DIGITAL WONDERS:

EXAMINING AWE-INSPIRING VIRTUAL REALITY AS A TOOL TO PROMOTE CURIOSITY AND EXPLORATION

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by

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The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

DIGITAL WONDERS: EXAMINING AWE-

INSPIRING VIRTUAL REALITY AS A TOOL TO

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presented by Alex Urban,

a candidate for the degree of Doctor of Philosophy of Information Science and Learning technologies, and hereby certify that, in their opinion, it is worthy of acceptance.

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Professor Jenny Bossaller

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Professor Lissa Behm-Morawitz

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Professor Isa Jahnke

DEDICATION

To Mom and Dad, who gave me the chance to experience awe.

To Margaret, who tries to keep me present.

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Countless people have supported me throughout this journey.

When presenting a proposal early in my program, Dr. Jenny Bossaller was one of the first professors to pointedly ask “So what?” It made me pause. On top of this helpful scrutiny, she supported my qualitative mindset and scholarly wanderings within the field of Information Science.

When Dr. Danielle Oprean began her position at SISLT, I quickly asked her to be on my dissertation committee. Even before the committee, I often left her office with my head spinning, realizing how little I knew about subjective experiences with novel media (as well as quantitative methods). I am now a better scholar because of her.

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Last, I want to thank those who participated in this study. I hope you continue to experience awe.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES & PLATES

LIST OF ABBREVIATIONS

AR	Augmented Reality
MR	Mixed Reality
VR	Virtual Reality
HMD	Head-mounted Display
IPA	Interpretative Phenomenological Analysis
IRB	Institutional Review Board
5DCR	Five Dimensional Curiosity Scale Revised

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Alex Urban

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ABSTRACT

Awe is a sense of enormity that alludes comprehension. Because of awe's properties as a knowledge emotion, awe elicitors can increase awareness of knowledge gaps, boost scientific interest, and promote inquiry. However, the relationship between awe and exploratory behavior, such as information seeking, remains unclear. Using a mixed-methods approach, this dissertation asks how and to what extent awe fosters information seeking. This question was examined through a two-pronged approach. First, in a laboratory setting, participants (n = 32) were exposed to a variety of awe elicitors through a virtual reality (VR) head-mounted display. Participants' quantitative and qualitative responses were gathered immediately after exposure in the laboratory as well as 24 hours later through questionnaires. Second, a stratified sample of participants who voluntarily conducted information seeking (n = 8) completed phenomenologically-informed interviews. Findings indicate that although awe is primarily experiential, information seeking may arise from surprising learners with unknown and unexplained phenomena. Additionally, feelings of perceptual envelopment and accessing the inaccessible characterized participants' VR-based awe experiences. From a practical perspective, these findings suggest that simulating moments of discovery during travel may increase learners' intrinsic motivations for formal and informal research. Emergent findings also reveal that creating awe-inspiring VR content may require reduced

didactic information to generate feelings of presence. From a theoretical perspective, this study pushes empirical awe literature beyond the confines of laboratory settings, illustrates how understudied awe elicitors pique curiosity, and provides a nuanced, qualitative report on the phenomenon of virtually-induced awe.

CHAPTER ONE: INTRODUCTION

When I walk the fields, I am oppressed now and then with an innate feeling that everything I see has a meaning, if I could but understand it. And this feeling of being surrounded with truths which I cannot grasp amounts to indescribable awe. — Charles Kingsley (James, 1902/1982, p. 346–347).

1.1 Background

Standing on the shoreline, you look up. You see the Augustinian monastery above, jutting out of rock formations. A mix of admiration, dread, and wonder sweep over you. The sheer height of this mountain, surrounded by endless water, makes your hair stand on end. You begin to consider the lives of the monks who inhabited the unforgiving locale. How many lives were lost building this architectural feat? You take a breath and adjust your focus. Surveying the structure again, you see the oratory, the chapel where the monks worshipped. You remember that the monastery was formed sometime in the 10th century, but who is it attributed to? St. Finnia? Did he worship in this desolate place? Mind swimming, you ascend the path, curious and ready to explore.

The anecdote above demonstrates the emotions experienced during awe and how it may push people to explore. Awe is an aesthetic experience embodied by a sense of wonder and sometimes fear. People experience awe from a number of stimuli, ranging from tornados, celebrities, mathematical theories, childbirth, paintings, or, as presented in the above example, a seaside monastery. These eliciting phenomena activate the two dimensions that typify awe: a sense of vastness and a need for accommodation (Keltner & Haidt, 2003). Vastness, which may be physical or conceptual, describes the enormity of the perceived stimulus. If the awe elicitor is atypical, meaning it falls out of everyday

experience or knowledge, it may not assimilate to pre-structured mental schemas. Instead, a need for accommodation ensues. The mind shifts to stimulus-focused processing (Fiedler, 2001; Piaget, 1970, 1973), a sense of self diminishes, and interconnectedness rises (Keltner & Haidt, 2003; Rudd et al., 2012; Shiota et al., 2007; van Elk et al., 2016).

Because of this stimulus-driven processing, awe may fuel the pursuit of knowledge. As a knowledge emotion, awe has the company of similar affective states, such as surprise, interest, confusion, and curiosity. These knowledge emotions stem from goals associated with learning (Silvia, 2010). Moreover, awe's primary function may be to produce curiosity, the desire to learn and acquire new knowledge (Anderson et al., 2020; Kang et al., 2009). Empirical investigations have linked awe to interest in science (Cuzzolino, 2019; Gottlieb et al., 2018; Valdesolo et al., 2017), increased performance in learning actives (van Limpt - Broers et al., 2020), reduction of reliance on tenuous arguments (Griskevicius et al., 2010; Yee & Shiota, 2013), and increased awareness of knowledge gaps (McPhetres, 2019). Some argue that the link between all of awe's related emotions and behaviors—including spirituality (Van Cappellen et al., 2013) and prosocial behavior (Gordon et al., 2017; Piff et al., 2015; Rudd et al., 2012)—is information seeking and learning about physical and social environments (Anderson et al., 2020).

The link between awe and curiosity appears in both informal and formal learning environments. Students feel awe when they look at a *Tyrannosaurus Rex* skeleton (Shiota et al., 2007), budding archivists and archeologists feel transported when handling an artifact in a classroom (Chatterjee et al., 2008), and tourists flock to visit natural and cultural landscapes in search of awe (Hicks, 2018). Today, with increasing access to

computing technologies, researchers are using virtual reality (VR) to induce awe and investigate its impact on learning (McPhetres, 2019; van Limpt - Broers et al., 2020). VR-induced awe studies rely on the technology's ability to foster presence, generate complex stimuli, and measure user behavior with ecological validity (Chirico et al., 2016).

Despite the rise in studies concerning on awe (Schneider, 2017), little empirical research has focused on the relationship between specific awe elicitors and how they promote curiosity. If particular virtual awe elicitors do motivate exploratory behavior, such as information seeking, findings from this study will show the benefits of leveraging VR for inquiry-based curricula; awe-inspiring VR could be leveraged for to increase students' motivation to conduct authentic research. On the other hand, if virtual awe elicitors do not foster curiosity, this study's findings will present how and why the effects of the virtually-induced awe change over time as well as how this emotion evolves during exploratory behavior. In sum, dissecting participant responses (or lack thereof) may help to improve the future design of learning-oriented VR content.

1.2 Problems Addressed

In this dissertation, I examined how awe elicitors foster curiosity and exploration. Specifically, I leveraged VR to investigate responses to nature-oriented and human-made awe elicitors, users' exploratory intentions and behaviors, and the behavioral outcomes of virtually-induced awe in naturalistic settings. The possibility of using VR to foster student exploration is grounded in scholarship which shows that awe and curiosity, as knowledge emotions, are critical to learning, academic achievement, and well-being. As such, this study has practical implications for education, such as increasing intrinsic

motivation in student research. Theoretically, this dissertation also expands awe research to consider awe elicitors beyond nature-oriented phenomena. This dissertation also uncovers the lived experiences with virtual awe elicitors. The following section outlines the implications of this study and how it addresses these challenges.

1.2.1 Increasing Intrinsic Motivation in Student Research

Although research shows that awe may relate to dispositional curiosity (Anderson et al., 2020), science interest (Valdesolo et al., 2017), and knowledge gaps (McPhetres, 2019), there are not, to the best of my knowledge, any empirical studies on how awe instills curiosity and the resulting behavior of information seeking. Researchers have tested various tactics to increase motivation in student inquiry projects, such as alternate reality scenarios (Bonsignore et al., 2013), video games (Urban, 2019), and creative nonfiction (Urban et al., 2020). If awe induced by VR fosters intrinsic motivation for information seeking, stakeholders in both formal and informal learning environments may find value in incorporating virtual awe elicitors within their curricula.

1.2.2 Expanding Awe Elicitors beyond Nature-oriented Objects

Researchers have typically deployed VR to investigate responses to nature-oriented, physical awe elicitors. These elicitors are often panoramas of forests and mountains (Chirico et al., 2017, 2018; Kitson et al., 2020; Quesnel & Riecke, 2018; Rauhoeft et al., 2015) or views of Earth from space (e.g., Chirico et al., 2018; Kitson et al., 2020; McPhetres, 2019; Quesnel et al., 2018; Quesnel & Riecke, 2017; Reinerman-Jones et al., 2013; van Limpt - Broers et al., 2020). Few VR-based studies have investigated awe elicitors beyond such nature-oriented landscapes.

Human art and artifacts also induce awe. Consider the sheer size of Michelangelo's David, the heroic figures and stories of Greek mythology, or the magnitude of forces that create a single piece of art; all of these examples may instill a sense of vastness and create a need for accommodation (Keltner & Haidt, 2003). An individual may even feel that an object has an aura (Benjamin, 1935/2008), a profundity tied to its authenticity and cultural history. Similarly, museum exhibits and historic places can conjure visceral images of an earlier time and connect people with a spirit of the past (Cameron & Gatewood, 2000, 2003; Greenblatt, 1991; Latham, 2013).

Because this study explored various awe elicitors, including human-made objects, it expands the narrow focus of the current body of awe literature. Furthermore, the data produced provides insight into the specific qualities of elicitors that promote exploration.

1.2.3 Uncovering Lived Experiences with Virtual Awe Elicitors

This study also resolves the lack of research on the phenomenology of virtually-induced awe. There are concerns that VR-based awe research relies on contrived experiences that are not wholly replicative of life (Schneider, 2020, p. 102). According to Schneider, (2017), current psychological studies take a "quick boil" approach to awe. This approach, Schneider (2017) contends, simplifies self-transcendent experiences as the product of particular ingredients. Instead, Schneider suggests that researchers need to investigate awe as a "slow simmer" that includes the nuances of life and time. By taking a phenomenologically-informed, mixed-methods approach, I provide depth to the current literature on virtually-induced awe, which has relied primarily on quantitative methods. I uncover the lasting impacts of a "quick boil" approach to awe, including behavioral changes that transfer outside of the laboratory as well as how these experiences compare

to learners' long-standing memories of awe from educational settings. In doing so, I provide further information on digitally-mediated, self-transcendent experiences and how they may be used for education.

1.3 Research Questions

My over-arching goal was to determine if awe-inspiring, immersive technologies can excite learners to conduct intrinsically-motivated informal research. As such, I asked the following main research question: *How and to what extent do virtual awe elicitors foster curiosity and exploration?* Through an analysis of literature relating to awe, curiosity, and VR, I relay how awe elicitors may encourage exploratory behavior. Considering this relationship and the possibility of awe-fueled curiosity induced by VR, I asked the following supporting questions:

1. Out of a selection of virtual awe elicitors, which do participants find the most awe-inspiring and curiosity-provoking and why?
2. What, if any, information-seeking behaviors do participants adopt after exposure to virtual awe elicitors and why?
3. What do participants propose when envisioning awe-inspiring VR that motivates exploration?

