Visitor Perceptions of Augmented Reality in Science Museums

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Abstract

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Augmented reality (AR) is a new technology that has recently been gaining popularity in museums. In an ongoing debate about the role of technology in museums amongst museum professionals, one voice has been largely absent: visitors. Research has been conducted on how individuals learn from augmented reality, but little has been done to understand museum visitor perceptions of augmented reality. The purpose of this study was to explore how visitors describe the value and role of AR experiences in science museums. A secondary purpose is to explore the extent to which AR changes visitors' impressions of that institution. This study was a qualitative survey conducted on 51 adult visitors at two science museums–Pacific Science Center in Seattle, WA and the Lawrence Hall of Science in Berkeley, CA—both of whom have augmented reality experiences. Findings suggest that visitors value the use of AR in science museum settings, particularly as an educational tool that engages and entertains its users. Additionally, visitors feel their AR experience has enhanced their perception of the institution as being more modern and up-to-date. This study contributes to the body of knowledge about best practices associated with augmented reality in museums, and raises several cautions associated with incorporating AR into a museum exhibit.

Keywords: augmented reality, science museums, technology, best practices

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Chapter 1: Introduction

Definition

Augmented Reality: an interactive, real-time direct or indirect view of a physical environment that has been enhanced by the superimposing of computer-generated sensory information, such as images, sounds, videos, and haptics.

The pervasiveness of AR in modern culture is imminent. Augmented reality is predicted to be a $50 billion industry by 2022, and with the introduction of ARkit and ARcore, AR development kits for iOS and android apps, by Apple™ and Google™ respectively, AR is becoming ever more mainstream.[1] AR technology affords museums a unique opportunity to disseminate knowledge in a way that is both fresh and engaging.

A rudimentary form of AR has been in existence since the 1960s but has recently exploded in public consciousness and is still a relatively new phenomenon—particularly in museums. The American Alliance of Museums (AAM) Trendswatch 2016 edition devotes a section to place-based augmented devices in which they labeled these devices as one of the biggest trends in museums in 2016.[2] In Trendswatch 2016, Barry Joseph acknowledges that augmented reality can inspire curiosity within museum visitors, generate deeper interest in content, and encourage people to pursue knowledge outside of the museum setting.[3]

Empirical studies demonstrate that AR has many applications in learning, such as having a positive effect on learning outcomes as compared to non-augmented

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[1] ARPost, "Key Augmented Reality Statistics You Need to Know," *AR Post* (blog), November 15, 2017, https://arpost.co/2017/11/15/key-augmented-reality-statistics/.

[2] American Alliance of Museums, "TrendsWatch2016," 2016.

[3] Ibid.

learning experiences.[4] In fact, augmented reality increases a visitor's knowledge about a topic as compared to non-augmented exhibits, their motivation to learn, their attitudes towards learning, and their engagement with the learning material. This shows that AR can be a useful tool in museums to further their educational missions. However, the New Media Consortium's (NMC) New Horizons Report: Museum Edition, affirms that AR is about two to three years away from adoption.[5] Although museums are in the infancy stage in adopting AR in their exhibit spaces, and with the world shifting to the adoption of more and different types of technologies, some museums have begun to experiment with augmented reality. The potential for AR's learning applications in museums, and the advancements of new technology, is important in the debate about whether museums should adopt technology and keep up with the advancements of society.

Although proof exists on AR's learning applications, some have been critical of the adoption of technology in museums. Nick Prior, in *Postmodern Restructurings,* is critical of the museums shift from what he calls "an aesthetic of distinction to a culture of distraction."[6] His argument is that museums are becoming places of entertainment, much like theme parks.[7] Critics of technology in museums believe that technology is a

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[4] Peter Sommerauer and Oliver Müller, "Augmented Reality in Informal Learning Environments: A Field Experiment in a Mathematics Exhibition," *Computers & Education* 79, no. Supplement C (October 1, 2014): 59–68, https://doi.org/10.1016/j.compedu.2014.07.013.

[5] "NMC Horizon Report > 2016 Museum Edition," *The New Media Consortium* (blog), 2016, https://www.nmc.org/publication/nmc-horizon-report-2016-museum-edition/.

[6] Nick Prior, "Post Modern Restructurings," in *A Companion to Museum Studies*, ed. Sharon Macdonald, 4. print, Blackwell Companions in Cultural Studies 12 (Malden, Mass.: Wiley-Blackwell, 2011), 518.

[7] Ibid.

distraction to the visitors. In the debate, we have empirical evidence on the learning applications of AR, we have museum professionals' opinions on whether technology, such as AR, should be incorporated in museums, but one voice is missing from the debate: visitors[8] As a service-based industry that ultimately answers to the public, museums must consider how visitors feel about AR. Without visitors, museums would not serve a purpose; to better serve them, we must include them in the debate.

The purpose of this study is to explore how visitors describe the value and role of AR experiences in science museums. The research questions are divided up into three questions:

1. In what ways do visitors see the value of AR in science museums?
2. How do visitors perceive the specific application of AR in science museums?
3. To what extent does augmented reality change the visitor impressions of that institution?

By utilizing a qualitative survey to explore visitor thoughts on the role and value of AR in science museums, this study hopes to better understand how visitors describe this technology as useful to their visit and if their AR experience adds value to their overall museum experience.

The significance of this study is threefold. First, museum professionals who are involved in cultivating an environment in which technology is encouraged will become more familiar with how their investment in AR technology can impact the visitor experience and visitor perceptions of the institution. It will inform museum staff on the usefulness of AR and demonstrate when and how implementation of AR is appropriate

[8] Mark Walhimer, *Museums 101* (Lanham; Boulder; New York; London: Rowman & Littlefield Publishers, 2015); Sommerauer and Müller, "Augmented Reality in Informal Learning Environments."

within an institution. Secondly, this study will contribute to an ever-growing body of literature surrounding augmented reality in museums and its best practices. Lastly, this study gives visitors a voice in which they can express their opinions on AR in museum.

Chapter 2: Literature Review

The purpose of this study is to explore how visitors describe the value and role of AR experiences in science museums. Since AR is a new phenomenon in museums, not much is known about how visitors perceive its function in informal learning environments. This chapter focuses on four main bodies of literature: 1) new media and the new museum, 2) what is augmented reality, 3) augmented reality in education, and 4) perceptions and meaning. It is important to understand the context in which the implementation of AR is surrounded, and as such, the first section focuses on new media in museums. The implementation of AR is not happening in a vacuum but is a part of an overall trend in technology adoption in museums and society. The second section informs the study as to what augmented reality is, so one can broadly understand how this technology is used, the challenges associated with AR, and its application in museums. The third body of literature explores AR in education (i.e. the understanding and comprehension of content) since it serves as the foundation of many museums' missions. Museums must have a reason to utilize AR as a technology and education is often one of those primary reasons. Specifically, this literature examines the usefulness of AR in education and the challenges associated with AR in an educational setting. Lastly, to better understand how visitors portray the value and role of AR in science museums, literature surrounding perception, attitude, and meaning was explored. This literature primarily focuses on the selection, organization, and interpretation of stimuli, and how those perceptions create attitude and meaning. Perception was explored to answer how perceptions and attitudes about objects are

formed, and meaning was explored using Geoffrey Leech's seven types of meaning to better understand how one describes value through language.

New Media and the New Museum

New media is often a catch-all term. Manovich describes new media as innate to computers, controlled by software, and rely on computers for distribution and exhibition.[9] The New Media Institute defines new media as technologies that are digital in nature which can be "manipulated, networkable, dense, compressible, and interactive."[10] For the purpose of this study, new media is described as a digital medium which can be manipulated, networkable, and interactive, which relies on computers for the dissemination of knowledge or entertainment.

New media is transforming museums. According to Michelle Henning, "advocates of new media see it as a means to modernize, popularize, and increase the efficiency of a rather staid or old-fashioned institution."[11] Those advocating for new media in museums are reacting to an ever-changing landscape for museums. As government funding for museums shrink, and a shrinking U.S. middle class, and an increase in competition for visitors, museums are looking for ways to stay relevant.[12] Mark Walhimer in Museums 101 states that, "In an era of stringent funding cuts…it is, therefore, vital that new life and excitement are injected into museums if they are to

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[9] Lev Manovich, "New Media From Borges to HTML," in *The NewMediaReader*, ed. Noah Wardrip-Fruin and Nick Montfort (Cambridge, Mass: MIT Press, 2003).

[10] New Media Institute, "New Media Institute - Internet Facts, Statistics, Research & Analysis | What Is New Media?," New Media Institute - Internet Facts, Statistics, Research & Analysis, 2018, https://www.newmedia.org/what-is-new-media.

[11] Michelle Henning, "New Media," in *A Companion to Museum Studies*, ed. Sharon Macdonald (Malden, MA: Weiley-Blackwell, 2011), 302.

[12] Henning, "New Media."; Pew Research Center, "America's Shrinking Middle Class: A Close Look at Changes Within Metropolitan Areas," May 11, 2016.

survive."[13] The quote goes on to state that "museums need to stay up-to-date in areas such as technology."[14] To stay relevant in an era of funding cuts, museums are turning to technology. It is important to note that not everyone believes that museums should incorporate new media. Henning states that "skeptics see new media as threatening the authenticity of the artifact, the authority of traditional sources of knowledge, and as vulgarizing museums, turning them into commercialized sites for 'edutainment.'"[15] Although there are some skeptics, the incorporation of new media in museums can lead to personalized visits for museum visitors, participatory experiences, and the eventual acceptance of technology in museums.

According to the New Media Consortium's 2016 Museum Horizon Report, museums are "refining how they tailor communications, content, and offerings to their audience."[16] The personalization of museum content, communication, and offerings are being implemented by creating personalized goods, such as apps, that can be customized based on visitor preferences, the filtering of targeted content, such as advertisement that are catered to a person's interest, and the creation of personalized experiences, such as the Rijksmuseum Amsterdam's CHIP project that allows users to create a profile with their art preferences.[17] Furthermore, Elizabeth Merritt at the Center for the Future of Museums states that there may be technologies on the horizon that

[13]Walhimer, *Museums 101*, 141.

[14] Ibid.

[15] Henning, "New Media."

[16] "NMC Horizon Report > 2016 Museum Edition," 14.

[17] Ibid.,14-15

can help museum educators provide personalized learning.[18] Merritt explains that museum educators should look towards adaptive learning, a technology that personalizes education based on the learner's development, needs, and learning preferences. Adaptive technology achieves this by changing content based on a learner's progress, adaptive assessment based on previous responses, and adaptive sequences which changes what a learner sees next.[19] Although these tools may still be on the horizon, museums can learn from these concepts to better personalize the museum for their visitors.

New media in museums allow visitors to partake in participatory experiences, which are experiences that allow visitors to create, share, and connect with each other around content.[20] The New Media Consortium 2016 report states that "participatory experiences are becoming the norm, both onsite and online, and museums are increasingly finding new ways to encourage and incorporate community contributions."[21] Some of the ways that museums are incorporating community contributions and participatory experiences is by using crowdfunding and crowdsourcing tools, using social media networks and hashtags to encourage engagement with artifacts, and using digital interactives within exhibits. The Chicago History Museum used Instagram as a

[18] Elizabeth Merritt, "Museums and Personalized Learning," *American Alliance of Museums* (blog), March 22, 2016, https://www.aam-us.org/2016/03/22/museums-and-personalized-learning/.

