Behavior in National Parks: The Development of a Conceptual Framework." *Journal of Sustainable Tourism* 20(2): 257–76.

Reed, J., R. Sigafoos, and G. Fisher. 1980. *The River and The Rocks*. Washington, D.C.: United States Government Printing Office.

Remondino, F., L. Barazzetti, F. New, M. Scaioni, and D. Sarazzi. 2012. "UAV Photogrammetry For Mapping And 3d Modeling – Current Status And Future Perspectives." *Isprs - International Archives Of The Photogrammetry, Remote Sensing And Spatial Information Sciences* Xxxviii-1/C22: 25–31.

Renfrew, C., and P.G. Bahn. 2016. *Archaeology: Theories, Methods, and Practice*. Seventh edition revised&updated. London: Thames & Hudson.

Rey, F.B., and D. Casado-Neira. 2013. "Participation and Technology: Perception and Public Expectations about the Use of ICTs in Museums." *Procedia Technology* 9: 697–704.

Richards-Rissetto, H. 2017. “What Can GIS + 3D Mean for Landscape Archaeology?” *Journal of Archaeological Science* 84: 10–21.

Rome Reborn. “About/Contact | Rome Reborn.” https://www.romereborn.org/content/aboutcontact (August 15, 2019).

Roundtree, H.C. 1989. *The Powhatan Indians of Virginia: Their Traditional Culture*. 1st ed. University of Oklahoma Press.

Royal Irish Academy. 2017. *Archaeology 2025: Strategic Pathways for Archaeology in Ireland*. Dublin, Ireland.

Sadowski, W., and K. Stanney. 2002. “Presence in Virtual Environments.” In *Human Factors and Ergonomics. Handbook of Virtual Environments: Design, Implementation, and Applications,* K.M. Stanney, 791–806.

Saldaña, J. 2016. *The Coding Manual for Qualitative Researchers*. 3E [Third edition]. Los Angeles ; London: SAGE.

Sarsons, H. and X. Gu. 2015. “Confidence Men? Evidence among top economists.” Department of Economics, Littauer Center, 1-26. Harvard University

Sanders, D. 2008. “Why Do Virtual Heritage? - Introduction - Archaeology Magazine Archive.” *Archaeology*. https://archive.archaeology.org/online/features/virtualheritage/ (August 16, 2019).

Šašinka, Č., Z. Stachon, M. Sedlak, J. Cmelik, L. Herman, P. Kubicek, A. Sasinkova, M. Dolezal, H. Tejkl, T. Urbanek, H. Svatonova, P. Ugwitz, and V. Jurik. 2018. “Collaborative Immersive Virtual Environments for Education in Geography.” *ISPRS International Journal of Geo-Information* 8(1): 3.

Schubert, B.W., and S.C. Wallace. 2009. “Late Pleistocene Giant Short-Faced Bears, Mammoths, and Large Carcass Scavenging in the Saltville Valley of Virginia, USA.” *Boreas* 38(3): 482–92.

Schwind, V., P. Knierim, N. Haas, and N. Henze. 2019. “Using Presence Questionnaires in Virtual Reality.” In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI ’19*, Glasgow, Scotland UK: ACM Press, 1–12. http://dl.acm.org/citation.cfm?doid=3290605.3300590 (August 17, 2019).

Seawright, C. 2015. “Time Perspectivism: Time as a Methodological Tool in Archaeology.” LaTrobe University.

Selmanovic, E., S. Rizvic, C. Harvey, D. Boskovia, V. Hulusic, M. Chahin, and S. Sljivo. 2018. “VR Video Storytelling for Intangible Cultural Heritage Preservation.”

Eurographics Workshop on Graphics and Cultural Heritage. https://diglib.eg.org/handle/10.2312/gch20181341 (August 17, 2019).

Slater, M., and S. Wilbur. 1997. “A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments.” *Presence: Teleoperators and Virtual Environments* 6(6): 603–16.

Smith, M. E. 1992. “Braudel’s Temporal Rhythms and Chronology Theory in Archaeology.” In *Archaeology, Annales, and Ethnohistory*, ed. A. Bernard Knapp. Cambridge: Cambridge University Press, 23–34. https://www.cambridge.org/core/product/identifier/CBO9780511759949A011/type/book_part (August 4, 2019).

Soheili, F., R. Karimi, B. Avazpour, and S.M.E. Sepasgozar. 2020. “The Effect of Place Attachment on Educational Efficiency in Elementary Schools.” In *Smart Cities and Construction Technologies*, eds. Sara Shirowzhan and Kefeng Zhang. IntechOpen. https://www.intechopen.com/books/smart-cities-and-construction-technologies/the-effect-of-place-attachment-on-educational-efficiency-in-elementary-schools (February 19, 2021).