1.4 Research Design

Most of the identified studies outlined in this dissertation utilize quantitative, experimental approaches with immersive technologies to investigate awe. Although these studies are valuable in that they pioneer VR-based awe research, such an approach comes with limitations. Their employed methods may (1) be too narrow and objectivizing, (2) yield transient results, and (3) lead to the perpetuation of "quick fix" forms of awe rather

than considering the effects and nuances of life across time (Schneider, 2017). By answering my research questions with a mixed-methods approach that occurs both in the lab and in naturalistic settings, this study also addresses the methodological gaps that exist in the current literature.

First, I exposed a sample of undergraduate students (n = 34) to a series of awe elicitors presented with a head-mounted VR display in a laboratory setting. After exposure, participants reported their levels of awe (Shiota et al., 2007), feelings of vastness and the need for accommodation (Yaden et al., 2019), state curiosity, and exploration intentions. Through descriptive statistics and mixed-effects logistic regressions, I determined which stimuli had the greatest effects on these quantitative variables. Then, I collected qualitative data via open-ended, text-based questions. These questions yielded insight into how and why particular awe elicitors pique participants' curiosity as well as their intentions for closing any knowledge gaps that emerged.

Next, I investigated virtually-induced awe beyond the laboratory. First, all participants completed a follow-up questionnaire 24 hours after the laboratory sessions. Again, participants reported their levels of awe, feelings of vastness and need for accommodation, state curiosity, and exploration intentions. They also described whether they conducted any exploratory behaviors to learn more about the presented elicitors. This qualitative data collection technique may shed light on how the participants' awe, curiosity, and exploratory behaviors shift over time in naturalistic environments (i.e., the participants' daily lives).

I then conducted and recorded one-on-one interviews with a stratified sample of participants (n = 8) who voluntarily conducted information seeking. I adopted a

phenomenological approach to these interviews. Phenomenology uncovers the essence of a phenomenon, typically by drawing comparisons between the experiences of several participants (Creswell & Poth, 2018). Interpretative phenomenology, in particular, promotes participant reflections and guides the researcher toward a better understanding of the participant's sense-making process with a specific experience (Smith et al., 2009). This approach illuminated the phenomenology of virtual awe experiences, which may differ from experiences of awe in naturalistic settings, as well as how and why participants sought information on the presented stimuli.

1.5 Definitions of Terms

The following definitions list highlights the main concepts covered in this dissertation:

Table 1: Definition of Terms

Awe	A positively- or negatively-valenced affective state that emerges when a perceived object's vastness prevents assimilation into pre-existing mental schemas. The vastness or enormity experienced may be perceptual or conceptual, and it is typically outside of an individual's everyday experiences. Keltner and Haidt's (2003) functional, prototypical conceptualization of awe informs this definition.
Curiosity	The awareness and desire to explore a novel, challenging, or uncertain object or event. This term may be used synonymously with interest. Kashdan's and Silvia's (2009) synthesis of theoretical writing on curiosity and interest informs this definition.
Exploration	The appetitive actions one pursues to satiate a knowledge gap, typically due to the novelty or challenge of the object or event in question. Exploratory behaviors may emerge from the (a) joy of learning or fascination or (b) deprivation, such as the discomfort of a perceived information gap. This term may be used synonymously with information seeking, as this phrase also embodies uncertainty reduction (Case & Given, 2016). Works by Berlyne (1960), Kashdan and colleagues (2004, 2009), and Litman and colleagues (2004, 2005) inform this definition.
Immersion	The extent to which a delivery system provides a surrounding environment that diminishes stimuli from the 'outside world.' Slater's

	(1999) differentiation of presence and immersion informs this definition.
Knowledge Emotion	Affective states associated with learning goals as well as individuals' beliefs regarding knowledge. These emotions include awe, curiosity and interest, surprise, and confusion. These states or beliefs are sometimes referred to as epistemic emotions. Silvia's (2010) explication of confusion and interest inform this definition.
Presence	Presence is the subjective experience of transportation that mediating devices, such as VR, may foster—a sense that 'you are there' in a virtual environment (Lombard & Ditton, 2006). People may also experience spatial presence, which refers to the conviction of being *located* within a mediated environment (Wirth et al., 2007).
Self-transcendence	An emotional state characterized by the qualitative sense that the mind has turned outward rather than inward. The self turns away from mundane or immediate needs, and an increased sense of connectedness emerges. In addition to awe, other self-transcendent experiences include mindfulness, flow, peak experiences, mystical experiences, inspiration, and elevation. Chirico's and Yaden's (2018) as well as Shiota's and colleagues' (2017) writing on self-transcendence inform this definition.
Virtual Reality	Environments that consist solely of virtual objects that are displayed via computer graphics—whether through a desktop screen or a head-mounted display. Milgram's and colleagues' (1995) conceptualization of the Reality-Virtuality Continuum informs this definition.
Virtual Awe Elicitors	Digital representations of human-made and nature-oriented objects that may instill perceptual and/or conceptual vastness.

1.6 Structure of this Study

In Chapter 2, I describe the notion of awe, highlighting its functions, the properties of physical awe elicitors, and its distinction from other self-transcendent emotions. Next, I outline how awe is a knowledge emotion alongside curiosity. With the epistemic qualities of awe and curiosity established, I then turn to the nature of immersive technologies, focusing on how they foster presence with representations of awe elicitors. With these affordances described, I present a synthesis of identified studies that use immersive technologies to elicit awe. From this review, I highlight the paucity of VR research on awe as a knowledge emotion, its limited investigation of human-made

stimuli, and the need to understand lived experiences with awe-inspiring VR so that designers may improve virtual experiences.

In Chapter 3, I outline the methodologies used to investigate the supporting research questions that emerged from the literature review. This includes descriptions of my selected methods, stimuli, data analysis, participants, and procedures. This section ends with how I ensured trustworthiness and upheld ethical standards, as well as my positionality with this research topic.

In Chapter 4, I relay the findings from this study. First, I present the outcome of the pilot study. Then, I summarize the final data produced. Next, I provide my analysis of the data and how they answer the research question. Last, I present unanticipated findings that materialized from the interview analysis that add to this study's discussion of awe, information, and inquiry.

In Chapter 5, I summarize and provide an overall interpretation of the results. Next, I discuss theoretical, methodological, and practical implications. Then, I outline potential validity threats and limitations to the study. Last, I conclude the study with future research directions.

CHAPTER TWO: LITERATURE REVIEW

For this dissertation, I examined the links between awe and curiosity by focusing on individuals' experiences with virtual awe elicitors. In this chapter, I review literature from the domains of positive and motivational psychology as well as human-computer interaction. First, I present an explication of awe. Next, I describe awe as a knowledge emotion, focusing on the need for accommodation. Following this, I present how awe relates to curiosity, another knowledge emotion. Then, I outline how exploratory behaviors satiate this knowledge emotion. Following this analysis, I describe how immersive technologies may induce awe. This is accompanied by a review of previous studies within this domain. Last, I consider a critique of empirical investigations that use VR to induce awe.

2.1 An Overview of Awe

This section provides an overview of awe. To accomplish this, I draw from Chaffee's (1991) notion of concept development. As Chaffee describes, "without explication, our words are nothing more than words, and our data add nothing to them. Theory, or more exactly, theorizing, consists of an interplay among ideas, evidence, and inference" (Chaffee, 1991, p. 14).

2.1.1 A Brief History of Awe Scholarship

Although awe is evident in ancient religious texts, such as the conversion of Paul in the Christian Bible or Arjuna's epiphany in the Hindu epic *Bhagavad-Gita* (Keltner & Haidt, 2003), the following brief history of awe is limited to scholarship on the phenomenon. Namely, this section focuses on the works of Edmund Burke, Abraham

Maslow, and William James. These influential scholars inform how behavioral scientists conceptualize awe today.

The 18th-century philosopher Edmund Burke's review of sublime experiences (Burke, 1757/2013) overlaps with today's notions of awe. Burke posited that aesthetic responses to literature, paintings, landscapes, and other awe elicitors are based on power and obscurity. Power represents the ability to destroy as well as control the perceiver's will; this differentiates awe from other aesthetic emotions, such as beauty (Keltner & Haidt, 2003). Obscurity, on the other hand, represents the perceiver's difficulty in understanding the object in question, thus aligning with current notions of the need for accommodation.

From a psychological perspective, Maslow's (1964/1994) writing on peak experiences also influences today's awe scholarship. According to Maslow, a sense of ego transcendence, disorientation of time and space, humble acknowledgement of the world, and perception of beauty characterize peak experiences. These experiences, located at the apex of human needs, have transformative qualities, such as influencing one's attitudes throughout life. This transformative ability echoes William James' (1902/1982) phenomenology of religious experiences and self-transcendent experiences.

What ultimately connects these early works is the emphasis on objects that promote a sense power, difficulty in comprehension, and transformation. Based on these influential scholars and other research in religion, sociology, philosophy, and psychology, Keltner and Haidt (2003) propose a prototypical definition of awe that behavioral researchers frequently adopt today.

2.1.2 A Prototypical Approach to Awe

Keltner and Haidt (2003) proposed the first prototypical definition of awe from a cognitive perspective. They conceptualize awe as a sense of vastness that cannot be assimilated into existing mental schemas. This inability to assimilate new, vast information creates the need for accommodation. Drawing from Piagetian theory, accommodation is the adjustment of mental structures that cannot assimilate new information (Piaget & Inhelder, 1969/2000), and stimulus-driven information processing ensues (Fiedler, 2001; Piaget, 1970, 1973; Shiota et al., 2017).

Researchers often frame emotions using a prototypical approach. Prototypical definitions establish certain features of a phenomenon, while still allowing variants when some features are missing or new elements are applied (Fehr & Russell, 1984). Thus, awe's definition has fuzzy boundaries, making it difficult to delineate sharply into a distinct concept (Rosch, 1983). However, as Keltner and Haidt (2003) explain, an 'awe family' of emotions exists that includes peripheral or 'flavoring' features. These flavors include threat, beauty, ability, virtue, and supernatural causality. Because of these flavorings, awe can be both positively and negatively valenced (Gordon et al., 2017). Physiologically, awe is frequently accompanied by goosebumps (Schurtz et al., 2012) as well as facial positions that include raised eyebrows and eyelids and loosely opened mouths (Campos et al., 2013). See Figure 1 for an illustration of awe as a two-dimensional construct and its capacity for positive and negative attributes.