[19] Kelly Blair, "What's Happening Inside the Adaptive Learning Black Box?," EdSurge, n.d., https://www.edsurge.com/research/special-reports/adaptive-learning/definition.

[20] Nina Simon, "Chapter 1: Principles of Participation," accessed June 1, 2018, http://www.participatorymuseum.org/chapter1/.

[21] "NMC Horizon Report > 2016 Museum Edition," 18.

platform to have visitors share their own personal interpretations.[22] The American Museum of Natural History is using apps to further the participatory experience of their visitors by linking visitors to additional learning content that they may not get inside the museum.[23]

Technology acceptance can be measured based off a model designed by Fred Davis. This model uses two different constructs: perceived ease of use and perceived usefulness.[24] Perceived ease of use refers to how one believes the technology would be easy to use, while the perceived usefulness refers to how one believes the technology would be useful. Perceived ease of use and perceived usefulness correlates to how one would accept the use of a certain technology in their lives. In other words, if many people find that a technology is easy to use and useful, it is more likely to be accepted by a larger population.

Technology is accepted in museums of various disciplines. Haugstvedt and Krogstie discovered that perceived usefulness and perceived enjoyment had a positive effect on intent of use for visitors experiencing an AR cultural heritage application.[25] In other words, visitors intended to use the application due to their thoughts on the usefulness and enjoyment of the AR technology. This study, although not generalizable,

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[22] Ibid,19.

[23] Jessica Leber, "The Future Of Museums Is Reaching Way Beyond Their Walls," Fast Company, April 17, 2015, https://www.fastcompany.com/3044731/the-future-of-museums-is-reaching-way-beyond-their-walls.

[24] Fred D. Davis, "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology," *MIS Quarterly* 13, no. 3 (1989): 319–40, https://doi.org/10.2307/249008.

[25] A. C. Haugstvedt and J. Krogstie, "Mobile Augmented Reality for Cultural Heritage: A Technology Acceptance Study," in *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 2012, 247–55, https://doi.org/10.1109/ISMAR.2012.6402563.

demonstrates how AR technology is becoming more accepted by society, and as this technology is gaining acceptance, museums are beginning to experiment with it.

What is Augmented Reality?

> *I'm excited about Augmented Reality because unlike Virtual Reality, which closes the world out, AR allows individuals to be present in the world but hopefully allows an improvement on what's happening presently.*
>
> *- Tim Cook*[26]

There is no universal definition for augmented reality, and the literature surrounding AR varies in definition. Horea Avram, in the Encyclopedia of Aesthetics, describes it as an array of technologies and visualization systems that allow an overlay of virtual information on top our reality in a real-time, site-specific, interactive manner.[27] Carmignani and Furht, describes augmented reality as a "real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information," while the Virtual Reality Society states that augmented reality is a combination of the present real-world and digital imagery and sound projection. [28] Although each of these definitions describe augmented reality in different ways, there are similarities. All three definitions describe AR as a

[26] Raymond Wong, "Tim Cook Thinks Augmented Reality Is a 'Big Idea like the Smartphone,'" Mashable, February 10, 2017, https://mashable.com/2017/02/10/tim-cook-augmented-reality-opportunity-apple/.

[27] Horea Avram, "Augmented Reality," in *Encyclopedia of Aesthetics* (Oxford University Press, 2014),http://www.oxfordreference.com.offcampus.lib.washington.edu/view/10.1093/acref/9780199747108.001.0001/acref-9780199747108-e-62.

[28] Borivoje Furht and Julie Carmigniani, "Augmented Reality: An Overview," in *Handbook of Augmented Reality* (New York, NY: Springer, 2011), 3; "Augmented Reality - What Is It?," *Virtual Reality Society* (blog), May 5, 2017, https://www.vrs.org.uk/augmented-reality/.

combination of the real-world environment and some type of information overlay. The first definition is limiting in that it does not mention any indirect views of reality. Carmignani and Furht expands augmented reality's definition to the projection of computer-generated information onto indirect views of a real-world environment—such as photographs. The third definition ascribes augmented reality as not only an image projection, but as a sound projection as well; however, it is constrained by focusing on the real-world of the present. For this study, augmented reality is defined as an interactive, real-time direct or indirect view of a physical environment that has been enhanced by the superimposing of computer generated sensory information, such as images, sounds, videos, and haptics. This definition utilizes ideas from each of the aforementioned definitions to create one that encompasses all the strengths from the three different definitions.

Some may find it difficult to distinguish AR from other similar technologies. Augmented reality is not simply an image altered in Photoshop. Although it is an indirect view of a physical environment, and it can incorporate a 2D overlay, it is not, however, interactive. Moreover, motion pictures that incorporate computer-generated information, such as a mythical creature placed in a shot, is not augmented reality. This computer-generated information has been edited into the shot after the fact. Lastly, augmented reality is not virtual reality. It can be easy to confuse these two, but one overlays computer-generated information onto the real-world environment, and the other is a fully immersive environment. In fact, augmented reality and virtuality are positioned quite differently on the reality-virtuality continuum.

According to Milgram et. al. the continuum has, on one end, real environments. **Real environments** are surroundings that consist solely of real objects. They can include first-hand perceptions of a real environment, viewing real-world scenes though some type of window, and via a video display.[29] **Virtuality**, which can be described as an environment that consists solely of virtual objects, is on the other end of the spectrum. This is what many consider virtual reality. In the middle of this continuum is what scholars call **mixed reality**. Augmented reality exists on the continuum closer to real environments; whereas augmented virtuality, a completely graphic environment augmented with some "reality," is closer to virtuality.

Figure 1. Reality-Virtuality Continuum. (source: Public Domain, https://en.wikipedia.org/w/index.php?curid=14356884)

In addition to the reality-virtuality continuum as described by Milgram et. al., Barry Joseph, the Associate Director for Digital Learning at the American Museum of Natural History, created the Mooshme Matrix of Place-based Augmented Devices (Figure 2). This matrix, although museum specific, is based on user experience. The

[29] Paul Milgram et al., "Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum," ed. Hari Das, 1995, 282–92, https://doi.org/10.1117/12.197321.

matrix is divided into four sections: here, there, me, and us.[30] These four sections describe the place in which AR can be experienced (i.e. here, in the real-world environment and there, in a virtual environment), and by level of social interaction (i.e. me, being alone and we, being together in a group). Museums should strive for the here/we quadrant because it allows a visitor to be in the physical museum environment (here) while still participating in the social aspects museums offer (we). Joseph has put HoloLens™, Microsoft's wearable augmented reality headset, in the here/we quadrant.[31]

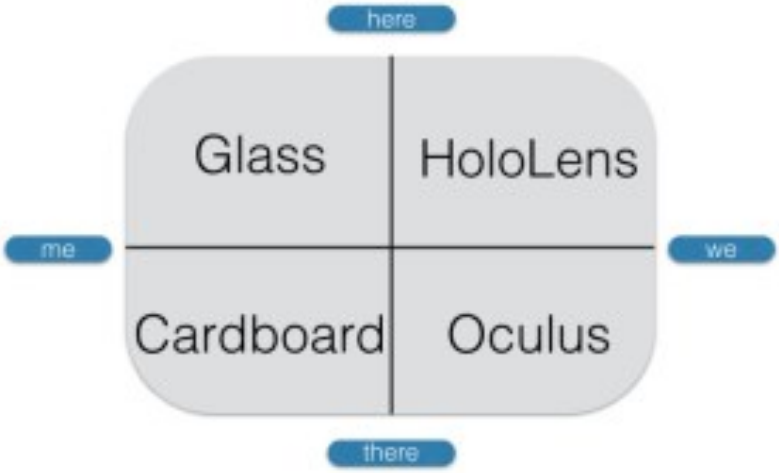

Figure 2. *Mooshme Matrix of Place-based Augmented Devices.*[32]

[30] American Alliance of Museums, "TrendsWatch2016."

[31] Barry Joseph, "Augmented Wearables and the Future of Museums | Moosha Moosha Mooshme," 2016, http://www.mooshme.org/2015/03/augmented-wearables-and-the-future-of-museums/.

[32] Joseph, "Augmented Wearables and the Future of Museums | Moosha Moosha Mooshme."

Implementation. There are four different methods for the deployment of augmented reality. **Marker-based (recognition or pattern)** augmented reality uses a camera to identify a marker (usually a QR code or some other simple shape). Once the camera identifies the marker, a computer overlays the information onto the real-world object.[33] **Marker-less (location-based)** augmented reality uses GPS, digital compass, velocity meter, or accelerometer to provide location data. This data is then used to overlay computer-generated content upon the screen. As you move around, the content moves or changes.[34] **Outline (superimposed)** augmented reality outlines parts of the body, such as hands, face, and body, or the real-world environment and overlays the computer-generated element on the outline.[35] Examples of this type include Snapchat filters and the IKEA furniture app. Mobile phones and tablets often use this type of augmented reality. Finally, **surface (projection-based)** augmented reality works by projecting computer-generated information onto a real-world surface. This type of augmented reality allows one to interacts with the computer-generated information and senses when the information is touched.[36]

Since augmented reality has recently become mainstream, there are many challenges to its implementation and adoption. Object recognition is one of the main

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[33] "The Ultimate Augmented Reality Technology Guide," Reality Technologies, 2016, http://www.realitytechnologies.com/augmented-reality; [33] Sanket Prabhu, "Types of Augmented Reality (for Me and My Business) – ARreverie Technology," December 18, 2017, http://www.arreverie.com/blogs/types-of-augmented-reality/.

[34] Ibid; Gregory Kipper and Joseph Rampolla, "Types of Augmented Reality," in *Augmented Reality: An Emerging Technologies Guide to AR*, 1st ed (Amsterdam; Boston, MA: Syngress/Elsevier, 2013).

[35] Ibid.

[36] Prabhu, "Types of Augmented Reality (for Me and My Business) – ARreverie Technology."

difficulties[37] If the real-world objects and the virtual-world objects do not align perfectly, the illusion of the two objects coexisting in the same world is shattered, and when the augmented reality technology uses sensors, such as GPS, camera, and gyroscopes, the accuracy of these sensors may inhibit the coexisting illusion[38] Moreover, some security concerns have been raised about augmented reality. According to Kipper and Rampolla, having a camera that sees everything one sees, coupled with GPS and facial recognition technology, would create an environment where one would be able to pull any data from the internet about a stranger and augment that information onto the real-world environment.[39] This would allow a stranger to know about your intimate details. Although not a reality up to this point, and a very extreme example, this scenario is possible. In addition to the technical challenges, augmented reality also faces adoption challenges, such as the learning curve. One must learn the technology before they can use it, and since it is new, some may not be familiar with how it works without proper instruction.

Augmented reality has various uses. One of the most widely known uses of augmented reality is on televised football games where a computer-generated yellow line of scrimmage is overlaid on top of an indirect view of a real-world environment (the football game) live for viewers. The line of scrimmage is considered augmented reality because it placed on the indirect view of the game in real-time. The military uses a technology called tactical augmented reality (TAR) that allows soldiers to see in the dark

[37] Kipper and Rampolla, “Types of Augmented Reality.”

[38] Kipper and Rampolla, “Types of Augmented Reality”; Furht and Carmigniani, “Augmented Reality: An Overview.”