Solly, M. 2020. “How to Virtually Explore the Smithsonian from Your Living Room.” *Smithsonianmag.com*. https://www.smithsonianmag.com/smithsonian-institution/how-virtually-explore-smithsonian-your-living-room-180974436/ (July 15, 2020).

St Louis. 2019. “Virtual City Project.” http://vcities.ite-stl.org/ (August 18, 2019).

Stokols, D., and S.A. Schumaker. *People in Places: A Transactional View of Settings*. Hillsdale, N.J.: J. Harvey.

Supernant, K. 2017. “Modeling Métis Mobility? Evaluating Least Cost Paths and Indigenous Landscapes in the Canadian West.” *Journal of Archaeological Science* 84: 63–73.

Thomas, K.A. et al. 2017. “Explaining the Origin of Fluting in North American Pleistocene Weaponry.” *Journal of Archaeological Science* 81: 23–30.

Tost, L. P., and M. Economou. 2009. “Worth a Thousand Words? The Usefulness of Immersive Virtual Reality for Learning in Cultural Heritage Settings.” *International Journal of Architectural Computing* 7(1): 157–76.

Tuan, Y. 2011. *Space and Place: The Perspective of Experience*. 7. print. Minneapolis, Minn.: Univ. of Minnesota Press.

United States Fish and Wildlife (USFW). 2020. *Atlantic Sturgeon*. United States

Department of the Interior. https://www.fws.gov/fisheries/freshwater-fish-of-america/atlantic_sturgeon.html (October 15, 2019).

Unity. 2019. “Unity.” *Unity*. https://unity3d.com (February 28, 2019).

Vaske, J., and K. Kobrin. 2001. “Place Attachment and Environmentally Responsible Behavior.” *The Journal of Environmental Education* 32(4): 16–21.

Virginia Department of Historic Resources (VDHR). 2020. “First People: The Early Indians of Virginia.” *Virginia Department of Historic Resources*. https://www.dhr.virginia.gov/first-people-the-early-indians-of-virginia/ (September 20, 2020).

Virtual Bejing. “Beijing | Virtual Beijing.” http://beijing.virtualcities.fr/ (August 15, 2019).

Vote, E., D.A. Feliz, D.H. Laidlaw, and M.S. Joukowsky. 2002. “Discovering Petra: Archaeological Analysis in VR.” *IEEE Computer Graphics and Applications* 22(5): 38–50.

Watts, W. A. 1979. “Late Quaternary Vegetation of Central Appalachia and the New Jersey Coastal Plain.” *Ecological Monographs* 49(4): 427–69.

Wells, J. J., E.C. Kansa, S.W. Kansa, S.J. Yerka, D.G. Anderson, T.G. Bissett, K.N. Myers, and R. Carl DeMuth. 2014. “Web-Based Discovery and Integration of Archaeological Historic Properties Inventory Data: The Digital Index of North American Archaeology (DINAA).” *Literary and Linguistic Computing* 29(3): 349–60.

Williams, D. 2000. *Notes of Measuring Recreational Place Attachment*. fs.fed.us/rm/value/docs/pattach_notes.pdf.

Williams, D.R., and D.S. Carr. 1993. “The Sociocultural Meanings of Outdoor Recreation Place.” In *Culture, Conflict, and Communication in the Wildland-Urban Interface*, Boulder, Colorado: Westview Press, 209–19.

Williams, D.R., and J.W. Roggenbuck. 1989. “Measuring Place Attachment: Some Preliminary Results.” In *NRPA Symposium on Leisure Research*, San Antonio, Texas.

Witmer, B.G., and M.J. Singer. 1998. “Measuring Presence in Virtual Environments: A Presence Questionnaire.” *Presence: Teleoperators and Virtual Environments* 7(3): 225–40.

Wolf, I.D., H.K. Stricker, and G. Hagenloh. 2015. “Outcome-Focused National Park

Experience Management: Transforming Participants, Promoting Social Well-Being, and Fostering Place Attachment." *Journal of Sustainable Tourism* 23(3): 358–81.

Zimmer, A. 2019. "Pocket Portal VR." *PocketPortalVR*. https://github.com/andrewzimmer906/PocketPortalVR (September 16, 2019).

BIOGRAPHY

Alisa Pettitt received her Bachelor of Science in Anthropology (Archaeology concentration) and Philosophy and Religion (Religion concentration) from James Madison University in 2007. She received her Master of Arts in Art History from George Mason University in 2012 and a graduate certificate in Geographic Information Science in 2016. Alisa has worked as an archaeologist in North America since 2007.