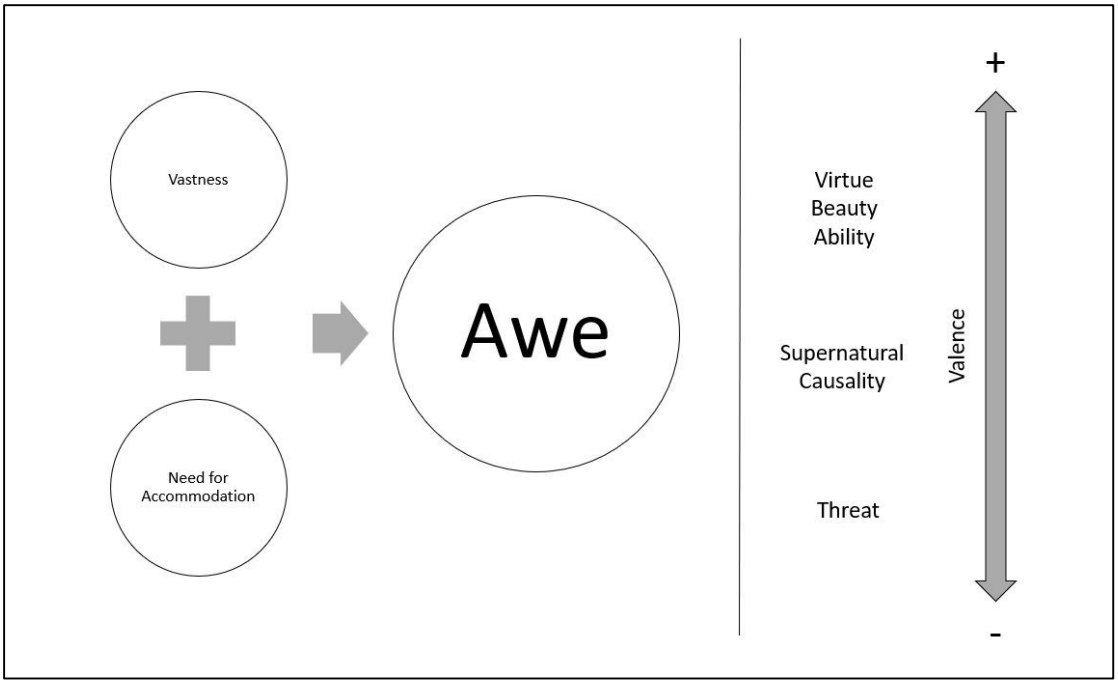


Figure 1: Awe as a Two-Dimensional Construct with a Variety of Valences (adapted from Keltner & Haidt, 2003)

Yet, what is the purpose of awe with all its positive and negative flavors? Awe may be a key function of human adaptation. Keltner and Haidt (2003) draw from the functionalist paradigm, which emphasizes emotion as an adaptive behavior to achieve goals.

The adaptive functions of awe become apparent when considering one of the three potential awe sources: social elicitors. Social awe elicitors describe individuals or groups of people who seem 'larger than life.' Keltner and Haidt explain that, from a primordial standpoint, awe-inspired subordinates may experience both fear and wonder in reaction to someone more powerful, thus facilitating social functions. From an elaborated standpoint, awe-inspiring figures may include celebrities, whose vastness stems from social size or perceived importance of the individual. Awe may also extend to people who are not famous, thus encompassing a flavor of ability or admiration. For example, skilled artisans

with exceptional ability or individuals who exhibit extraordinary virtue may also cause awe.

Another way to induce awe is through cognitive elicitors. Cognitive awe elicitors include grand theories (e.g., biological evolution, feminism, string theory, Marxism) and reactions to the supernatural. Thus, responses to cognitive elicitors may be considered culturally situated. One such response is the notion of epiphany. As Keltner and Haidt describe, epiphanies emerge once individuals form connections between what may appear to be remote individual events. As such, cognitive elicitors embody the restructuring of knowledge.

Last is physical awe elicitors. Keltner and Haidt distinguish physical elicitors between extensions to nature and human art and artifacts. Because this dissertation concerns how digital representations of objects may motivate exploration, I devote considerably more attention to these elicitors.

2.1.3 Nature-oriented Elicitors

Nature-oriented scenes are perhaps the most frequently discussed physical awe elicitors. This emphasis may stem from human preferences for the presence of trees and water, the sense of mystery provided by winding paths or hidden areas, and internally uniform regions (e.g., copses of trees, clearings, etc.) (Kaplan, 1992; Kuo et al., 1998). This affinity may be an outgrowth of evolutionary needs (Kaplan & Kaplan, 1989). However, nature-oriented settings on their own do not instill awe; the individual must experience vastness and a need for accommodation. Natural awe elicitors often include objects (e.g., mountains), events (e.g., storms), and patterns of infinite repetition (e.g., fractals in snowflakes) that instill a sense of enormity (Burke, 1757/2013). These

physically and conceptually vast awe elicitors represent the "original information-rich stimuli" (Shiota et al., 2007, p. 951).

Researchers have written extensively on the positive influences of being in nature on well-being (e.g., Berman et al., 2008; Berto, 2005; Capaldi et al., 2015; Mayer et al., 2009), and how awe toward nature increases a sense of interconnectedness (Van Cappellen & Saroglou, 2012) and prosocial behavior (Piff et al., 2015; Prade & Saroglou, 2016). Why might this sense of connection emerge from nature-induced awe? Chirico and Yaden (2018) suggest that social primordial awe first evolved from reactions to nature or natural scenery rather than powerful people. According to their view, primordial awe was first a response to unexpectedly safe shelters that offered vantage points for spotting enemies, leading to an ideal setting for prosocial behavior to occur. This emphasis on vantage points also aligns with prospect-refuge theory, which suggests that human evolution instilled an inclination to spaces that allow for observation without being seen (Appleton, 1996).

Experimental awe research frequently employs vantage points, panoramas, or tall objects as elicitors. For example, a common technique is asking participants to recall sunsets, high places, or prestigious views and then examining the effects of these memories (e.g., Piff et al., 2015; Shiota et al., 2007; Van Cappellen et al., 2013). Other research has utilized videos of panoramic views, such as mountains, valleys, and waterfalls (e.g., Rudd et al., 2012; Valdesolo & Graham, 2014; van Elk et al., 2016). Even more immersive tactics include accompanying participants to specific locales, such as groves of trees or cliffs (e.g., Davis & Gatersleben, 2013; Piff et al., 2015). Still,

possibly the most discussed and employed nature-oriented awe elicitor is the overview effect.

Drawing from interviews with astronauts, White (1987) defines the overview effect as the profound experience of viewing common landscapes from tall vantage points, such as viewing Earth from space. The overview effect not only instills perceptual vastness but also conceptual vastness, including thoughts about eternity, fragility, and the complexity of life (Keltner & Haidt, 2003; Yaden et al., 2016). Yaden and colleagues (2016) stress, however, that the overview effect is distinct from other vantage points: "But where natural features on Earth suggest enormity, a distant view of Earth also suggests totality. Unlike the Grand Canyon, for example, the planet has an incredibly rich and broad context of meanings when viewed from above" (p. 4). Images of Earth include the juxtaposition of empty space and an otherworldly sense of perspective that typical landscapes may not. Nonetheless, the overview effect describes a state of heightened awareness and mental restructuring, and this experience has been induced in previous awe studies (e.g., Gallagher et al., 2014; Rudd et al., 2012; Silvia et al., 2015).

Awe produced by vantage points may also include both positive and negative emotions. Comparing visitor experiences to wild or untamed environments (i.e., cliffs) and manicured or cultivated environments (i.e., gardens), Davis and Gatersleben (2013) found that cliffs produced both awe-inspiring and unpleasant arousal. Although the authors admit that this conclusion may not be novel, findings such as this iterate the need to move beyond one-dimensional views of positive experiences. As Burke (1757/2013) describes, the experience of transcendence can be described as beautiful, terrifying, awesome, and awful.

2.1.4 Human-made Elicitors

Human-made objects, such as architecture, art, and artifacts, may also be awesome and awful. One way that human creations elicit awe is through sheer size (e.g., statues, skyscrapers, or cathedrals), but these physical attributes may also instill conceptual vastness. Smaller objects, similarly, may promote conceptual vastness. This section reviews these perceptual and conceptual qualities through a handful of human-made awe elicitors.

Religious or monumental architecture provides a prism for investigating how vastness may be both perceptual and conceptual. Due to their representation of powerful social institutions, places of worship and monuments may elicit awe—and are often designed to do so (Francis et al., 2008). Through costly measures to increase architectural height and size, such buildings signal the competitive ability of powerful social elite and instill a sense of vertical stratification within communities (Joye & Verpooten, 2013; Trigger, 1990). This power exists even when the architecture is not actually present; images alone of high buildings can also instill awe, a sense of smallness, and a perceived sense of immobility (Joye & Dewitte, 2016). Last, it is worth noting that buildings do not gain their awesome qualities simply from vastness. Just as awe may have particular "flavors," architecture may also provoke specific feelings. For example, a dark interior within a monumental building may color awe with shades of fear (Joye & Verpooten, 2013).

Of course, human-made objects do not always have the same properties as exceptional buildings. Although Keltner and Haidt (2003) theorize that art and artifacts are more likely to elicit awe when they are larger, smaller objects may still promote

nuanced, conceptual forms of awe. Art "can produce awe by rendering exceptional moments in time that are signs of vast, powerful forces, as when seemingly trivial events foreshadow larger developments in the narrative" (Kelner & Haidt, 2003, p. 310).

Behavioral studies that utilize Keltner and Haidt's model of awe, however, typically do not focus on art or artifacts. This may be due to the abundance of discipline-specific concepts covering such objects (e.g., museology, art history, etc.). (These considerations are detailed in Section 2.5.3.) Still, an object's power to fixate individuals has been well-theorized (Dudley, 2012), and it bears some similarity to nature-oriented forms of awe. Additionally, like nature-oriented elicitors, the arresting experience of handling an artifact or fascination during a museum visit can increase well-being (Chatterjee et al., 2009; Packer & Bond, 2010)

To understand how awe may emerge from interactions with human-made objects, I briefly review four prevalent phenomena that have some parity with awe: *aura*, *resonance*, *wonder*, and *numinosity*. Shedding light on how these responses intersect with awe may illuminate the qualitative features of self-transcendent moments with human-made elicitors.

In his book titled *The Work of Art in the Age of Mechanical Reproduction*, Benjamin (1935/2008) originally posited that aura—a profound sense of presence—with an object is tied to its authenticity and sense of cultural history. Concerned with the rise of copies of fine works of art, Benjamin posited that the locale and context of creation are inseparable from an *objet d'art* and its aura. This emphasis on historical contexts echoes awe; the observer becomes less concerned with her current state and, instead, re-directs her attention to the vast cultural forces that created the object at hand.

Where Benjamin emphasized aura as a singular feeling tied with authenticity and distance, Stephen Greenblatt (1991) proposes two dimensions of aesthetic experiences with artifacts: *resonance* and *wonder*. Greenblatt concentrates on how historic artifacts can "reach beyond the formal boundaries of existence" and evoke resonance, a sense of "the complex, dynamic cultural forces from which [the artifact] has emerged" (1991, p. 42). Wonder, on the other hand, is "the power of the displayed object to stop the viewer in his or her tracks, to convey an arresting sense of uniqueness, to evoke an exalted attention" (Greenblatt, 1991, p. 42). This conceptualization is similar to other characterizations of the immobilizing potential of awe, such as "paralysis" (Solomon, 2007), "freezing" (Griskevicius et al., 2010), "passivity" (Fuller, 2008; Keltner & Haidt, 2003), and "immobility" (Shiota et al., 2011) (See Joye & Dewitte, 2016 for an overview of behavioral immobility).

Resonance and wonder bear a likeness to vastness and the need for accommodation, and some scholars treat awe and wonder as connected phenomena. Quesnel and colleagues (2018) describe wonder as the cousin of awe. Reinerman-Jones and colleagues (2013) suggest that wonder is the reflective version of awe *after* it does not fit into already-formed mental schemas. Bulkeley (2002) likewise describes wonder as the decentering of self in response to novel or powerful stimuli and the subsequent re-centering in response to creating new mental structures. Anderson and colleagues (2020) also note the conceptual overlap between awe and wonder—a term that sometimes signifies curiosity. (I further explore this connection between awe and curiosity in Sections 2.2 – 2.4.)