[39]Kipper and Rampolla, “Types of Augmented Reality.”

and locate themselves, friends, and foes.[40] This allows military personnel to engage with their surroundings. The medical field uses augmented reality for education. For example, the Visual Korean Human Phantom uses technology to overlays inner organs onto a phantom (life-sized anatomically correct replica of a human), and with accurate depth perception, the organs appear to be inside the body.[41] In addition to education in the medical field, augmented reality is used widely within the general education field. More about augmented reality's use in education will be in the next section.

Implementation in Museums. Some museums have begun to experiment with augmented reality technologies, such as the Detroit Institute of Arts (DIA), the Smithsonian Museum of Natural History, and the Tech Museum of Innovation (the Tech Museum). These experiences are all different, are unique to the museum, and complements, not replaces, the museum experience. The DIA has created an app-based mobile tour called *Lumin* in which the app overlays videos, photographs, animations, and games onto DIA's collection. Some examples of AR experienced offered by *Lumin* include, but not limited to, x-ray views of a 2000-year-old mummy, the overlay of original colors on an Assyrian palace, and walking through a digital reconstruction of the gates of ancient Babylon.[42] The DIA decided to use AR because

[40]David Vergun, "Heads-up Display to Give Soldiers Improved Situational Awareness," US Army, May 19, 2017, https://www.army.mil/article/188088/heads_up_display_to_give_soldiers_improved_situational_awareness.

[41] Andrei Sherstyuk et al., "Mixed Reality Manikins for Medical Education," in *Handbook of Augmented Reality*, ed. Borivoje Furht (New York, NY: Springer, 2011).

[42] Detroit Institute of Arts, "Detroit Institute of Arts to Premiere Lumin, a Mobile Tour Using Augmented Reality, Jan. 25 Developed by DIA in Partnership with Google and Mobile Developer GuidiGO" (Detroit Institute of Arts, January 10, 2017), https://www.dia.org/about/press/news/detroit-institute-arts-premiere-lumin-mob.

they wanted to "provide visitors with new, in-depth ways to engage with the DIA's renowned collection."[43]

The Smithsonian Museum of Natural History utilizes the *Skin & Bones* app to provide visitors to the Bone Hall a different and deeper educational experience.[44] The *Skin & Bones* app superimposes virtual information, such as animations, onto the bones of various animals. The app also provides viewers with videos that immerse themselves into the environments of the animal or explains the ideas of evolution.[45] This experience also solves a problem of accessibility because it allows individuals to experience the educational aspects of the Bone Hall even if they are unable to travel to the museum. Although the best way to experience the app would be in person, one can go to the Bone Hall's website and download images that will trigger the app to augment a user's experience (*Skin & Bones* app required).[46]

The Tech Museum in San Jose, California augmented the *Body Worlds* exhibit. The augmented reality experience created by the Tech Museum utilized a tablet to transform *Body Worlds* into an "anatomy lab" in which visitors can see motion in an otherwise static experience and see "what you might otherwise see as just a 2D picture in a book."[47] Examples of the various experiences include, but are not limited to,

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[43] Ibid.

[44] Smithsonian National Museum of Natural History, "A Hall Through New Eyes: Skin & Bones," Smithsonian National Museum of Natural History, n.d., https://naturalhistory.si.edu/exhibits/bone-hall/.

[45] Ibid.

[46] Smithsonian National Museum of Natural History, "Skin & Bones" (Smithsonian National Museum of Natural History, n.d.), https://naturalhistory.si.edu/exhibits/bone-hall/Triggering_images.pdf. Downloadable images that trigger the *Skin and Bones* app can be found at this website.

[47] Dean Takahashi, "Tech Museum Embraces Augmented Reality with Body Worlds Decoded Exhibit," *VentureBeat* (blog), October 15, 2017, https://venturebeat.com/2017/10/15/tech-museum-embraces-augmented-reality-with-body-worlds-decoded-exhibit/.

exploring inside of an eyeball, seeing a moving digestive system, and dissecting a human body. AR was added to *Body Worlds* to allow visitors to explore the body more deeply and to provide more in-depth detail than just by walking through the exhibit.[48]

In addition, AR has been utilized in museum spaces without the permission of the museum. At the Museum of Modern Art (MoMA) in New York City, members of MoMAR created an unofficial augmented reality app entitled *MoMAR* to augment Jackson Pollock's artwork by overlaying computer-generated information onto the paintings to either remix the paintings or create a game.[49] *MoMAR*'s goals in augmenting the paintings was to make a statement against the elitism and exclusivity of museums.[50] MoMAR states that the "act of "opening art to the public" simultaneously closes its definition to the commons; explicitly defining both space and art as exclusive and invulnerable."[51] MoMAR's goal was to democratize the physical exhibition spaces, museums, and curation of art.[52] This example shows that AR's use in museums is not limited to officially sanctioned AR experiences, but can be an open sourced experience that can be used to critique museums and democratize the curation of art.

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[48] The Tech, "Silicon Valley Visionaries Bring Mesmerizing Exhibit to Life with Technology," *Medium* (blog), September 20, 2017, https://medium.com/@TheTech/silicon-valley-visionaries-bring-mesmerizing-exhibit-to-life-with-technology-dbcffa0e5898.

[49] Miranda Katz, "Augmented Reality Is Transforming Museums," WIRED, accessed June 1, 2018, https://www.wired.com/story/augmented-reality-art-museums/; Mack DeGeurin, "Internet Artists Invaded the MoMA With a Guerrilla Augmented Reality Exhibit," Vice, March 5, 2018, https://motherboard.vice.com/en_us/article/8xd3mg/moma-augmented-reality-exhibit-jackson-pollock-were-from-the-internet.

[50] MoMAR, "MoMAR," MoMAR, accessed June 1, 2018, http://momar.gallery/.

[51] Ibid.

[52] Ibid.

Augmented Reality and Education

Education is the most powerful weapon which you can use to change the world. - Nelson Mandela[53]

A synthesis of the literature pertaining AR has found that AR facilitates learning in museums in four ways: increasing knowledge, increase motivation, increase positive attitudes and enjoyment towards learning, and increases engagement. Various studies address one or more of these concepts and state that their findings suggest that one or more of these concepts is a way that AR can facilitate learning in individuals. It is important to understand how AR facilitates learning in museums because it will lead to a greater understanding as to how visitors will create meaning and assign value for their AR experience in science museums.

Augmented reality is useful in many cases. According to Finn, augmented reality provides multisensory engagement, intellectual engagement, and emotional connection.[54] Although Finn is focused on how businesses will find use for augmented reality, these same practices apply to museums. AR can be used to engage a visitor by utilizing touch, sight, and audial senses, inspire intellectual engagement by scaffolding knowledge and allowing for more exploration into a topic, and create an emotional connection with a visitor by personalizing a visit.

Increase in Knowledge. Augmented reality increases the comprehension of content displayed through an AR experience. According to the cognitive theory of

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[53] Valerie Strauss, "Nelson Mandela on the Power of Education," *Washington Post*, December 5, 2013, sec. Answer Sheet, https://www.washingtonpost.com/news/answer-sheet/wp/2013/12/05/nelson-mandelas-famous-quote-on-education/.

[54] Gavin Finn, "Why Augmented Reality and Virtual Reality Will Be Important for Your Business," Entrepreneur, September 12, 2017, https://www.entrepreneur.com/article/300071.

multimedia learning, the brain has two channels, audial and visual, with limited capacity.[55] The two channels, which lead to the sensory memory, organize the sensory information it receives in the working memory and integrates it with prior knowledge or long-term memory as outlined in Figure 3. Since AR utilizes computer-generated information, such as images and/or words, to help facilitate learning, AR helps an individual learn content by utilizing the combination of the audial and visual channels to decrease cognitive load. This allows information to arrive in the working memory better and integrate the new information with one's prior knowledge. The overlaying of organized and relevant computer-generated information, such as text, photos, and video, onto a real-world environment can help prevent cognitive load and lead to improved knowledge outcomes.

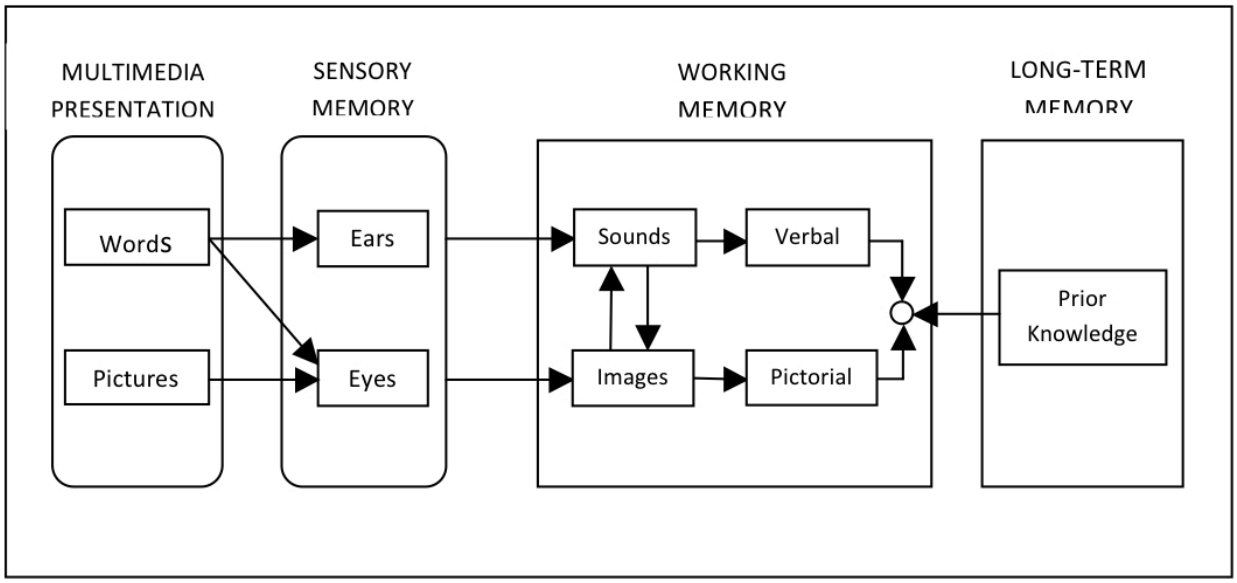

Figure 3. Cognitive Theory of Multimedia Learning. (Source: Mayer, 2005)

[55] Richard E. Mayer, *The Cambridge Handbook of Multimedia Learning* (Cambridge University Press, 2005).

Studies have shown that individuals who use an AR-based application perform higher on posttests then those who have used other means.[56] Each of these studies use a pretest/posttest research design to examine how individuals increase their comprehension of content. Each study utilizes a control group (non-augmented learning scenario) and a treatment group (augmented learning scenario). Both groups took a pretest on the concepts being taught to establish a baseline, after which all participants experienced a learning scenario based on their experiment groups. In each of the studies, a statistically significant difference in the posttest scores between the treatment and control group exist. For example, Sommerauer and Müller created a study which had each participant experience six augmented exhibits and six non-augmented exhibits. The authors found that not only did most participants (66 out of 101) perform better on the augmented posttests, but most participants (62 out of 101) had a higher score gain (which measures magnitude of learning improvement) than the non-augmented exhibits.[57]

Increase in motivation. Augmented reality increases one's motivation to learn.[58] According to Malone and Lepper, an activity is intrinsically motivating if "people engage

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[56]Paul Milgram et al., "Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum," ed. Hari Das, 1995, 282–92, https://doi.org/10.1117/12.197321; Sommerauer and Müller, "Augmented Reality in Informal Learning Environments; Susan Yoon et al., "How Augmented Reality Enables Conceptual Understanding of Challenging Science Content," *Educational Technology & Society* 20, no. 1 (2017): 156–68.

[57] Sommerauer and Müller, "Augmented Reality in Informal Learning Environments."

[58] Ibáñez et al., "Experimenting with Electromagnetism Using Augmented Reality: Impact on Flow Student Experience and Educational Effectiveness"; Murat Akçayır and Gökçe Akçayır, "Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Review of the Literature," *Educational Research Review* 20 (February 2017): 1–11, https://doi.org/10.1016/j.edurev.2016.11.002; Rafał Wojciechowski and Wojciech Cellary, "Evaluation of Learners' Attitude toward Learning in ARIES Augmented Reality Environments," *Computers & Education* 68 (October 2013): 570–85, https://doi.org/10.1016/j.compedu.2013.02.014;

in it for its own sake."[59] In informal learning environments, such as museums, people visit on their own accord and are often intrinsically motivated to engage with exhibits. Malone and Lepper assert that four kinds of learning situations are present in intrinsic learning motivations: challenge, curiosity, control, and fantasy.[60] People are intrinsically motivated by challenge; however, something too challenging can hinder one's motivation. AR's novelty can be considered a challenge. Those who have an interest in learning how to use this technology may be intrinsically motivated to engage with augmented content. However, those who find technology difficult to learn may have little motivation to participate in the technology. The sensory curiosity provided by the novelty of AR can motivate one to participate in the experience and learn more about a topic. The sensory stimulation by an AR learning tool encourages interaction with the content, which increases the prospect of one acquiring more knowledge. AR can allow one to control and manipulate computer-generated content and allows the user to be in control of their own experience. AR gives a visitor a sense of control over their visit by allowing visitors to interact more in depth with content. Lastly, fantasy, as described by Malone and Lepper, is an environment that "evokes mental images of physical or social situations not actually present."[61] The authors state that fantasies can create analogies or metaphors that can facilitate in a more comprehensive understanding of new information, and AR's use of computer-generated content allows one to create a fantasy by augmented the real-world.

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[59] Thomas W Malone and Mark R Lepper, "Making Learning Fun: A Taxonomy of Intrinsic Motiviations for Learning," in *Aptitude, Learning, and Instruction: Conative and Affective Process Analyses*, vol. 3 (Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1987), 87.

[60] Ibid.

[61] Ibid., 240

Increased positive attitude and enjoyment towards learning. Participation in an AR experience can foster a positive attitude towards learning.[62] Akçayır and Akçayır, in a literature review on the topic of advantages and challenges with AR in education, state that some learner outcomes associated with AR include adopting a positive attitude towards AR-enhanced learning activities.[63] The author's state that AR learning activities are perceived by students as more satisfying than traditional classroom activities. A more satisfying learning experience will increase one's attitude towards learning positively and can make them more motivated to learn new concepts and ideas.

In addition, studies have shown that students perceive AR-based learning as enjoyable which leads to an increase in motivation for learning. Wojciechowski and Cellary assert that "learning in image-based AR environments can be particularly attractive and evocative for younger generations, by whom it can be perceived more like edutainment than pure learning."[64] Thus, by 'playing' with AR technologies, the person is able to enjoy their learning experience.

Although participation in AR experiences can lead towards a positive attitude and enjoyment towards learning, Wojciechowski and Cellary state that the positive attitude could be due to novelty.[65] This novelty factor is important to discuss because any

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[62]Akçayır and Akçayır, "Advantages and Challenges Associated with Augmented Reality for Education."; Wojciechowski and Cellary, "Evaluation of Learners' Attitude toward Learning in ARIES Augmented Reality Environments."

[63] Akçayır and Akçayır, "Advantages and Challenges Associated with Augmented Reality for Education."

[64] Wojciechowski and Cellary, "Evaluation of Learners' Attitude toward Learning in ARIES Augmented Reality Environments," 584.

[65] Ibid.

increase in positive attitudes towards learning caused by AR could be lessened in the future once the novelty of the technology wears off. In addition, these studies have been conducted on students in an educational setting. Age of students and degree of technology familiarity could be a factor in positive learning experiences associated with AR.

Increased Engagement. Dieck, Jung, and Rauschnabel examined visitor engagement through AR at science festivals and found that the AR experience had a positive effect on engagement with science.[66] Furthermore, Akçayır and Akçayır found that AR increased engagement with learning content and increased interest in content.[67] Yoon and Wang, in studying an AR learning experience, found that students spent more time physically interacting and engaging with the AR device.[68] An increase in engagement, interaction time, and interest in content allows a learner to learn more about the content. Engagement allows a learner to better acquire knowledge by increasing their attention to a topic. An increase in interaction time, due to greater engagement, can increase the amount of knowledge acquired by allowing a person to spend more time learning the content. Increase in interest can lead to a greater

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[66] M. Claudia tom Dieck, Timothy Hyungsoo Jung, and Philipp A. Rauschnabel, "Determining Visitor Engagement through Augmented Reality at Science Festivals: An Experience Economy Perspective," *Computers in Human Behavior* 82 (May 2018): 44–53, https://doi.org/10.1016/j.chb.2017.12.043.

[67] Akçayır and Akçayır, "Advantages and Challenges Associated with Augmented Reality for Education."

[68] Susan A. Yoon and Joyce Wang, "Making the Invisible Visible in Science Museums Through Augmented Reality Devices," *TechTrends* 58, no. 1 (January 1, 2014): 49–55, https://doi.org/10.1007/s11528-013-0720-7.

motivation to learn more, and perhaps ignite a curiosity within a learner to seek out more knowledge later.

Challenges with AR in learning. Although AR can have a positive impact on learning, it can also have challenges that can lead to a negative effect on learning. These challenges, which can be summed up into technology-based challenges and user-based challenges, are about the effectiveness of technological adoption. Technological-based challenges include challenges due to the novelty of AR. With most new technology come issues that need mending, such as hardware issues. Forms of technology-based challenges include things like the technology not working, camera issues, and GPS issues. These issues can cause users frustration and lead to a lower motivation to learn and decrease one's attitudes towards the technology.

User-based challenges are challenges that involve usability of the technology. Usability is an important factor which can affect all the ways in which AR facilitates learning. People most often cite difficulty of use as a challenge facing students who participated in an AR learning experience.[69] In addition, utilizing AR as a learning tool leads to a longer training period.[70] The learning curve associated with AR technologies can hinder one's motivation, attitude, and enjoyment to learn using the technology, which results in a decrease in the amount of knowledge acquired.

These studies have mainly focused on short-term retention of learning content, and not much research has been conducted on the long-term effects of AR and

[69]Akçayır and Akçayır, "Advantages and Challenges Associated with Augmented Reality for Education."

[70]Ibid.

learning. To better understand how AR facilitates learning, one must study how AR affects long-term knowledge retention.

Perceptions and Meaning

Perception. Perception is the way one selects, organizes, and interprets sensory information.[71] One uses the five senses to take in information but are constantly bombarded with various stimuli. The brain cannot process every stimulus, and therefore needs to concentrate on the stimuli that are most salient. The salience of the stimulus is based on what one believes is important and interesting to them.[72]

After the brain selects which stimuli to concentrate on, it organizes it utilizing both bottom-up and top-down processing, where bottom-up processing is the notion that perceptions are built off sensory inputs, and top-down processing is how one interprets the sensory information by accessing their knowledge and experiences.[73] One also organizes stimuli based on proximity, similarity, and differences.[74] Once the stimuli are sorted, one interprets them based on their existing knowledge, such as one's beliefs, values, prejudices, expectations, culture, and life experiences.[75] For example, one may expect that augmented reality in museums is educational due to the environment in which it is employed, but another may have experienced augmented reality in a game

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[71] "Perception Process," in *Communication in the Real World: An Introduction to Communication Studies.* (University of Minnesota Libraries Publishing, 2013), https://open.umn.edu/opentextbooks/BookDetail.aspx?bookId=274.

[72] Ibid.

[73] Rosie M Spielman, "Sensations and Perceptions," in *Psychology* (Houston, Texas: OpenStax, 2017), https://openstax.org/details/books/psychology.

[74] "Perception Process."

[75] Spielman, "Sensations and Perceptions."; "Introduction to Perception," Lumen: Boundless Psychology, n.d., https://courses.lumenlearning.com/boundless-psychology/chapter/introduction-to-perception/.

and associate it with entertainment. These perceptions influence one's attitudes on an object.

Attitude is one's evaluation of a person, idea, or object and are informed by three components: affective, behavioral, and cognitive. These attitudes are formed in response to learning, modeling others, and direct experiences.[76] Our attitudes determine what we do, and attitudes can include varying degrees of the three components.[77] Affect is the feelings and emotions one has about an object, while cognition is one's belief and knowledge of an object.[78] For example, someone may use affective language, such as enjoyment, to describe an object or experience, while someone would use cognitive language to project a belief, such as an object having educational qualities, onto an object or experience. Someone may also describe their attitude towards an object based on how they interact with it. For example, someone may state that they do not like augmented reality, and therefore, will not engage with the technology.[79] The affective and cognitive attitudes of an individual impacts how they intend to behave in certain settings.[80]

According to Fishbein and Ajzen, it is possible that attitude can help determine one's overall intention to behave in a certain way, and in return, intention may help

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[76] Spielman, "Sensations and Perceptions."

[77] "The ABC Model of Attitudes: Affect, Behavior & Cognition - Video & Lesson Transcript," Study.com, accessed May 28, 2018, http://study.com/academy/lesson/the-abc-model-of-attitudes-affect-behavior-cognition.html.

[78] Spielman, "Sensations and Perceptions."; Jeffrey Pickens, "Attitudes and Perceptions," n.d., http://healthadmin.jbpub.com/borkowski/chapter3.pdf.

[79] Spielman, "Sensations and Perceptions."

[80] Martin Fishbein and Icek Ajzen, *Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research*, Addison-Wesley Series in Social Psychology (Reading, Mass: Addison-Wesley Pub. Co, 1975).

predict behavior.[81] However, attitudes can only predict behavior when "the social situations in which the behavior occurs is similar to the situation in which the attitude is expressed."[82] There are two types of behavior that can be expressed by the various components of attitudes. Instrumental behavior, behavior used to accomplish a goal independent of an object, and consummatory behavior, behaviors engaged in to achieve satisfaction, are driven by cognitive and affective attitudes respectively.[83] According to Millar and Tesser, "different attitudes may be obtained depending on whether current environmental conditions make affect or cognition salient."[84] In other words, one would give an affective response if affect is more salient in the environment and vice versa. Therefore, examining one's attitudes, such as affective or cognitive attitudes, can aid in the prediction of one's behavior and what aspects of attitudes are most salient for visitors.

Meaning. Semantics is a branch of linguistics that involves the study of how one conveys meaning through language.[85] There are three types of meaning: conceptual, thematic, and associative. Conceptual, sometimes called denotative or cognitive, is the logical meaning of a word, and thematic meaning is organized based on the order and emphasis of the words. Associative meaning deals with the individual understanding of

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[81] Ibid.

[82] Charles Stangor, "Exploring Attitudes," in *Principles of Social Psychology- 1st International Edition*, 2011.