Greenblatt's attention to the exalted and transformative when describing resonance and wonder dovetails with Cameron and Gatewood's (2000, 2003) empirical work on numinous experiences. A numinous experience includes visceral images of an earlier time and connects people with a "spirit" or a particular time or place. Latham (2013) expands on their notion of numinosity through a phenomenology of numinous experiences. She found that four elements characterize numinous moments: (1) a sense unity of the moment, (2) the tangible form of the historic object, (3) a feeling of transportation, and (4) connections bigger than self and reflective moments.

Ultimately, these theories and models of singular moments with human-made objects may fall within the umbrella of awe experiences. We feel the cultural connections that produce the object at hand, and we situate ourselves outside of our everyday experiences and within the vast timeline of history. Similarly, we begin stimulus-driven processing, diverting our attention to the object's material qualities. Depending on the object's qualities, different flavors influence our reflection.

2.1.5 Awe as a Self-transcendent Experience

Thus far, I have described how social, cognitive, and, particularly, physical elicitors promote awe. The sense of vastness established by these elicitors diminishes a sense of self and may be described as a self-transcendent experience (Chirico & Yaden, 2018; Yaden et al., 2016). According to Yaden and colleagues (2016), self-transcendent experiences include mental states of "decreased self-salience and increased feelings of connectedness to other people and one's surroundings" (p. 3). The following section of this literature review highlights empirical studies on awe as a self-transcendent mental state.

Through a series of experimental studies, Shiota and colleagues (2007) found that participants in awe conditions (i.e., providing personal awe narratives) were more likely to feel as if they were in the presence of something greater than the self, less concerned with their day-to-day concerns, and more connected with the world. Similarly, by exposing participants awe-based narratives, videos, and *in-vivo* conditions, Piff and colleagues (2015) report that awe is positively related to a sense of connectedness that prompts prosocial behavior. Also using physically and cognitively awe-inspiring videos of nature and childbirth, Saroglou and colleagues (2008) found that awe relates to increased spirituality (but not religiosity), which led participants to state that they had transcended into a greater, vaster reality. Self-transcendence may also relate to time. Interested in determining how to shift participants' perception of time and promote well-being, Rudd and colleagues (2012) performed three studies that induced awe by using videos as well as reading and writing awe-based narratives. They found that reported awe related to decreased impatience and preference of experiential goods compared to material goods.

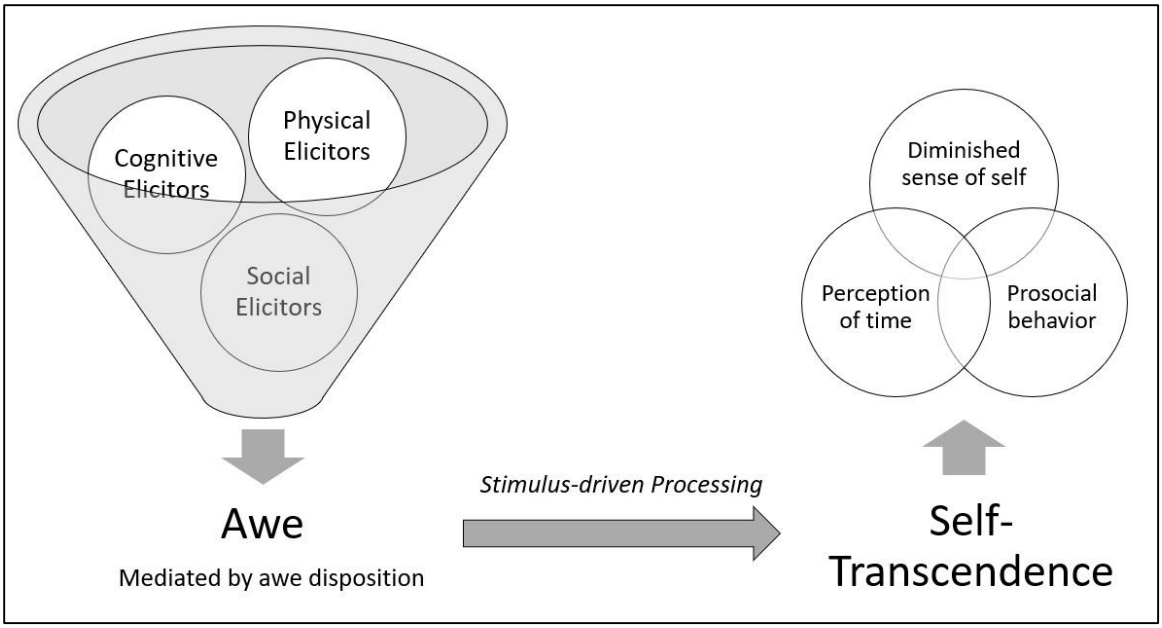


Figure 2: A representation of how elicitors and stimulus-driven processing lead to self-transcendence based on the reviewed literature.

2.1.5.1 Other Self-transcendent Experiences

Before proceeding to highlight how immersive technologies induce awe, it is worth discerning how this phenomenon (with all its fuzzy boundaries) relates to other forms of self-transcendence. Similar self-transcendent experiences include *mindfulness*, *flow*, *peak experiences*, *mystical experiences*, *inspiration,* and *elevation*. Yaden and colleagues (2017) detail these phenomena in their integrative review of self-transcendent experiences, and Shiota's and colleagues' (2017) explication of elevation and inspiration provides further insight into self-transcendence. Drawing from these works, I provide a brief outline of these experiences. (See Table 2.) In reviewing these self-transcendent experiences, what becomes apparent is awe's emphasis on the stimulus-driven processing of perceptually and/or conceptually vast objects.

Table 2: Related self-transcendent experiences

Elevation	Elevation is an uplifting emotion felt when witnessing acts of moral character. Elevation is one of the potential flavorings of awe;

	however, without the key ingredient of vastness, it constitutes its own state, which may be called a moral emotion (Haidt, 2003). Awe and inspiration are also similar in that they are discrete emotions—a complex amalgamation of responses to situations, which may serve adaptive functions, such as social cohesion (Shiota et al., 2017).
Flow	Flow represents the time-altering absorption of pleasurably challenging and interesting tasks (Csikszentmihalyi, 1991). This absorption is also associated with higher self-determination and intrinsic motivation (Kowal & Fortier, 1999). Unlike flow, however, awe is not typically linked with challenge.
Inspiration	Three dimensions characterize inspiration: (1) an awareness of possibilities better than current affairs, (2) the feeling that inspiration came from outside the individual's own will, and (3) the drive to express or actualize the instilled vision or idea (Thrash & Elliot, 2003). Thus, inspiration is interwoven with notions of creativity, the transmission of an idea or vision. It does not, however, have the same emphasis on stimulus-driven processing that characterizes awe.
Mindfulness	Mindfulness is the dissolution of self-other dualities with an emphasis on non-judgmental awareness (Davidson et al., 2003; Jha et al., 2007; Kabat-Zinn, 2005). Mindfulness, although referring to a sense of awareness, is not necessarily prompted by vastness.
Mystical Experience	During mystical experiences, an individual's position in time and space shifts beyond their immediate self. Awe is a core feature of mystical experiences (Keltner & Haidt, 2003), but it may not wholly represent insight into the nature of the universe that mystical experiences provide. This insight is often accompanied by positive behavior change, change in the meaning of life, satisfaction with life, and altruism (Griffiths et al., 2008; Griffiths et al., 2006; Streib & Hood, 2016; Yaden et al., 2017).
Peak Experience	The concept of peak experiences stems from Maslow's (1964/1994) interviews with individuals described as self-actualized. These individuals had feelings of unity with the universe, which is often developed throughout a lifetime. Awe may be involved in peak experiences, but its emphasis on atypical stimuli makes it its own distinct phenomenon.

2.2 Awe as a Knowledge Emotion

As I have outlined, awe is a sense of vastness that cannot be assimilated into pre-existing knowledge structures. Subsequently, the need for accommodation develops. Drawing from Piagetian theory, accommodation is the adjustment of mental structures that cannot assimilate the new experience (Piaget & Inhelder, 1969/2000). Stimulus-driven information processing ensues (Fiedler, 2001; Piaget, 1970, 1973; Shiota et al., 2007), and a sense of self diminishes. As Shiota and colleagues (2017) state, awe has a way of "encouraging us to transcend the self and its expectations" (p. 362).

Because of this stimulus-driven processing and outward orientation, awe may be considered part of a broader group of knowledge emotions (Keltner & Shiota, 2003). Awe has the company of similar emotions, such as surprise, curiosity or interest, and confusion (Silvia, 2010). There are different labels for knowledge emotions, such as epistemic emotions (McPhetres, 2019), epistemological emotions (Keltner & Shiota, 2003; Oatley & Johnson-laird, 1987; Shiota et al., 2007), or epistemic states (Yaden et al., 2017). These knowledge emotions may be broadly defined as affective states involved in the knowledge acquisition process (Morton, 2009; Schindler et al., 2017). Research on awe as a knowledge emotion has primarily focused on (1) the reformulation or rejection of mental schemas and (2) scientific interest, inquiry, and knowledge gaps.

2.2.1 The Reformulation or Rejection Mental Schemas

Those with a disposition to awe may have a general willingness to modify mental structures or have an increased tolerance of ambiguity. Shiota and colleagues (2007), for example, found that dispositional awe was associated with a low need for cognitive closure, a preference for 'correct' answers, and situational continuity. Interestingly, however, a series of five studies by Valdesolo and Graham (2014) show that individuals

with experimentally induced awe—or state awe—may have a decreased tolerance for ambiguity. This finding echoes writing by thinkers like Søren Kierkegaard (1843/1985) and William James (1902/1982) who describe awe as interwoven with uncertainty and a desire to find meaning in the world (Valdesolo & Graham, 2014).

Awe may also inhibit reliance on already formed knowledge structures. Griskevicius and colleagues (2010), for example, show that persuasive messages with weak arguments were more likely to persuade participants in a neutral condition compared to those who completed an awe-induction task. When repeated in comparison to other positive emotions (i.e., enthusiasm, amusement, contentment, and love), awe stood alone in preventing the influence of weak messages (Griskevicius et al., 2010). Similarly, Yee and Shiota (2013) found that awe (again, compared to other positive emotions) reduced reliance on stereotypes when rating fictional profiles. It is important to note, however, that these studies demonstrate the reduction of reliance on prior knowledge structures; they do not equate to more effective processing of information (Shiota et al., 2017).

2.2.2 Scientific Thinking and Interest, Inquiry, and Knowledge Gaps

Others suggest that awe has a relationship with scientific thinking, inquiry, and knowledge gaps. Through a series of six studies, Gottlieb and colleagues (2018) establish a positive correlation between dispositional awe and scientific thinking. Moreover, they found that that a disposition to awe in daily life predicted an appreciation of the scientific process and rejection of scientifically unwarranted beliefs. Their findings also show that this relationship was specific to awe and not other emotions, such as pride, joy, or amusement.

Cuzzolino (2019), taking a developmental approach, investigated the connections between awe and scientific inquiry among professional scientists and adolescent students in science programs. She found that awe, especially for professional scientists, may have some inward-facing impacts. For example, scientists described awe as 'fuel,' and they 'chased' that feeling throughout their careers. For the student participants, however, they had not experienced awe due to the prescriptive nature of the science programs (i.e., textbooks and lectures, replicating experiments, etc.). Such findings emphasize the importance of awe—a perception expanding, epistemic emotion—for educational endeavors.