[83] Murray G. Millar and Abraham Tesser, "Attitudes and Behavior: The Cognitive-Affective Mismatch Hypothesis," *ACR North American Advances* NA-17 (1990), http://acrwebsite.org/volumes/7001/volumes/v17/NA-17.

[84] Ibid.

[85] R Umagandhi and M Vinothini, "Leech's Seven Types of Meaning in Semantics," *International Journal of Multidisciplinary Research and Development* 4, no. 3 (March 2017).

a word and has six subtypes: connotative, social, affective, collocative, and reflective.[86] Connotative meaning deals with the thoughts activated by a word. Geoffrey Leech uses the example "woman."[87] He writes that the connotative meaning of "woman" could include meanings such as "maternal instinct" or "experienced in cookery."[88] The social meaning of a word gives insight into the social context, like pronunciation, of the word, and the affective meaning of a word is the emotional response to that said word.[89] Collective meaning is best described as "the associations a word acquires on account of the meanings of words which tend to occur in its environment," while the last meaning deals with the multiple conceptual meanings of a word.[90]

Conclusion

The adoption of AR does not exist in a vacuum. There has been a trend in museums to adopt technology within their exhibits, and this technology, called new media, is transforming museums. The environment in which museums traditionally operated is changing, and to keep up with the times, museums are adopting technology to stay relevant; however, critics are afraid that this adoption of technology trivializes museums. Although it may trivialize museums, AR technologies are becoming more accepted by society.

There is no universal definition for AR; however, for this study, AR is defined as an interactive, real-time direct or indirect view of a physical environment that has been

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[86] Geoffrey Leech, "Seven Types of Meaning," in *Semantics: The Study of Meaning*, Second (Middlesex, England: Penguin Books Ltd, 1981).

[87] Ibid.

[88] Ibid, 12.

[89] Ibid.

[90] Ibid, 17.

enhanced by the superimposing of computer generated sensory information, such as images, sounds, videos, and haptics. In fact, there are four different types of AR that exist: marker-based, marker-less, outline, and surface. These four AR types have potential technological and user-centered challenges associated with their adoption.

Despite these challenges, AR affords many benefits such as military combat and medical education. In fact, AR has significant potential to facilitate learning. By ascribing to the cognitive theory of multimedia learning, AR stimulates both visual and audial pathways to prevent cognitive overload. This allows the visitor to better comprehend what is being presented. AR experiences contribute to learning by increasing knowledge, increasing motivation, increasing positive attitudes and enjoyment of learning, and increasing engagement with content.

Perceptions about an object inform one's attitude towards that object. Attitude, broken down into affective, behavioral, and cognitive, can help one understand what aspects, such as cognitive or affective features of an object, are most salient with visitors. These attitudes help form intentions for people, and those intentions can help predict behaviors.

There has been scholarship on and how technology is slowly being accepted into museums, the nature of AR, and how it can facilitate education; however, not many studies focus on how the visitors perceive AR in the museum. Building upon this work, this study attempts to describe qualitatively how visitors describe the role and value of AR within science museums.

Chapter 3: Methods

The purpose of this study was to explore how visitors to science museums describe the value and role of augmented reality experiences and was guided by the following three research questions:

1. In what ways do visitors see the value of AR in science museums?
2. How do visitors perceive the specific application of AR in science museums?
3. To what extent does augmented reality change the visitor impressions of that institution?

Research Approach

This study utilized a qualitative survey approach that allowed visitors to give more in-depth, nuanced answers on how they describe the value and role of AR in science museums. A qualitative survey was utilized to allow for analysis of a diverse array of responses for as many visitors as possible. Visitor data was aggregated across all experiences because this study focused on AR as a technology and not on individual experiences. This study was conducted at two different sites with three different augmented reality experiences to provide varying perspectives that one would not be able to achieve with just one site or one experience. With multiple sites and multiple AR experiences, this study allowed for various visitor opinion and experiences to be included, strengthening the results of this study.

Site Selection

Site selection for this study was based on the institution's academic discipline and the type of AR experiences offered. Each site had a different type of AR experience that would acquire varying opinions. Science museums were chosen for this study due

to the prevalence of AR experiences within the discipline. Each site had to have their AR experience open to the public, and visitors could participate without an additional charge. A description of each site, their location, and their AR experience is outlined below in Table 1.

Table 1: Various Experiences in Study

Experience	Site	Location
Puget Sound Model-Outline AR	Pacific Science Center	Seattle, Washington
AR Sandbox - Projection AR	Lawrence Hall of Science	Berkeley, California
Dinosaurs HoloLens	Lawrence Hall of Science	Berkeley, California

Pacific Science Center. The Pacific Science Center (PacSci) is a science museum in Seattle, Washington. Their mission is to "ignites curiosity in every child and fuels a passion for discovery, experimentation, and critical thinking in all of us."[91] Their newest set of experiences, entitled *What is Reality,* highlights immersive technologies. One of these experiences is an update to the museum's Puget Sound model. The museum utilizes AR to share the geological and environmental uniqueness of the region.[92] The model uses three tablets devices to tell three different stories: lahar flows from a future Mt. Rainier eruption, the glacial history of the Puget Sound, and the watershed of the Puget Sound region (see Figure 4). The Puget Sound model uses

[91] Pacific Science Center, "About," Pacific Science Center, 2018, https://www.pacificsciencecenter.org/about/.

[92] Wall text, *Puget Sound Tide Model*, Pacific Science Center, Seattle, WA.

outline AR (outlines real-world environment to superimpose computer-generated information) to teach visitors more about the topics.

Figure 4. Puget Sound Tide Model

Lawrence Hall of Science. The Lawrence Hall of Science (LHS) is a science museum in Berkeley, California. Their mission is "to inspire and foster learning of science and mathematics for all, especially those who have limited access to science."[93] LHS uses AR to teach visitors about water flows and topography mapping. The AR sandbox allows visitors to manipulate the kinetic sand to form various landscapes (see Figure 5). The AR sandbox uses projection augmented reality to project a topographical map onto the sandbox landscape. Visitors can change the map by digging in the sandbox, and they can hold their hand above the sandbox to simulate rain and watch

[93] Lawrence Hall of Science, "About," The Lawrence Hall of Science, 2018, https://www.lawrencehallofscience.org/about.

where the water flows. Additionally, LHS uses a Microsoft HoloLens to interact with dinosaurs (see Figure 6). Visitors put on the HoloLens and experience an interactive movie about two different types of dinosaurs. Using 'air tap' (holding out one's hands in front of the HoloLens and tapping the computer-generated information in their line of sight), visitors can advance the movie to its next stage after the narrative was over.

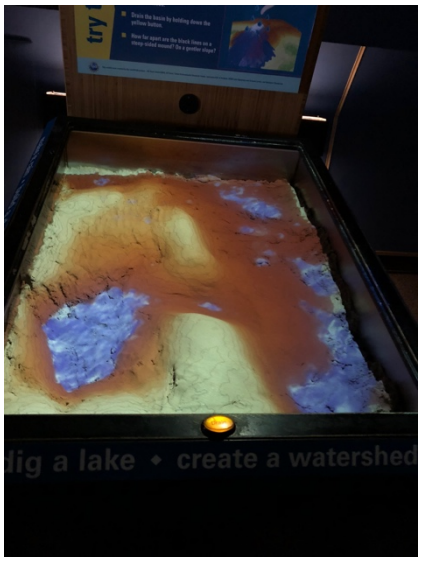

Figure 5. AR sandbox

Figure 6. Microsoft HoloLens. From: Ramadhanakbr, *English: Microsoft Hololens*, October 1, 2016, Own work, https://commons.wikimedia.org/wiki/File:Ramahololens.jpg.

Participant Selection and Recruitment

Data was collected from the Pacific Science Center between March 20, 2018 and April 6, 2018, and from the Lawrence Hall of Science from April 13, 2018 through April 15, 2018. Participants were adult visitors who were recruited within proximity of the museum's AR exhibits, and participants had to experience that technology. No other criteria were used to select participants to ensure an accurate representation of museum visitors. The visitors were watched to ensure they engaged with the technology, and after they were finished, they were approached and invited to participate in this study. Subjects were recruited using convenience sampling. On busy

days, every third adult visitor who finished the experience was approached; however, on slow days, every adult was approached.

Method

In-person interviews were conducted with visitors at each site (see Appendix A). Interviews lasted approximately five minutes and took place near the augmented reality experience. The interview asked six open-ended questions, and a series of Likert scales. The interviews were structured as follows:

- Respondents self-administered the demographic portion of the interview, followed by the series of Likert scales in question 3.
- Respondents were asked to answer question 5 orally, and answers were recorded by the data collector.
- Respondents filled out the final series of Likert scales in question four.
- Respondents were asked the remaining open-ended questions (questions 6-10)

Data Analysis Procedures

Each interview response was entered into a database. A rubric was created for open-ended questions based on emerging themes, and the data was coded based on those rubrics (see Appendix B). The Likert scales were coded based on an ordinal scale, with 1 being *Strongly disagree* and 5 being *Strongly agree*. Descriptive statistics were used to look for key trends within the data. Data was not analyzed based on site, but rather in aggregate because the nature of the study did not examine each experience by case.

Analyses were also conducted on what people said about who. Some respondents answered questions based on their own personal opinions of AR while other respondents answered questions based on how they think other people would

describe the value and role of AR (i.e. someone stating that AR provided an interactive experience for themselves versus parents citing that AR is engaging for their children). The latter may play on stereotypes, such as AR is what kids are using or older generations are not tech savvy; however, these stereotypes, although generalized assumptions, give insight into respondents' subjective perspectives on the value and role of AR in science museums.

Institutional Review Board (IRB) Exemption

This study was granted IRB exemption from the Institutional Review Board at the University of Washington on January 26, 2018.

Limitations of Study

Site Diversity. The original scope of the study aimed to aggregate visitor data from different museum disciplines – e.g., art, history, science. However, due to the novel nature of AR experiences within museums, only a limited number of sites were available. The final two sites selected were influenced by cost and time constraints as well as the ability to obtain permission for onsite data collection. Due to these constraints, rather than three different sites of different disciplines, two sites of similar discipline were chosen. The scope of this research study was narrowed to focus on science museums. Data was collected at three different experiences to ensure diversity of responses from visitors.

Sample Size. The generalizability of this study is called into question due to the limited sample size. Due to the cost and time constraints outlined above, the sample did not reach its intended goal of 60 participants. As such, it is not possible to generalize this study's results. Further research on the topic of potential usefulness of augmented

reality in science centers, and museums as a whole, would be needed to be able to generalize about the population.

Site Location. Data was collected in Seattle, Washington and Berkeley, California. Both cities are associated with a technology-based economy. This may have influenced how visitors to both institutions perceive and talk about AR as a technology.

Chapter 4: Analysis

Description of Sample

A total of 51 adult visitors participated in this study. Thirty visitors participated in Puget Sound Tide Model at the Pacific Science Center. Twenty-one individuals participated at the Lawrence Hall of Science, with five participating in the HoloLens experience and sixteen participating in the augmented reality sandbox.

Minimal demographic data was collected and focused on variables that were believed to have some bearing on technology use and adoption such as previous use of AR, familiarity with AR, and age of visitor. Almost half of respondents (43%) have used augmented reality before compared to the 57 percent that had not. When asked if they were familiar with augmented reality (letting them define their own familiarity,) 66% of visitors stated they were familiar with AR and 33% said they were not familiar with AR. Visitors' ages varied between age brackets with a notably small sample among those 55-years and older (see Figure 7). The largest age bracket surveyed was those between the ages of 35-44 (n=14).

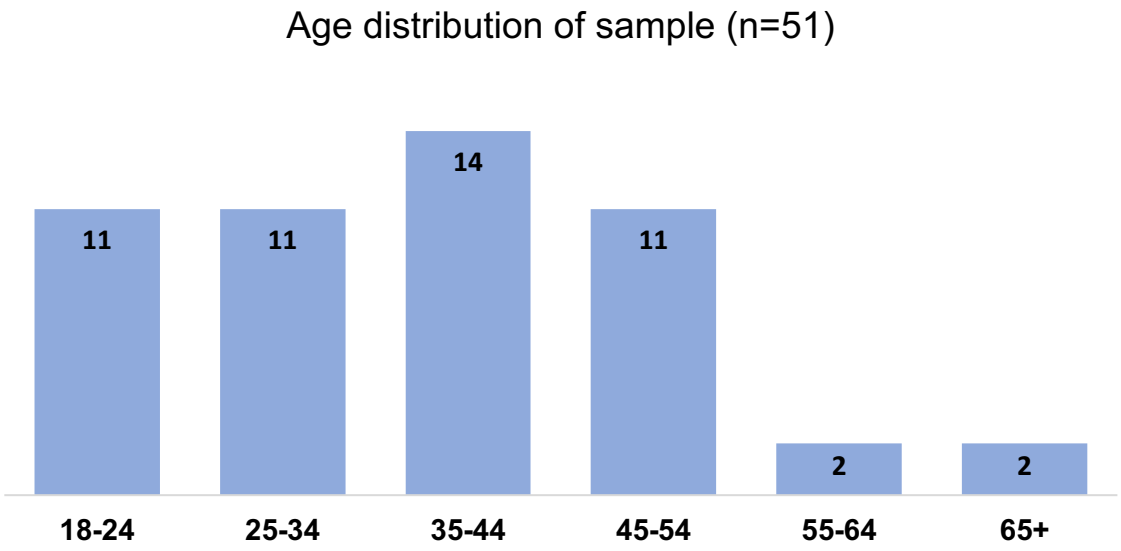

***Figure 6**: Age distribution of Sample*

The data suggests that age and familiarity is inversely related, but the small sample size makes these findings inconclusive. The general trend, as shown in Figure 8, suggests that as a visitor's age goes up, visitors tend to state that they are not as familiar with AR. Visitors aged 18-24 were most likely to state that they were familiar with AR; however, there is a spike in both familiarity and nonfamiliarity in the 35-44 age group. This could be because the 35-44 age bracket had the highest response rate. Because there were more respondents below age 55, these results show a skewedness towards a familiarity with technology.

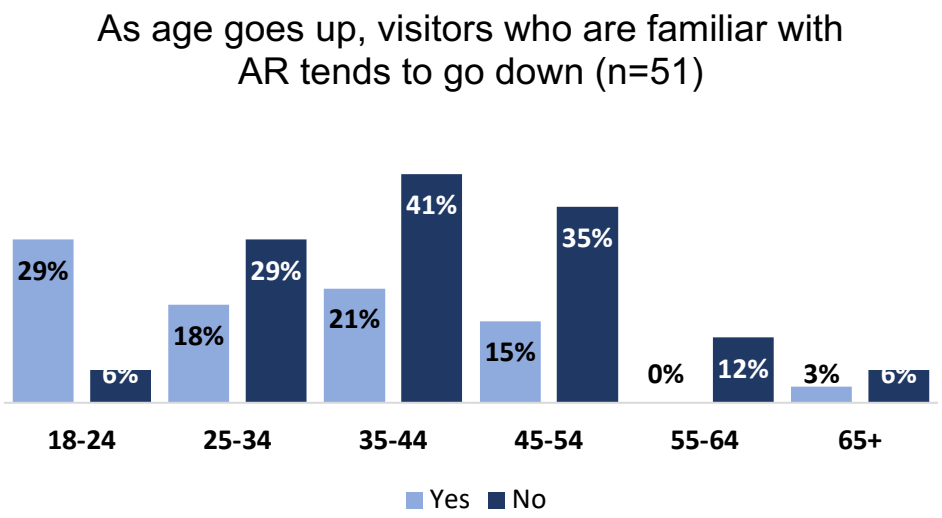

***Figure 7**: As age goes up, visitors who are familiar with AR tends to go down*

Furthermore, visitors who identified a familiarity with AR also stated that they have used AR before (n=23). This finding is not unexpected since those who have used AR before would be familiar with the technology. Again, these results may be skewed slightly due to the higher representation of respondents below 55 years of age.

Table 2: Familiarity vs Prior Use

n=51	Familiar	Not Familiar
Used Before	23	6
Never Used Before	11	11

Findings

The purpose of this research was to explore how visitors describe the value and role of AR experiences in science museums. This was done by conducting interviews with museum visitors near an augmented reality experience. Data was analyzed by looking for emerging themes within the data. The results are presented in reference to the study's three main research questions.

Research Question 1: How do visitors see the VALUE of AR in Science Museums?

Ultimately, visitors believe that **the value of AR is a positive, educational, and engaging experience**. This suggests that visitors express both affect and cognitive attitudes towards the value of AR in science museums. Research question one was explored by using three questions:

- In what ways, if at all, has your augmented reality experience contributed to your overall museum experience?
- Thinking about museums in general, do you think augmented reality is useful in enhancing a museum experience? Why or why not?
- A series of Likert scales that ask visitors to the extent in which they agree that their AR experience made their museum experience more entertaining, educational, engaging, satisfying, and personal.

Responses of visitors' descriptions of how participating in an augmented reality experience contributed to their overall museum experience can be found in Table 3. The most popular responses were: a *general educational experience* (20%), *making their museum experience more positive* (18%), and *learning more about experience specific*

*content (*12%) (i.e. learning about watersheds, thickness of glaciers). Two of the top three trends from this question state an educational aspect of their AR experience. When combining *general education* and *learning specific content* together under the broader category of 'education,' 32 percent of visitors cited this aspect of AR as contributing to their overall museum experience. In general, these findings may suggest that **visitors appreciate the educational experience that augmented reality can offer them, and by participating in augmented reality, their overall museum experience was more educational and positive.**

Table 3: In what ways, if at all, has your augmented reality experience contributed to your overall museum experience? (n=51)

Code	Percentage	Frequency
General education	**20%**	**10**
Positive experience	18%	9
Learn more about content	**12%**	**6**
Affective language	12%	6
Positive for younger generation	12%	6
Awareness of technology	10%	5
Entertaining/interesting	10%	5
More memorable	8%	4
Engagement	6%	3
Visual	6%	3
Interactive	6%	3
None	4%	2
Other	16%	8

Most visitors responded affirmatively (*Yes*) if an AR experience would be useful in enhancing a museum experience (80%). Eighteen percent of visitors had some reservations about AR in museums generally (see Table 4). Those who stated *Yes* believed that AR was more positive compared to a traditional museum experience (29%), would help with the educational pursuits of the museum (27%), and would help create interactive and participatory experiences (20%). They explained their sentiments as follows: “It’s hard to stay focused in traditional museums” and that in museums you usually “go, see, but don’t touch. No interaction there, but here you can touch, see, and participate.”

Those who stated “it depends” or “yes, but” were coded as *It depends* (18%). Those who fall into this category generally believe that there is a certain time and place for a museum to utilize AR within their exhibits. When asked to elaborate, the general trends were: *not in certain museum environments* (89%), *if the technology worked* (33%), and that AR should *complement, not replace, actual content/artifact* (33%). These responses, although not generalizable due to the limited number of participants and the setting of science museums, show that some visitors do not see the usefulness in certain museum environments (i.e. art museums). Moreover, it suggests that **an AR experience should be used to complement, not replace, an artifact, and should be tested extensively to make sure that the technology is running properly.**

Table 4: Thinking about museums in general, do you think augmented reality is useful in enhancing a museum experience? Why or why not?

Code	Percentage	Frequency
Code A: (n=51)		
Yes	80%	41
It depends	18%	9
Did not answer	2%	1
Code B: Yes		
Positive compared to traditional experience	29%	12
Educational	27%	11
Interactive/participatory	20%	8
Play/hands-on	12%	5
Fun/entertaining	10%	4
Engagement	10%	4
Attracts younger generation	7%	3
Immersive	7%	3
Another dimension	5%	2
Deeper learning	2%	1
Other	37%	15
Code C: It depends		
In certain museum environments	89%	8
If technology works	33%	3
Not to replace content/artifacts	33%	3
Other	22%	2

Visitors were also given a series of statements and asked to indicate their level of agreement on a five-point Likert scale (where 1 is *Strongly disagree* and 5 is *Strongly agree*). First, visitors were asked if their AR experience made their overall museum experience more: entertaining, educational, engaging, satisfying, and personal. This question helped gauge how visitors valued AR in science museums, and if they regarded any of the terms as a value that AR adds to a science museum. Results for these statements are found in Table 5. When determining central tendency, median is preferred when the data is heavily skewed. Note that when examining skew, there is an inverse relationship between the skew and the data. For example, the larger the negative skew, the stronger the visitors agree with the statement. Outliers were examined, but nothing conclusive could be drawn.

Table 5: This technology made my museum experience more... (n=51)

Word	Median	Skewness
Engaging	**5**	**-2.4359078**
Satisfying	4	-1.6384192
Entertaining	4	-1.5036642
Educational	4	-1.1890283
Personal	4	-0.7904839

AR made visitors' museum experience more engaging. Affective words, such as engaging and satisfying, resonated with visitors more than cognitive words, such as educational. This may suggest that affect is more salient for visitors when asked about how they personally value AR in science museums.

Second, visitors were asked to respond to a series of statements about their AR experience and how it compares to other traditional exhibit experiences. Results for these statements are detailed in Table 6.

Table 6: Research Question 1 Likert Scales (n=51)

Question	Median	Skewness
I would visit another technology experience similar to this.	5	-2.373189243
I enjoyed this technology experience today.	4	-2.214110395
I prefer a technology experience like this over a traditional exhibit experience.	4	-0.323022435

This data suggests that **visitors enjoyed their AR experience, and they would visit another experience like it**, likely due to the high level of engagement and satisfaction. However, visitors were unsure if they preferred an AR experience to a traditional museum experience. This finding is complementary to the result in Table 4 above, which states that visitors who had reservations about AR and its usefulness in enhancing a museum experience identified a certain time and place to incorporate AR, and that it should complement, not replace, traditional exhibits and artifacts.

Research Question 2: How do visitors perceive the specific application of AR in science museums?

Visitors perceive the application of AR as interactive, educational, and entertaining. Echoing the findings in the previous research question, both affective and cognitive attitudes towards the specific applications of AR in science museums are salient for visitors. Visitors also foresee issues of technological functionality and knowledge of how the technology works as some challenges associated with AR in science museums.

When visitors were asked why an exhibit designer would incorporate AR into an exhibit, *interactivity* (29%) was the most popular response (Table 7). This suggests that visitors perceive the role of AR as adding an interactive component to an exhibit. Visitors who cited *attractive to younger generation* had explained that “It appeals to generations that grew up with tablets” and “this is what kids are used to.” Those who cited *realism* described a “sense of realism” and “for getting a real-life experience.”