Awe may also foster greater awareness of knowledge gaps and interest in science. Compared to a control condition, McPhetres (2019) cautiously confirms this hypothesis through a series of four quantitative studies that used videos and VR. McPhetres, however, admits that his findings are tentative; the experimental conditions consistently influenced other positive emotions (e.g., pride and love), thus pointing to the possibility that these emotions might have impacted awareness of knowledge gaps and science interest. Nevertheless, his findings are theoretically consistent with awe as a knowledge emotion. Additionally, he found that teaching participants about the stimulus just encountered (e.g., the *aurora borealis*) slightly diminished their science interest but did not decrease their awareness of their knowledge gap. He proposes that explanatory information may satisfy *curiosity*, but not necessarily larger questions regarding the epistemological system of knowledge represented by science. In the end, he suggests that further research is necessary to explore how broader, awe-induced knowledge gaps can be satisfied.

In sum, awe is a unique knowledge emotion due to its ability to stimulate the reformulation or rejection of mental schemas and increase science interest or awareness of knowledge gaps. Still, awe is like all other knowledge emotions in that it describes "people's beliefs about their own thoughts and knowledge, and these emotions stem from goals associated with learning" (Silvia, 2010, p.75). Ultimately, the over-arching goal of this study is to determine if awe-inspiring, immersive technologies can excite learners to conduct informal research. This investigation of exploratory behavior will push behavioral research on awe beyond the laboratory; I will determine if or how virtually-induced awe translates to specific learning actions. Because such actions may satiate knowledge gaps formed by awe, it is important to consider another knowledge emotion—curiosity.

2.3 Curiosity as a Knowledge Emotion

Curiosity is a positive emotion similar to enjoyment, but its association with exploration makes the concept better suited to the knowledge emotions family, which includes awe (Kashdan & Silvia, 2009). As another knowledge emotion, curiosity fosters personal growth through exploration and the creation of knowledge, which are inevitable outcomes of approaching something unfamiliar (Kashdan et al., 2004). The following section of this literature review provides an overview of curiosity and then shows possible connections between this emotion and awe.

2.3.1 An Overview of Curiosity

Curiosity has long been understood as an appetitive emotion (Arnold, 1910; Dewey, 1913). The appetite stimulation motivates people to adopt exploratory behavior, according to Berlyne's theory of the Optimal Level of Arousal (1960). This exploration is

maintained as long as the state of arousal is neither too high nor too low. Furthermore, novelty or surprise activates a reward system that generates positive affect (Berlyne, 1971). A sense of dissonance also piques arousal. Aligning with Berlyne's conceptualization of arousal, Hunt (1963) posited that new information that is dissonant with previously formed schemas or memories intrinsically motivates people. Fundamentally, the amount of curiosity someone experiences is based on recognizing something as interesting and warranting attention (i.e., novel, mysterious, uncertain, or complex objects or events) and the individual's belief that they can adequately cope with the stress of exploring that event (Kashdan et al., 2020).

It is also important to note that curiosity may be considered synonymous with interest. This thinking falls in line with Kashdan's and Silvia's (2009) synthesis of these two knowledge emotions, both of which are associated with exploratory behavior. Although some have posited the curiosity is solely aversive-based and interest is pleasure-based (e.g., Hidi & Bendorff, 1998), there is limited research proving this differentiation (Kashdan & Silvia, 2009). As Silvia (2006) notes, interest promotes learning, exploration, information seeking, and engagement with novelty; this definition is conceptually identical with curiosity.

Whether discussing interest or curiosity, the emphasis on approach orientation and subsequent exploration unites all theories of curiosity, according to Kashdan and Silvia (2009). Synthesizing theories of curiosity, they define this knowledge emotion as "the recognition, pursuit, and intense desire to explore novel, challenging, and uncertain events" (Kashdan & Silvia, 2009, p. 368). It is important to recognize that this intense desire is a form of intrinsic motivation. Intrinsic motivations are unbound from external

awards or recognition and relate to innate human needs to autonomy, relatedness, and competence (Ryan & Deci, 2000).

Last, it is worth noting that, similar to dispositional awe or awe proneness, some individuals may have a propensity for experiencing curiosity more readily, frequently, or for longer periods than others (Kashdan & Roberts, 2004). This individual difference is called trait curiosity, and, according to Kashdan and Silvia (2009), it may be related to other states, such as openness to experience (McCrae, 1996) or sensation seeking (Zuckerman, 1994). Although trait curiosity is related to state curiosity, the latter better signifies intense yet momentary feelings of curiosity that are more likely to emerge from reward, pleasure, or excitement (Kashdan & Roberts, 2004).

2.3.2 Different Curiosity Experiences

Although curiosity is typically considered as a positive motivational-emotional state (Kashdan & Silvia, 2009), curiosity can be negatively valenced. For example, Litman and Jimerson (2004) expand on Berlyne's (1954) concept of epistemic curiosity. Epistemic curiosity specifies the state of arousal that one feels in anticipation of learning something new as well as relatively unpleasant feelings derived from the knowledge gap itself (Litman & Jimerson, 2004). According to Berlyne's (1954) original conception of epistemic curiosity, unpleasant states of uncertainty that arise from the deprivation of information may be more powerful than interest or pleasure-driven forms of curiosity. Litman and Jimerson label these two forms of curiosity as interest-induction curiosity (I-type curiosity) and deprivation-elimination (D-type curiosity).

Taking a holistic perspective, Kashdan and colleagues (2020) provide a five dimensional, comprehensive framework (and accompany scale) for curiosity that accounts for different curiosity experiences along the spectrum of emotional valence. At the positive end of curiosity is the (1) *Joyous Exploration* dimension, which characterizes a love of learning and fascination that, in turn, promotes well-being. (2) *Deprivation Sensitivity*, on the other hand, describes the experience of frustration or discomfort that remains until an information gap is closed. In a similar vein, an individual's ability to cope with stress from information gaps represents the (3) *Stress Tolerance* dimension. It should be noted, however, that some individuals willingly risk undergoing stress to acquire new experiences, which encompasses the (4) *Thrill Seeking* dimension. Last is the (5) *Social Curiosity* dimension, which describes acquiring new information through social experiences.

In the end, while there are other subtypes of curiosity, such as epistemic (Litman & Spielberger, 2003), information deprivation (Litman & Jimerson, 2004; Litman & Silvia, 2006), or perceptual (Collins et al., 2004), I utilize the term curiosity holistically throughout this dissertation and in alignment with Kashdan's and Silvia's (2009) synthesis of curiosity experiences. Specifically, I follow their emphasis on the trait curiosity model. This model assumes that curiosity states and traits are psychologically equivalent, but trait curiosity influences the frequency or intensity of the state experience (Fleeson, 2001; Silvia, 2008). This comprehensive approach may be best suited to investigate the relationship between awe and curiosity.

2.4.3 Exploratory Behavior

Novel questions, unsolved problems, uncertainty, or complex ideas highlight knowledge gaps; curiosity then drives individuals to adopt exploratory behavior to close knowledge gaps. As such, exploratory behavior may be defined as the "appetitive strivings for novelty and challenge irrespective of source" (Kashdan et al., 2004, p. 296).

Berlyne (1960, 1966) suggests that there are two forms of exploratory tendencies: (1) diversive curiosity, actively seeking novelty and challenge from various sources and (2) specific curiosity, seeking depth in one's knowledge or experience with a certain activity or experience. Considering the differences between these forms, Kashdan and colleagues (2004) explain that these two types of curiosity work in tandem: diversive curiosity exposes individuals to new stimuli, and those stimuli that prompt uncertainty and complexity foster specific curiosity. They posit, however, that the objects that induce curiosity are primarily based on individual interests, expectations, and prior knowledge. Because of this variability, Kashdan and colleagues (2004) suggest focusing on absorption in exploration.

It must also be remembered that the size of a knowledge gap may influence individuals' exploratory behavior. One way to measure knowledge is through a feeling-of-knowing judgement (Loewenstein, 1994). The stronger an individual's feeling of knowing, the smaller the knowledge gap—the discrepancy between what is known and unknown information. The feeling-of-knowing state may be trisected into three qualitatively distinct levels: information that is known, on the tip-of-the-tongue, or unknown (Litman et al., 2005). Typically, tip-of-the-tongue feelings of knowing correspond with more epistemic curiosity (Litman et al., 2005). Litman and colleagues (2005) investigated the relationship between the feeling of knowing, its three levels, and

actual exploratory behavior while also considering individual differences. Their findings indicate that smaller perceived knowledge gaps were associated with more curiosity and exploratory behavior.

2.4 Linking Awe and Curiosity

Awe and curiosity share similar effects on individuals. As outlined earlier, awe has been shown to increase well-being, and curiosity may also diminish distressing states of self-awareness by pushing individuals to try new things (for a review, see Kashdan and Silvia, 2009). Trait curiosity, specifically, may even lead to a greater sense of meaning and purpose in life—or *eudemonia*—compared to those with less trait curiosity (Gallagher & Lopez, 2007; Kashdan & Steger, 2007). Furthermore, like awe, trait curiosity has been linked to greater pro-social behavior (Kashdan & Roberts, 2004) and less interpersonal aggression (Kashdan et al., 2013).

Anderson and colleagues (2020) go further, proposing that a primary function of awe is to produce curiosity, which, at its most general definition, is the desire to learn and acquire new knowledge (Kang et al., 2009). Moreover, Anderson and colleagues suggest that the link between awe behaviors and emotional states, such as prosocial behavior (Piff et al., 2015; Rudd et al., 2012; Stellar et al., 2018), spirituality (Van Cappellen et al., 2013), and interest in science (Gottlieb et al., 2018; Valdesolo et al., 2016, 2017), is information seeking and learning about physical and social environments.

Through an empirical investigation, Anderson and colleagues (2020) show a relationship between dispositional awe and trait curiosity while controlling for openness to experience and other positive emotion dispositions. They found that dispositional awe was positively related to self-rated and peer-rated curiosity. Moreover, they determined

that dispositional awe via curiosity was related to academic outcomes—in this case, work ethic, behavioral engagement, and academic self-efficacy—of high-school students (Anderson et al., 2020). Although Anderson and colleagues find a directional influence of awe on curiosity, this relationship does not necessarily embody causality. They suggest experiments focusing on state-level curiosity may be necessary to determine if the effects of awe are stronger than other positive or knowledge emotions.

In sum, there are theoretical connections and nascent empirical evidence of the relationship between awe and curiosity. With a variety of possible elicitors that may prompt either awe or curiosity, I arrived at my first supporting question: *RQ1. Out of a selection of virtual awe elicitors, which do participants find the most awe-inspiring and curiosity-provoking and why?* By first uncovering why specific elicitors prompt awe, curiosity, or an amalgamation of the two emotions, I then shifted my attention to my second supporting research question: *RQ2. What, if any, information-seeking behaviors do participants adopt after exposure to virtual awe elicitors and why?* I focus on information seeking as a concrete appetitive action one pursues to satiate a knowledge gap. Information seeking may be used synonymously exploratory behavior, both phrases embody uncertainty reduction (Case & Given, 2016). By pursuing these questions, I aimed to reveal the relationship between awe, curiosity, and exploration.

2.5 Immersive Technologies and Awe

Having drawn the connection between awe and curiosity, I now turn to how immersive technologies present curiosity-piquing awe elicitors and review previous studies within this domain.