Table 7: Why do you think an exhibit designer would incorporate augmented reality in an exhibit? (n=51)		
Code	Percentage	Frequency
Interactivity	29%	15
Education	24%	12
Attractive to younger generation	24%	12
Realism	22%	11
Engagement	16%	8
Versatility	14%	7
Affective language	10%	5
Keeping up with modern technology	8%	4
Visual	8%	4
Enhance visitor experience	8%	4
Understanding	6%	3
Other	29%	15

Visitors primarily described the challenges of AR as *user-centered* (71%) and a *technological limitation* (41%). These two challenge categories were broken down further to gauge the types of responses recorded in each category. Categories can be found in Table 8.

The participants who cited a user-centered challenge communicated the challenges based on a personal challenge (36%) or challenges they believed others would face (56%). The latter may be due to two reasons: respondents originally had challenges and expected others to have them as well or respondents perceive others as less competent than themselves. Due to the phrasing of the question, specifically the vagueness of the words “for visitors,” both types of responses were valid. The duality of the responses demonstrates that individuals interpret the user-centered challenges as

something that they personally had or as something that they perceive others would have.

Table 8: What do you think are some of the challenges for visitors with augmented reality in a museum setting? (n=51)		
Code	Percentage	Frequency
Code A: (n=51)		
User-centered	71%	36
Technology limitation	41%	21
Other	2%	1
Did not answer	4%	2
Code B: User-centered		
Knowing how to use technology	50%	18
Needing instruction	19%	7
Accessibility	14%	5
Understanding technology's purpose	14%	5
Time constraints	8%	3
Other	14%	5
Code C: Technological Limitation		
Functionality	57%	12
Programming limitations	19%	4
Equipment safety	14%	3
Amount available	10%	2
Other	5%	1

The highest response for a user-centered challenge was *knowing how to use the technology* (71%). **Visitors were worried about understanding how to technology worked, especially for the non-tech savvy person.** When broken down further, 55

percent of visitors who cited *knowing how to use the technology* described it as a presumed challenge of other, while 45 percent described it as a personal challenge. Moreover, 19 percent of visitors who cited a *user-centered challenge* stated that more instruction was needed to fully comprehend how to work the technology. Of those who stated needing more instructions, 71 percent stated this challenge as a personal challenge. The third most frequent response was *accessibility issues* (14%). Some visitors were aware of how AR could create accessibility issues for certain visitors (i.e. the blind, individuals with epilepsy).

Visitors who cited a technological limitation as a challenge stated *functionality* (57%) at the highest frequency. These responses include "getting the technology to work properly" and citing problems like cameras not focusing and sensors and projectors not working properly. The second highest response in the technological limitation category was *programming limitations* (19%). Making sure that the technology is in full working condition and free from bugs would help negate these challenges for visitors. Analysis was conducted to examine whether perceived challenges were correlated to factors such as age or technological familiarity; however, no significant relationships were evident.

When asked if other museums should implement AR in their exhibits, responses were broken down into three categories (Table 9): With *Yes* being the most frequent response (76%), this data suggests that **visitors tend to believe that museums should be incorporating AR within their exhibits.**

Of the visitors that stated *Yes, 32* percent of visitors cited *Education*. This suggests that visitors tend to think that education plays an important role in why

museums should implement AR in their exhibits. This data reinforces results from research question one which states that visitors describe education as one of the values of AR in science museums. Those who cited an attraction to younger generations utilized the stereotype that younger people are more attracted to technology; however, this may not be the case, and since this study was not conducted on people under the age of 18, the attractiveness to younger generations cannot be cited as a role for AR in science museums.

Those who stated *it depends* most frequently implied that AR should not be implemented in *certain museum environments* (55%). This is consistent with results from Table 4 which state that AR is not useful in enhancing a museum experience for certain museum environments. Responses included “not effective in art museums, where you go to look” and “not good for outdoor exhibits and botanical gardens. You should be enjoying the exhibits and not on technology.” However, since this data was collected in science museums, and participants may not have seen how art museums and botanical gardens may utilize AR, coupled with the small number of visitor responses, no conclusions can be drawn from this data. The one person who said that other museums should not implement AR explained that they did not have a good experience with AR at the museum that day, therefore did not have a positive outlook towards future implementation.

Table 9: After experiencing augmented reality in this museum, do you think other museums should implement augmented reality in their exhibits? Why or why not?		
Code	Percentage	Frequency
Code A: (n=51)		
Yes	76%	39
It depends	22%	11
No	2%	1
Code B: Yes		
Education	32%	13
Attraction to younger generation	22%	9
Interaction	20%	8
Modern/up-to-date	20%	8
Entertainment	15%	6
Enhance experience	15%	6
Hands-on/play	12%	5
Versatility	7%	3
Increase visitorship in museums	7%	3
Interesting	7%	3
Engagement	5%	2
Accessibility	5%	2
Other	15%	6
Code C: It depends		
Certain museum environments	55%	6
Must be educational	27%	3
Appropriateness	27%	3
If it worked/done well	18%	2
Other	9%	1

Visitors were asked to respond to whether AR enhanced their enjoyment of the exhibit, and if AR helped them learn more about the topic presented in the exhibit. Using a series of statements and a five-point Likert Scale like the one previously described, visitors indicated their sentiment (Table 10). In examining the distribution of responses across the five-point scale, enjoyment had slightly more agreement responses (responses above neutral) compared to learning more about the topic. Therefore, visitors appear to feel that AR technology contributed more enjoyment than education to their exhibit experience.

Table 10: Research Question 2 Likert Scales (n=51)

Question	Median	Skewness
This technology enhanced my enjoyment of the exhibit.	5	-2.100691968
This technology experience helped me learn more about the topic.	4	-1.422959364

Enjoyment is an affect attitude while education is a cognitive attitude. This series of Likert scales asked about visitors' personal experiences and did not prime them to think about AR's role generally. Since affect attitudes towards their experience most resonated with visitors as compared to cognitive attitudes towards their experience, this finding may suggest that **affect towards AR's personal role in a museum visitor's experience is more salient to science museum visitors than cognition**.

Research Question 3: To what extent does augmented reality change the visitor impressions of that institution?

The data suggests that visitors believe that museums that utilize AR are more modern. Visitors were asked to use Likert scales to quantify how their impressions of the museum changed due to their participation in an AR experience. Visitors were given the statement "Comparing my thoughts about the museum before and after this technology experience, I now think the museum is more..." They were then given seven words to finish the statement: innovative, immersive, interactive, entertaining, stimulating, modern, and educational. Central tendency and skewness can be found in Table 11.

Table 11: Comparing my thoughts about the museum before and after this technology experience, I now think the museum is more… (n=50)

Word	Median	Skewness
Modern	5	-2.158790465
Stimulating	4	-1.703766156
Immersive	4	-1.561790928
Interactive	4	-1.523100018
Innovative	4	-1.498583946
Educational	4	-1.492267483
Entertaining	4	-1.183382203

The word that most resonated with visitors was modern. This word, meaning being in/of the present, suggests that visitors think that museum who utilize AR are keeping pace with the changing times.

To attempt to get a deeper understanding of how impressions of the museum has changed, visitors were asked an open-ended question: “thinking about your expectation of this museum prior to coming today, how, if at all, has your augmented reality experience changed your impression of the museum?” About half of respondents indicated that their perception of the museum changed because of their AR experience (Table 12).

Table 12: Thinking about your expectation of this museum prior to coming today, how, if at all, has your augmented reality experience changed your impression of the museum?

Code	Percentage	Frequency
Code A: (n=51)		
Yes	55%	28
No	31%	16
Unclear	14%	7
Code B: Yes		
Modernity	39%	11
More educational	21%	6
Affective language	21%	6
Where museums are headed	14%	4
Attractive to younger generation	14%	4
Technologically advanced	11%	3
Better compared to other institutions	4%	1
Embracing scientific process	4%	1
Other	4%	1
Code C: No		
Excepted to see	31%	5
Other	25%	4
No follow up	44%	7
Code D: Unclear		
Affective language	29%	2
Other	71%	5

Those who explicitly stated *Yes* identified *modernity* (39%) at the highest frequency. Responses categorized under modernity include “shows that it is modern, shows they are keeping up with the times” and “catching up with the times.” This finding is similar to the above finding in Table 10 when visitors were asked their level of agreement with words that would describe their changed impression of the museum. In addition to *modernity*, visitors used *affective language* (21%; see Appendix B for examples of affective language) and cited that the museum was *more educational* (21%) when describing an impression change in the museum. *No* (31%) respondents explained that they expected to see AR in this type of institution. *Unclear* (14%) respondents simply used affective language (i.e. it was cool) to describe their experience but did not provide more in-depth explanation as to their sentiment. There were no trends in comparing change in impression of museum and prior use/familiarity with AR.

Chapter 5: Conclusion

The goal of this study was to explore how visitors describe the value and role of augmented reality in science museums, and was guided by three research questions: 1) in what ways do visitors see the value of AR in science museums; 2) how do visitors perceive the specific application of AR in science museums, and 3) to what extent does augmented reality change the visitor's impressions of that institution?

Findings from this study suggest that visitors value the educational, engaging, and entertaining aspects of AR in science museums. Visitors portray both cognitive and affective attitudes towards the value of AR. The cognitive attitudes reveal themselves when visitors use cognitive words, such as education, when describing the value of AR while the affective attitudes are revealed when visitors describe the value as engaging and entertaining. This suggests that **visitors both value the way that AR helps them gain knowledge and how it makes them feel**. Visitors also perceive the specific application of AR as an interactive educational tool that is entertaining to use**.** This data follows a similar pattern to research question one, in which visitors both describe the specific application of AR in science museum exhibits cognitively (to gain knowledge) and affectively (to make them feel entertained). Therefore, since visitors describe the role and value of AR using cognitive and affective responses, and AR creates both cognitive and affective salience, this technology is used both to achieve an educational mission while promoting satisfaction with a visitor. Lastly, **visitors perceive the museum as being more modern after their AR experience**. This suggests visitors perceive museums that utilize AR as one that is contemporary and keeping up with a modern society.

Although these findings are generally positive for those who may want to incorporate AR in their own museum spaces, it is important to note that visitors were reluctant to state that they prefer an AR experience over a traditional experience. Visitors were quick to describe challenges associated with incorporating new technologies, such as system or hardware failure, and user issues, such as knowing how to work the technology**.** In examining user-centered challenges (in the sub category of personal challenge), one conclusion to be drawn is that **explicit instructions and directions, perhaps even facilitation, on how to use the AR tool is needed to ensure that visitors are not feeling a sense of failure due to not knowing how the technology works**. Other visitors were concerned about accessibility issues for certain visitors such as individuals who are blind or epileptic. Although accessibility may be a limitation of the technology, exhibit designers must make sure that individuals with a visual impairment, or those with epilepsy, do not feel left out and can access the content in some other form.

While AR is a tool that can enhance the interaction, educational, entertainment, and engagement of a museum's exhibit, one must think thoroughly if AR is an appropriate addition to a museum exhibit. Visitors believe that AR should be used for educational purposes and incorporating augmented reality into a museum exhibit just for the sake of the technology does the visitor a disservice. Technology should solve an educational problem and have specific learning goals to ensure that the technology is keeping with the standards and ideas that visitors associate with it. After all, museums exist because of the support of their visitors.

Since AR is a new technology, and one that is changing rapidly, best practices on how to utilize this technology are needed. This study is a small step in understanding visitor perspectives, and was bound by limitations such as sample size, time constraints, site diversity, and site location. Therefore, more research into visitor perceptions of AR in museums in general is needed to get a better depiction into how visitors describe the value and role of AR in museums. Visitor representation in museums of varying disciplines, such as art museums and natural history museums, as well as those under the age of 18 and over 55 and in cities with less of a technology-focused economy, is needed to better generalize findings and develop best practices. Incorporating augmented reality into museums when it is not appropriate may trivialize the visitor experience unless best practices can establish this technology as a tool catered to the expectations of museum visitors.

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Appendices

Appendix A

1. How would you rate the following statements?

	Yes	No
I used augmented reality before today.	☐	☐
I am familiar with this type of technology.	☐	☐

2. Please select your age bracket:

☐ 18-24 ☐ 45-54

☐ 25-34 ☐ 55-64

☐ 35-44 ☐ 65+

3. Thinking about your augmented reality experience today, how much would you agree or disagree with each of the follow statements?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I enjoyed this technology experience today.	☐	☐	☐	☐	☐
This technology experience helped me learn more about the topic.	☐	☐	☐	☐	☐
This technology enhanced my enjoyment of the exhibit.	☐	☐	☐	☐	☐
I prefer a technology experience like this over a traditional exhibit experience.	☐	☐	☐	☐	☐
I would visit another technology experience similar to this.	☐	☐	☐	☐	☐

4. Thinking about your augmented reality experience today, how much would you agree or disagree with the following statements?

1. Comparing my thoughts about the museum before and after this technology experience, I now think **the museum** is more:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Innovative	☐	☐	☐	☐	☐
Immersive	☐	☐	☐	☐	☐
Interactive	☐	☐	☐	☐	☐
Entertaining	☐	☐	☐	☐	☐
Stimulating	☐	☐	☐	☐	☐
Modern	☐	☐	☐	☐	☐
Educational	☐	☐	☐	☐	☐

B. Are there any other words you would use? _____

C. This technology made **my museum experience** more:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Entertaining	☐	☐	☐	☐	☐
Educational	☐	☐	☐	☐	☐
Engaging	☐	☐	☐	☐	☐
Satisfying	☐	☐	☐	☐	☐
Personal	☐	☐	☐	☐	☐

D. Are there any other words you would use? _____

Data collector:_____ Date:_____Time:_____

Location: _____ Instrument #: _____

Hello, my name is Ben Dudzik and I am a Museology graduate student at the University of Washington in Seattle. I am conducting a study about visitor perceptions of augmented reality in museums for my thesis requirement. I noticed you have just participated in the augmented reality exhibit, and I'm interested in talking to visitors like yourself. Participation in this study will involve about 5 minutes of your time. Consenting to participation in this study means you are **18 years or older**, all your answers will **remain anonymous**, and that you may be **quoted**, but without any identifying information. Participation in this study is completely voluntary, and there are no consequences for choosing not to participate. You **do not have to answer** any question you feel uncomfortable answering. Would you like to participate in my study?

(*If yes, I will proceed. If no, I will thank them for they time and wish them a great rest of their day.)*

To begin the study, I would like for you to answer a few questions on the front of this sheet. **I want you to focus on the technology, and not the content.** (*Hand them the sheet with the Likert Scales)* Please take a minute or two to answer these questions thoughtfully.

(*After they answer the questions on the sheet)* Thank you very much. I will now ask you a question that pertains to the questions that you have answered.

5. Why do you think an exhibit designer would incorporate augmented reality in an exhibit?

(*After the Guest is finished answering question 1)* Thank you very much for your response. I am now going to ask you to flip your sheet over and fill out the back side of your sheet.

(*Once the guest is finished answering the rest of the Likert scales)* I now have a couple more questions that I would like for you to answer.

6. Thinking about your expectation of this museum prior to coming today, how, if at all, has your augmented reality experience changed your impression of the museum? (*Probe: Coming to the museum today, you had a certain expectation or idea about what your museum experience was going to be like. Has the augmented reality experience changed your impression of the museum? Why or Why not?)*

7. In what ways, if at all, has your augmented reality experience contributed to your overall museum experience? (*Prompt: Could you elaborate on that more for me please? How has that contributed?)*

Now we are going to shift gears. For the last 3 questions, I would like for you to think about museums in general.

8. Thinking about museums in general, do you think augmented reality is useful in enhancing a museum experience? Why or why not? (*Probe: If you could tell an exhibit designer one thing about how useful this technology was to you, what would it be?*)

9. What do you think are some of the challenges for visitors with augmented reality in a museum setting? (*Probe: Think of a challenge you or someone in your group may have had experienced, what was it? Why is that a challenge?)*

10. After experiencing augmented reality in this museum, do you think other museums should implement augmented reality in their exhibits? Why or why not?

Appendix B

Coding rubric for open-ended questions	
Question 5: Why do you think an exhibit designer would incorporate augmented reality in an exhibit?	
Education	"it helps people learn" "it expands the ability to educate people"
Interactivity	"more interactive" "interacting with allows them to engage more"
Attractive to younger generation	"it's more interesting for kids instead of just looking and reading."
Realism	"it's a lot more realistic" "it can put you in an actual environment about you want to exhibit"
Keeping up with modern technology	"keep up with modern technology" "the way technology is moving forward"
Understanding	"It's better for understanding" "understand better the situation you are seeing"
Versatility	"you can do a lot of moving things" "there are certain things that are impossible to show with traditional exhibit."
Visual	"visual representation of topic." " I wouldn't be able to visualize it without it"
Other	Responses that did not fit into any category.
Engagement	"to better engage people of any age" "it invites deep engagement by the human subject"
Affective language	"it's a lot more fun" " it's cool"
Enhance visitor experience	"it enhances the user experience" "enhances experience by utilizing all senses"
Question 6: Thinking about your expectation of this museum prior to coming today, how, if at all, has your augmented reality experience changed your impression of the museum?	
Yes: more educational	"exploring new avenues of teaching and making science interesting and engaging"
Yes: modernity	"It makes it a lot newer. Museum X doesn't have AR in it. Shows that is modern- shows they are keeping up with the times"
Yes: affective language	"yes, its cooler" "it's an exciting feature"
Yes: technologically advanced	"gives it a high-tech spin"
Yes: better compared to other institutions	"compared to local Museum X, Pacific Science Center actually exceeded other Bay area Science Museums."

Yes: embracing scientific process	"Shows they are willing to test new things"
Yes: other	Responses that did not fit into any category.
Yes: where museums are headed	"It is what museums are moving towards."
Yes: attractive to younger generation	"it's what kids use now" "good for younger kids"
No: excepted to see	"It fits in line with what I was expecting" "expected to see it. It was not unexpected due to being a part of UC Berkeley."
No: other	Responses that did not fit into any category.
No: no follow up	No follow up was provided
Unclear: affective language	"cool that they are being innovative. Cool that they are testing out ideas for future exhibits"
Unclear: other	Responses that did not fit into any category.
Question 7: In what ways, if at all, has your augmented reality experience contributed to your overall museum experience?	
Learn more about content	"it was nice learning about thickness of glaciers" "t was helpful to explain topography to children"
Memorable	"it will be one of the more easy ones to remember" "probably one of the things I'll remember"
Awareness of technology	"it made me more aware of AR technology" "learned more about AR"
General education	"learned more from it" "it added more education to it"
Entertaining/interesting	"made it more interesting" "good-entertaining"
Positive experience	"made it more positive" "it's made it better"
Affective language	"pretty cool"
Engagement	"engage younger generation"
Visual	"very visual"
Interactive	"learning more in an interactive way"
Positive for younger generation	"positively, my kids have been here for 10 minutes straight"
No	Specifically stated that their AR experience did not contribute to their overall museum experience
Other	Responses that did not fit into any category.
Question 8: Thinking about museums in general, do you think augmented reality is useful in enhancing a museum experience? Why or why not?	
Yes: positive compared to traditional experience	"It involves that interaction experience that you don't get with other exhibits" "Yes. It's hard to stay focused in traditional museums. Its engaging."
Yes: educational	"yes, it allows for a little bit more immersive

	education" "yes- for education definitely"
Yes: interactive/participatory	" Interactive- besides staring at artifact"
Yes: play/hands on	"It's more of a hands-on thing for kids to understand how things work"
Yes: fun/entertaining	"yes, it's fun and interactive"
Yes: engagement	"I like, often go to museums and zone out. The engagement aspect will help"
Yes: attracts younger generation	"yes, it fits more with level of tech that young people use today"
Yes: immersive	"yes, it allows for a little bit more immersive education"
Yes: another dimension	"yes. it brings another dimension to experience"
Yes: deeper learning	"some element that I can explore in more depth"
Yes: other	Responses that did not fit into any category.
It Depends: in certain museum environments	"things like art museums would benefit less" "When you think about art or history, I don't think it'll fit into it"
It Depends: if technology works	"if it was more modern. The tablets were fuzzy"
It Depends: not to replace content/artifacts	"There are certain situations in which it is unnecessary. if you can get real life version over virtual, it would be better"
It Depends: other	Responses that did not fit into any category.
Question 9: What do you think are some of the challenges for visitors with augmented reality in a museum setting?	
Technological Limitation: Functionality	"the tablet- trying to get the tablet to connect" "technology actually has to work"
Technological Limitation: programming limitations	"Limited to what is preprogrammed"
Technological Limitation: amount available	"chaotic-taking turns"
Technological Limitation: equipment safety	"people breaking equipment"
Technological Limitation: Other	Responses that did not fit into any category.
User-Centered: needing instruction	"Wasn't sure what to do with technology"
User-Centered: knowing how to use technology	"learning how to use device"
User-Centered: understanding technology purpose	"fully understanding what it is meant to show you"

User Challenge: accessibility	"depends on person- epileptic episodes, etc. how to make it accessible- braille-blind"
User Challenge: Time constraints	"time waiting"
User Challenge: Other	Responses that did not fit into any category.
Question 10: After experiencing augmented reality in this museum, do you think other museums should implement augmented reality in their exhibits? Why or why not?	
Yes: entertainment	" it more fun" " can see and do and learn fun things"
Yes: education	"these types of displays enhance knowledge"
Yes: interesting	"Keeps people interested in what they are learning about"
Yes: hands on/play	"better education with a hands-on approach" "for children to explore/ play instead of looking and reading"
Yes: attraction to younger generation	"can have positive affect on kids"
Yes: interaction	"other museums are not as interactive"
Yes: engagement	"makes sense for engagement purposes"
Yes: modern/up-to-date	"stay up-to-date"
Yes: enhance experience	"yes, because kids have better experience"
Yes: Versatility	"can showcase things you otherwise wouldn't be able to"
Yes: accessibility	"people with disabilities will have more access"
Yes: increase visitorship in museums	"attract younger people to engage/go/support museums"
Yes: other	Responses that did not fit into any category.
It depends: must be educational	"if exhibit is more detailed, it can aid in the transfer of knowledge"
It depends: If it worked/done well	"If it worked, yes"
It depends: certain museum environments	"museums with collections, what would be the reason? I don't know, some types of museums shouldn't"
It depends: appropriateness	"yes. for select exhibits. it may lose impact if not appropriate"
It depends: other	Responses that did not fit into any category.