Many of the awe elicitors described thus far, like grand panoramas or archeological treasures, are only accessible to individuals with particular privileges, such as physical ability or financial means (Quesnel & Riecke, 2018; Stepanova et al., 2018). Immersive technologies like VR, however, have been shown to elicit responses similar to real scenarios, making it an attractive tool for psychological research (Wilson & Soranzo, 2015). Furthermore, self-transcendent experiences like awe are rare, extremely subjective, and difficult to study, thus requiring the ability to create nuanced elicitors (Levin & Steele, 2005). Scholars recognize the affordances of immersive technologies for inducing and measuring self-transcendence. This attention has given the rise to interdisciplinary fields, such as Positive Technologies (see Kitson et al., 2018 for a review), and subdomains, such as Computer-Mediated Self-transcendence (Gaggioli et al., 2016). Scholarship on these topics emphasizes the use of hedonic technologies to instill positive emotions, eudaimonic technologies to promote self-actualization, and interpersonal technologies to increase social engagement and interconnectedness (Riva et al., 2012). Thus, immersive technologies provide the means for investigating human experiences beyond the minutia of daily life that may not be otherwise accessible.

Within this budding discipline, Chirico and colleagues (2016) see the potential of VR especially for studying awe. They suggest that laboratory experiments designed to evoke awe have typically only been able to induce low-intensity versions of the phenomenon. To remedy this challenge, they suggest that VR may be a valuable tool for fostering presence and ecological validity, generating complex stimuli, and measuring user behavior. Before reviewing how researchers have used immersive technologies to

induce awe, however, we must consider mediating devices and their influence on users' affective reactions.

2.5.1 Immersion, Presence, and Absorption

Because researchers now tout VR as a way to generate awe, it is crucial to differentiate user responses to immersive technologies, such as immersion, presence, and absorption. Although a complete synthesis of these key concepts and related terms lies outside this proposal's scope (see Oprean, 2014 for an explication), these user responses warrant review.

Immersion refers to the extent that a delivery system provides a surrounding environment that diminishes stimuli from the 'outside world' (Slater, 1999). Rather than signifying just the user's response to the mediated *experience*, such as the definition proposed by Witmer and Singer (1998), Slater (1999) emphasizes the *system's* affordances—including the hardware, software, and delivered content.

Once immersion is accomplished, presence may emerge. Presence is the subjective experience of transportation that mediating devices may foster—a sense that 'you are there' in a virtual environment (Lombard & Ditton, 1997). Slater (1999) proposes two additional elements that fall under presence: (a) the extent to which the virtual environment becomes the dominant frame of reference and (b) the sensation of having visited a 'place' rather than just seeing images. Heeter (1992) proposes that this transportation to a different place rests on three forms of presence: (1) personal presence (2) social presence, and (3) environmental presence.

Because awe elicitors are often environments within which an individual is positioned (e.g., a forest or a cathedral), spatial presence is particularly important for this

dissertation. Spatial presence, a subtype of presence, refers to the conviction of being *located* within a mediated environment (Wirth et al., 2007). Although Wirth and colleagues (2007) note that human imagination can promote spatial presence to a certain extent, this definition emphasizes the mediated environment's ability to foster a sense of embodiment.

Wirth and colleagues use a two-level approach to describe the process of spatial presence. First, the individual must construct a mental model of the spatial situation using space-related information presented by the medium. The attention allocated to this space-related information affects the development of the spatial model. Attention may be (a) involuntarily due to the medium triggering certain stimuli (i.e., media-induced) or (b) voluntary based on user interest or enjoyment (i.e., user-directed). Involuntary attention allocation may stem from a constant stream of highly detailed information as long as that information does not overwhelm the user and cause fatigue (de Rijk et al., 1999). Voluntary attention allocation, on the other hand, explains the user's motivation for attending to specific information. For example, a user with a domain-specific interest (Krapp et al., 1992) in astronomy may voluntarily allocate attentional resources to the content if it concerns the overview effect.

Once the user creates a spatial model based on attention to information, a perceptual hypothesis forms. This hypothesis accepts the presented environment as the primary-ego reference frame rather than the outside world. If that perceptual hypothesis is confirmed, the mediated environment is accepted, and spatial presence emerges.

The formation and preservation of spatial presence also rely on media factors and user factors. Media factors may include persistence, such as the steady stream of the

stimulus and supporting elements, such as narrative, drama, and plot. Other elements include realism of the stimulus presented and the amount of interactivity afforded to the individual. User factors include involvement, suspension of disbelief, and absorption. Involvement is a motivation construct that describes the act of *willingly* thinking about the content, such as appraising a particular narrative within the environment. Suspension of disbelief is the act of *not* attending to external or internal stimuli that might distract the user from enjoying the stimulus. Disbelief may be technology-oriented, such as actively ignoring the weight of a VR head-mounted display, or content-oriented, such as disregarding incongruous narratives or information.

Last and most important to the formation of spatial presence, according to Wirth and colleagues (2007), is absorption. Absorption refers to the hypnotic-like state of total attention or fascination with an object (Tellegen & Atkinson, 1974). Of particular importance to spatial presence is trait absorption, the disposition of becoming completely attuned to an object at hand. High-absorption individuals are more likely to become involved with media and fascinated with less effort (Wirth et al., 2007).

In sum, spatial presence represents a two-level process of feeling located within media content. This presence relies on the immersive abilities of the system as well as user factors. Because of VR's ability to generate high-fidelity representations of particular environments, spatial presence is key for the user's perception of virtual awe elicitors. With this connection established, I now turn to previous research that utilizes immersive technologies to present awe elicitors.

2.5.2 Previous Investigations of Awe with Immersive Technologies

The following section of this proposal surveys how researchers are leveraging immersive technology to elicit awe as well relevant research gaps in the literature. I compiled this set of peer-reviewed articles and conference proceedings by searching the following databases: ACM Digital Library, IEEE, PsycINFO, ERIC, Library Literature & Information Science, and Scopus. Although this proposal primarily concerns autonomous VR experiences—which do not require visiting a physical place—this literature review draws from augmented-reality (AR) and mixed-reality (MR) studies when applicable to investigations of awe.

The Boolean logic for these searches focused on terms located in the abstracts of peer-reviewed articles and conference proceedings. Specifically, I used the string: "Awe" OR "Self-transcendent" OR "self-transcendence" AND "Virtual reality" OR "VR" OR "Augmented reality" OR "AR" OR "Video game" OR "Simulated" OR "Simulation" OR "Gaming." I also conducted Google Scholar searches using these terms. I did not apply limits for publication year. The date of the latest search was January 26, 2021. After screening by title and abstract for relevance, 13 papers emerged that focused on the use of immersive technologies to elicit awe.

2.5.2.1 Elicitors Employed in Previous Works

Except for Quesnel and Riecke (2018, 2017), the identified studies used only nature-oriented elicitors. Frequently, these were representations of terrestrial stimuli, such as trees, mountains, and water. Some virtual landscapes included forests generally to instill vastness (Kitson et al., 2020; Quesnel et al., 2018), whereas others focused on tree height (Chirico et al., 2017, 2018). Rauhoeft and colleagues (2015) took a different approach by incorporating trees to increase the density of space and reduce vastness.

Another commonly employed elicitor was mountains or panoramas from mountaintops (Chirico et al., 2018; Quesnel & Riecke, 2018; Rauhoeft et al., 2015). The explicit inclusion of water only appeared in two studies (Chirico & Gaggioli, 2019; Quesnel et al., 2018), and only one study focused on tended/manicured landscapes (van Houwelingen-Snippe et al., 2020).

Other researchers simulated cosmic elicitors, such as the overview effect, scenes from space, and flight. These stimuli included iconic views of earth, the sun and neighboring galaxies, the aurora borealis, and deep space (Chirico et al., 2018; Kitson et al., 2020; McPhetres, 2019; Quesnel et al., 2018; Quesnel & Riecke, 2017; Reinerman-Jones et al., 2013; van Limpt - Broers et al., 2020).

Only Quesnel and Riecke (2018, 2017) incorporated a variety of elicitors. They accomplished this by utilizing Google Earth VR. Google Earth VR simulates flight, thus allowing subjects to view the totality of earth (i.e., the overview effect), visit terrestrial features (e.g., Mount Everest), and explore human-made elicitors like cities.

2.5.2.2 Technologies Employed in Previous Works

Nearly all of the identified studies utilized HMDs to present awe elicitors. Researchers often employed HMDs to present 360-degree videos of a particular space (Chirico et al., 2017; Chirico & Gaggioli, 2019; McPhetres, 2019; van Limpt - Broers et al., 2020). Others, however, used HMDs that allowed some form of navigation. For example, Chirico and colleagues (2018) operationalized the need for accommodation as a type of surprise. With this operationalization, users followed navigable paths that lead to an unexpected stimulus (e.g., panoramas of tall trees). Taking a different approach to navigation, Quesnel and Riecke (2018, 2017) gave subjects free exploration of different

environments in Google Earth VR through the use of controllers. Forgoing controllers in their *Awe-inspiring Wellness Environment*, Kitson and colleagues (2020) and Quesnel and colleagues (2018) utilized a system that responds to how the user leans her body to simulate *in-virtuo* movement.

Some researchers employed MR installations as well as HMDs. In these studies, individuals experienced space flight (van Limpt - Broers et al., 2020) or terrestrial settings (Kitson et al., 2020; Quesnel et al., 2018). Others, such as Gallagher and colleagues (2014) and Reinerman-Jones and company (2013), relied solely on MR settings for their pioneering work on simulating the overview effect. Van Houwelingen-Snippe et al. (2020) were the only researchers who opted for immersive video projections of natural landscapes.

2.5.2.3 Methods and Participants in Previous Works

The majority of identified studies utilized experimental approaches. Some researchers favored experimental studies with quantitative, between-subjects designs. These studies used self-report measures (Chirico et al., 2017; McPhetres, 2019; Quesnel & Riecke, 2017; van Houwelingen-Snippe et al., 2020) as well as psychophysiological data (Chirico & Gaggioli., 2019). Rauhoeft and colleagues (2015) chose the novel quantitative approach of avatar height adjustment and distance estimation tasks as well as self-reports for their within-subject experiments. Other within-subjects studies used both quantitative and qualitative techniques, such as psychophysiological data, self-report measures, and phenomenologically-informed interviews (Gallagher et al., 2014; Quesnel & Riecke, 2018; Reinerman-Jones et al., 2013). Last, van Limpt - Broers and colleagues (2020) used a within-subjects, correlational case study with structural equation modeling

to report links between dispositional awe and learning after participants experienced the overview effect.

A handful of studies were design-based, experimental research. For example, Chirico and colleagues (2018) designed and tested three separate VR environments to quantitatively determine which elicitors fostered the most awe. Quesnel and colleagues (2018) used participatory design to create an awe-inspiring MR/VR installation. Using the same installation, Kitson and colleagues (2020) took a mixed-method approach to investigate if their design aided in transitioning participants in and out of awe-provoking scenarios. In addition to quantitative measures, Kitson and colleagues employed self-image drawings, pen-drop measures, and semi-structured interviews to investigate self-diminishment and pro-social behavior.

Regarding participants, the identified studies relied primarily on undergraduate and graduate students as well as members from university communities (Chirico et al., 2017, 2018; Gallagher et al., 2014; Kitson et al., 2020; McPhetres, 2019; Reinerman-Jones et al., 2013; van Houwelingen-Snippe et al., 2020). Exceptions to this pattern included recruitment from the surrounding communities (Chirico & Gaggioli, 2019), such as local VR meetup groups (Quesnel et al., 2018; Quesnel & Riecke, 2017, 2018). Only van Limpt - Broers and colleagues (2020) recruited minors for their study on dispositional awe and learning.

2.5.2.4 Summary and Relevant Gaps

Overall, the identified studies indicate that immersive technologies (especially VR HMDs) may induce awe, and this was typically measured quantitatively (e.g., psychophysiological measures and self-report questionnaires). Some studies, however,

saw value in qualitative approaches, such as phenomenological analysis. Concerning elicitors, researchers typically used terrestrial or cosmic objects to induce perceptual vastness. Last, university students generally participated in these studies.

Reviewing these studies, two major gaps appear that align with this dissertation's purpose of determining how and to what extent virtually-induced awe fosters exploration. The first gap is the need for further investigation of awe as a knowledge emotion. As outlined earlier, awe embodies a fundamental quality of learning: the creation of new knowledge structures based on dissonant information. Despite this connection, only two of the identified studies focused on awe and learning. The first is McPhetres (2019), who leveraged video and VR technologies to determine that the self-reported intensity of an awe experience influences participant awareness of knowledge gaps and science interest. Another exception to this gap van Limpt - Broers et al. (2020), who found that primary school students who experienced the overview effect in an MR simulation had increased learning gains compared to a control condition. By answering *RQ2*, the findings from this study will address this first gap.

The second gap concerns the underrepresentation of human-made elicitors and conceptual vastness.

2.5.3 The Paucity of Research on Human-Made Awe Elicitors

Why aren't representations of human-made elicitors, such as art, artifacts, and architecture, included in digital awe research? It seems that, when conceptualizing awe, researchers have a tendency to envision space and, principally, filling of that space with perceptually vast nature-oriented objects. Chirico and colleagues (2016) similarly note that conceptual vastness has received less attention compared to perceptual vastness. This

is surprising as Keltner and Haidt (2003) describe that human art and artifacts induce conceptual vastness. For example, when looking at ancient Greek art, the heroic figures and actions in Greek mythology may come flooding into the individual's mind, revealing the magnitude of forces that create a single piece of art (Keltner & Haidt, 2003).

As I outlined earlier in this chapter, an individual may even feel that an object has an aura (Benjamin, 1935/2008), and researchers have shown that museum exhibits and historic places conjure visceral images of an earlier time. These images connect people with a spirit of the past (Cameron & Gatewood, 2000, 2003; Greenblatt, 1991; Latham, 2013). Yet, despite questions regarding whether virtual objects can have an aura appearing in the literature for two decades (e.g., Hazan, 2001), only a handful of researchers have conducted empirical studies on users' aesthetic experiences with virtual representations of art and artifacts (e.g., Kenderdine & Yip, 2018; Lee et al., 2020; Sylaiou et al., 2010). This paucity of research on the intersection of virtual awe and human-made elicitors may be due to several factors: discipline-specific considerations, the necessity of contextual information, and perceived authenticity.

First, there are discipline-specific considerations. Virtual museum researchers and designers, for example, tend to emphasize pragmatic topics, such as design and integration, due to the continual development (and popularity) of digital tools (Perry et al., 2017). Additionally, investigations of the cognitive and affective responses to virtual artifacts may simply be beyond the traditional scope of museum and psychology scholars alike, especially when empirical investigations into this topic are admittedly nascent. Furthermore, the complexity and interdisciplinary nature of aesthetics and virtuality may also frustrate research efforts (Moens, 2018; Parry, 2010).

Another difficulty with investigating human-made awe elicitors is the addition of contextual information. Typically, in museum settings, displayed artifacts include additional information or an accompanying narrative that helps to instill cultural presence, a feeling that "people with a different cultural perspective occupy or have occupied that virtual environment as a 'place'" (Champion, 2010, p. 72). Reporting on her interpretative phenomenological study of object authenticity, Latham (2015) calls this accompanying narrative and contextual information the *surround*. The surround is the supportive features of an object's environment designed to foster aesthetic experiences, including lighting, labels, or additional learning content. Despite the importance of the contextual information that surrounds objects, Champion (2010) suggests that virtual history experiences and, more specifically, the objects that fill them, have yet to overcome a lack of meaningful engagement: "They are simply three-dimensional objects" (p. 49).

Last, the authenticity of human-made elicitors may influence whether the immersant experiences awe. Feelings of authenticity produce a variety of intertwined sensations that relate to the *physical* object itself (Latham, 2015). Some even argue that digital artifacts simply inherit a certain "weirdness" (Jeffrey, 2015, p. 149). With no substance, location, or degradation, digital artifacts may feel inauthentic or overly sanitized; their strangeness may prevent awe (Jeffrey, 2015). Is it possible that the act of digitally reproducing human-made elicitors removes their ability to produce an aura or awe? Some scholars have pushed back on this notion, suggesting that it is the assemblage of object-oriented information (and copies) that create meaningful experiences (Groys, 2016; Latour & Lowe, 2010).

Because this study focuses on fostering curiosity and exploration after exposure to awe elicitors, it is important to include a variety of awe sources—human-made and nature-oriented. As Kashdan and colleagues (2004) note, "What object induces curiosity is largely based on individual differences in interests, expectations, and prior knowledge" (p. 292). *RQ1* will address this gap. By expanding the present study to include both nature-oriented and human-made representations of awe elicitors, I may better support users' domain-specific interests while simultaneously addressing the relative lack of research on whether or how digital representations of human-made objects foster awe.

2.6 Lived Experience: Pushing VR-Based Awe Beyond the Lab and Numbers

As a consequence of uncovering whether virtual awe elicitors move individuals to adopt exploratory behavior once outside of the lab, this study also addresses conceptual as well as philosophical arguments regarding the current boom in awe research—especially those that utilize immersive technologies. There are concerns that VR-based awe research relies on "mediated and contrived experiences of life" that are not wholly replicative of the profound experiences of life (Schneider, 2020, p. 102). Schneider (2017), a psychologist who champions existential-humanistic psychology, suggests that the research designs currently used may not be measuring the kind of awe that has been discussed throughout history.

According to Schneider (2017), psychological studies often take a 'quick boil' approach to awe, simplifying self-transcendence as the product of ingredients. Instead, Schneider continues, researchers need to investigate awe as a 'slow simmer' that includes the nuance of life and time; slow simmer awe is hard-won, ambiguous, and persistent. With this in mind, Schneider takes the position that awe cannot be assimilated or

accommodated at all. Rather, we must live with the awe experience and be okay with never fully or comfortably categorizing it. He emphasizes that awe provokes mystery that is "beyond schematization" (Schneider, 2017, p. 105).

In his rejoinder to Chirico and Gaggioli's "Awe: 'More Than a Feeling" (2018), Schneider (2020) commends the authors' forward-thinking approach to investigating awe; however, he expresses some reservations. Particularly, Schneider expresses doubt in their implication that VR or constructed environments are ideal for investigating awe. Instead, Schneider posits that naturalistic settings—those moments that emerge organically throughout one's life—are best suited for the investigation of awe. Rather, there is simply "a very strong likelihood that awe in its natural unconstructed state is qualitatively richer, and more holistic than awe that is contrived in a laboratory" (Schneider, 2020, p. 101).

To this end, Schneider argues that qualitative approaches, such as phenomenology, are vital to a richer understanding of awe's manifestations. According to him, mediated or contrived experiences of life may be interwoven with an awe experience, but "are they really as integral to this experience as the researchers (and many of their experimental colleagues) imply?" (Schneider, 2020, p. 102).

I, too, recognize that there may be different forms of awe—such as Schneider's boil/simmer typology. Because I am primarily concerned the use of immersive technologies to intrinsically motivate students, slow-simmer awe may be beyond what is capable within the confines of this study. Nonetheless, my own curiosity is piqued. What is the endurance of virtually-induced awe experiences? How do these experiences compare to awe in naturalistic settings, especially moments of awe derived from

educational experiences? If students had the resources to create awe-inspiring and curiosity-provoking VR systems based on their own experiences, what would they look like? Exploring lived experiences related to awe in educational settings, how such experiences compare to virtually-based awe, and learners' VR proposals may help to uncover the nature of computer-mediated self-transcendent experience as well as design considerations. Thus, I ask my final supporting question: *RQ3. What do participants propose when envisioning awe-inspiring VR that motivates inquiry?*

2.7 Summary

In this literature review, I synthesized research from positive and motivational psychology as well as human-computer interaction. First, I provided an overview of awe, focusing on awe as prototypical emotion characterized by a sense of vastness that cannot be assimilated into pre-existing mental structures. Elicitors of awe may be an amalgamation of physical, social, or cognitive objects. Because this study emphasizes the use of physical objects displayed through immersive technologies, I provided a review of how physical elicitors, both nature-oriented and human-made, prompt vastness. I then presented how awe is a knowledge emotion, its connection to curiosity, and the exploratory behaviors individuals adopt to satiate this appetitive emotion. With these characteristics established, I offered a foundational review of different immersive technologies as well as user responses to such technologies. Particularly, I focused on immersion and presence as important factors in response to digitally represented awe elicitors. Then, I examined previous studies that have used immersive technologies to induce awe. This examination revealed two gaps pertinent to this dissertation: (1) the limited recognition of awe as a knowledge emotion that piques curiosity and (2) the lack

of consideration for human-made elicitors. Recognizing this paucity of research, I questioned why awe studies are not including human-made elicitors; this is important as learners' interests may not be limited to natural elicitors. Last, I considered a critique of VR-based awe studies and how this dissertation may provide insight for future research in this field. I now turn to my proposed methods for determining how and to what extent virtual awe elicitors foster curiosity and exploration.

CHAPTER THREE: METHODOLOGY

In this chapter, I review the methods and procedures that I used to investigate my main research question: *How and to what extent do virtual awe elicitors foster curiosity and exploration?* To recap, the following research questions emerged from the literature review:

1. Out of a selection of virtual awe elicitors, which do participants find the most awe-inspiring and curiosity-provoking and why?
2. What, if any, information-seeking behaviors do participants adopt after exposure to virtual awe elicitors and why?
3. What do participants propose when envisioning awe-inspiring VR that motivates exploration?

As the previous chapter revealed, most of the current studies on virtually-induced awe utilize quantitative, experimental approaches. Although these studies are valuable in that they pioneer VR-based awe research, such approaches come with limitations. Their employed methods may (1) be too narrow and objectivizing, (2) yield transient results, and (3) lead to the perpetuation of 'quick fix' forms of awe rather than considering the effects and nuances of life across time (Schneider, 2017). By answering my research questions with a mixed-methods approach that occurs both in the lab as well as in naturalistic settings, this study also addresses the methodological gaps that exist in the literature.

To answer the research questions, I exposed a sample of undergraduate students (n = 35) to a series of awe elicitors presented with a VR HMD in a laboratory setting. This session included quantitative self-reports that measure awe and curiosity as well as brief open-ended questions regarding the VR experience. With the laboratory sessions

completed, my methods pivoted to exploring how exposure to virtual awe elicitors impacted participants' thoughts and behaviors over time and in naturalistic settings. As such, one day after the laboratory sessions, participants received and completed a brief follow-up questionnaire regarding their levels of awe and curiosity. Then, I selected a stratified sample of eight participants who reported conducting information seeking about the presented elicitors. I then conducted recorded interviews with each participant to better understand their experiences with the virtual awe elicitors and how and to what extent they acted upon intentions to close any ensuing knowledge gaps. (See Appendix A for a research alignment table.)

3.1 Selected Methods

To answer my research questions, I used two different approaches: self-report measures and open-ended questions as well as phenomenologically-informed interviews. Although the study was primarily qualitative, the inclusion of quantitative methods provides a holistic approach to answering my research questions.

3.1.1 Self-report Measures and Qualitative Questions

The following self-report measures and qualitative questions occurred after exposure to a series of awe elicitors presented through an HMD. This data was collected through Google Forms.

3.1.1.1 Emotional Label Ratings

To answer *RQ1*, I utilized a modified version of Shiota's and colleagues' (2007) Emotional Label Ratings instrument. It asked participants to rate the appropriateness of a series of emotions after exposure to each stimulus from 1 (*not appropriate at all*) to 7 (*very appropriate*). These emotions included *awe*, *contentment*, *excitement*, *fear*, *joy*,

love, *pride*, *sadness*, and *surprise*. To avoid any possible confusion with the concept of awe, I removed the emotion *rapture* from this instrument.

I opted for the Emotional Label Ratings tool because it compares the user's affective response to other emotions. Although awe was the primary affective response I investigated, it was pertinent to consider other emotions that participants experienced in response to the chosen elicitors. Additionally, this tool is brief and well-tested. Several previous studies have used the instrument or variations of it (e.g., Chirico et al., 2018; Joye & Dewitte, 2016; McPhetres, 2019; Piff et al., 2015; Rudd et al., 2012). (See Appendix B.)

3.1.1.2 Vastness and Need for Accommodation Scales

In addition to the general ratings of awe that the Emotion Label Ratings tool gathered for each video, I utilized two quantitative questions focused on awe. Specifically, I asked participants to indicate their levels of agreement with the following awe statements: (1) "I felt that I was in the presence of something grand," and (2) "I felt challenged to mentally process what I was experiencing." These two questions measured vastness and need for accommodation, respectively, in anticipation for different participant definitions of the meaning of awe. These questions were derived from the Awe Experience Scale (Yaden et al., 2019). These scale responses ranged from 1 (*absolutely inaccurate*) to 7 (*Absolutely accurate*). (See Appendices C & D.)

3.1.1.3 State Curiosity and Exploration Intention Scales

Answering *RQ1* and *RQ2* also required first determining the levels of state curiosity prompted by the laboratory session. Unfortunately, according to Litman (2017), there are currently no well-validated measures for state curiosity. Instead, he suggests

employing simple Likert scale questions that ask participants about their current curiosity. Then, the researcher may observe regression weights with theoretically relevant measures. This helps to calibrate the reported intensity of the experience alongside trait curiosity measurements.

With this in mind, after participant exposure to the VR stimuli, I employed a series of simple Likert-scale questions that ask the participant, "How curious are you about" each of the awe elicitor stimuli. These scales ranged from 1 (*not at all curious*) to 7 (*very curious*). To ensure that the analysis also accounted for motivations for information seeking beyond curiosity, the data collection included a prompt for participants to indicate their level of agreement with the following statement: "I intend to explore more information about this video." These scales range from 1 (*strongly disagree*) to 7 (*strongly agree*). (See Appendices E & F.)

3.1.1.4 Qualitative Laboratory Questions

After completing the quantitative measures immediately after exposure, the data collection tool presented participants with a casual description of awe based on Keltner and Haidt's (2003) prototypical definition. Then, participants responded to three open-ended questions via text-entry boxes. The first question asked, "1. Which single VR scene presented was the most awe-inspiring for you and why?" By determining the qualities of the participant's experience with the awe elicitor, this question provided qualitative data to support *RQ1 and RQ3*. The second question ask, "2. After watching this video that you found most awe-inspiring, what questions do you have about the content presented? (e.g., Was there something that you're interested to learn more about, was there anything that confused you, etc.)" This question further support *RQ2* by

determining any knowledge gaps that emerged. The last question asked, "3. Do you have any intention to seek information that answers these questions? If so, how will you find that information?" This question aided in better understanding the reasoning behind exploration intentions, thus supporting *RQ2*. (See Appendix G.)

3.1.1.5 Supplemental Search Materials

Because this study investigates the relationship between awe, curiosity, and learner motivations for closing knowledge gaps, I provided each participant with supplemental search materials. This approach provided an additional assurance that participants had the tools they need to conduct information seeking. I gave each participant in the final study a double-sided sheet of paper with resources about the presented VR-scenes. This sheet includes three corresponding resources per VR scene: (1) a Wikipedia article, (2) a short online news or magazine article, and (3) possible search terms. The two latter resources included QR codes and links for ease of access for participants. Although such supplemental material may incite information seeking that might otherwise not occur in naturalistic settings, this was intended to provide further data on how awe-inspiring VR content prompts curiosity and exploration. (See Appendix H.)

3.1.1.6 Follow-up Questionnaire

One day following the laboratory session, participants received a follow-up questionnaire via email regarding their levels of awe and curiosity. Again, participants completed the Emotion Label Rating as well as the vastness, need for accommodation, state curiosity, and exploration intention scales regarding each elicitor through Google Forms. I utilized these self-reports to determine the rates of change for awe and curiosity

outside of the laboratory, thus supporting *RQ2*. Furthermore, this questionnaire included three qualitative questions focused on curiosity and exploration: (1) “Since we met in laboratory, have you thought about any of the presented videos that you found awe-inspiring? If so, what video was it, and what were your thoughts regarding it.” (2) “Have you searched for any information about this awe-inspiring video? For example, did you use the Supplemental Search Material, conduct a Google Search, check out a book at a library, watch a documentary, etc.?” (3) “What pushed you to conduct this search or exploration? If you did not look up more information, why didn't you? What would have pushed you to look for more information or learn more?” These follow-up questions aided in sustaining communication and determining the stratified sample for the interviews. (See Appendix I.)

3.1.2 Phenomenologically-informed Interviews

To gain insight into the relationships between awe, curiosity, and exploration, thus supporting *RQ1*, *RQ2*, and *RQ3*, I also employed recorded, phenomenologically-informed, semi-structured interviews in this study. These interviews uncovered how the virtual scenes piqued participants’ curiosity as well as determined the phenomenology of virtually-induced awe (*RQ1*). They will also examine why or why not participants adopted exploratory behaviors (*RQ2*) as well as what participants desire and envision for both awe-inspiring and curiosity-provoking VR.

Because I adopted interpretative phenomenological analysis (IPA), I took an idiographic approach that required in-depth interviews and analysis. Studies that use this procedure typically require between six to eight participants to reach saturation (Smith et

al., 2009). As such, I conducted interviews with eight participants that reported searching for information on the stimuli. (See Appendix J.)

3.1.2.1 The Phenomenological Basis of this Study

By stepping out of what Husserl (1913/1983) calls our natural attitudes—our everyday experience—and adopting a phenomenological attitude, we can analyze our conscious relationships with the world (whether physical or digital) rather than simply how they appear. To develop this attitude, however, one must have a basic understanding of the major philosophical doctrines of phenomenology.

According to Sokolowski (2000), there are three themes of phenomenology. The first theme is *parts and wholes*. This term signifies how pieces or moments of a phenomenon constitute a whole experience. In this study, parts may refer to specific environments (*in-vivo* or *in-virtuo*), objects in that environment, the laboratory experience, or any other detail that contributes to the participants' virtually-induced awe (or lack thereof). The second theme of phenomenology is the *identity in manifold*, which describes how the same object or phenomenon under scrutiny may be expressed in various ways, such as through different individuals or at different times. The third theme is *presence and absence*, which describes how humans are conscious of or experience objects when they are present when they are not present. In this study, presence and absence may emerge when participants discuss particular elicitors during the lab session, memories of the VR experience, or imaginative moments that stem from that experience. Within these formal structures, we can begin to explore participants' memory and imagination, words, pictures, and symbols as well as their categorial intending—how participants assign syntax and logic to phenomena (Sokolowski, 2000).

With this foundational understanding established, researchers who adopt phenomenology may uncover the essence of a phenomenon, typically by drawing comparisons between the experiences of several participants (Creswell & Poth, 2018). IPA, a subtype of phenomenology, promotes participant reflection and guides the researcher toward a better understanding of the participant's sense-making process with a specific experience (Smith et al., 2009). IPA, in particular, aligns with suggestions for researching human information experiences that transcend daily life (Kari & Hartel, 2007). Moreover, IPA meets calls for the hermeneutic deconstruction of complex information experiences in immersive synthetic worlds (Robinson, 2015; Sköld et al., 2015).

3.1.2.2 Applying Phenomenology to Virtual Experiences

This study used stimuli that represent spaces with particular objects. Luckily, scholars have long adopted phenomenology to understand the subjective experience of places and spaces. These include key pillars of phenomenology, such as Heidegger (1953/2010), Husserl (1913/1983), Ingold (2011) and Tilley (1994). Drawing from these influential works, researchers are now examining spaces presented through immersive technologies (Champion, 2018).

For instance, with VR, Reinhard (2018) immersed himself in the synthetic landscape of the blockbuster game *Elder Scrolls V: Skyrim*. Specifically, he investigated whether the lived experience of surveying synthetic landscapes bears similarities to the natural world. Examining narrative architecture in a video game, Urban (2020) used phenomenology to explore users' selective attention and emotional reactions to digital objects placed throughout a virtual home. Urban found that a single object and its

surrounding could immerse an individual into particular plotlines, foster a sense of relatedness, or prompt personal memories. Smith Nicholls (2018), too, explores a phenomenology of a virtual place through the lens of dark tourism, the act of travelling to places imbued with death and tragedy. By forgoing Husserlian attempts to bracket herself from the gaming experience, Nicholls was able to provide her own phenomenological descriptions of *Town of Light*, a horror game, while simultaneously exploring Taylor's (2009) concept of the assemblage of human and non-human bodies.

These phenomenological case studies focus on lived experiences with particular video games. Of course, video games and VR are not synonymous. Video games, as digital play spaces, integrate design techniques specifically designed to evoke strong emotions from individuals (see Isbister, 2017 for a review). Virtual reality, on the other hand, is merely a means for presenting (and immersing individuals within) content. There are similarities, however, between these mediums. Like many video games, designers of VR content often intend to create transformative experiences by presenting wonders not typically experienced in day-to-day life. I consider such content in the following portion of this chapter.

3.2 Stimuli

During the laboratory sessions, I exposed each participant to a series of 360° videos that present nature-oriented or human-made wonders. Each video focused on a particular elicitor and lasted approximately from 1:12 to 1:59 minutes. In total, I presented 20 seconds of a test video and then proceed to three natural and three human-made elicitors, which accounted for 10 minutes of content. An Oculus Quest 2, a

stereoscopic HMD with an 1832 x 1920 resolution and 72Hz refresh rate, presented these stimuli. Integrated, in-strap speakers output the audio.

I chose videos that represent a variety of awe-inspiring qualities. (See Figure 4.) These videos were derived from the *New York Times*' Daily 360 project, an immersive journalism experience that exhibits 360° videos. Each of these two sets of stimuli (nature-oriented and humane-made) also included one negatively-valenced elicitor. All six videos contain brief contextual information that is superimposed onto each scene. Specifically, these videos presented:

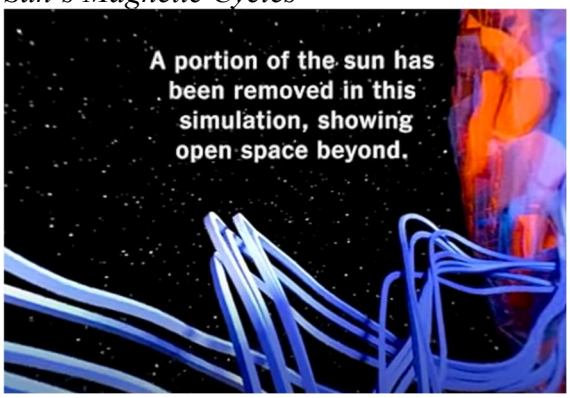
- Test Video:
    a. *36 Hours in Michigan's Upper Peninsula*, which presented a family kayaking.
- Nature-oriented Elicitors:
    a. *The Secret of the Sun's Magnetic Cycles*, which presented a cosmic elicitor. (Referred to as "the Sun's Magnetic Cycles video")
    b. *See Harvey's Path from a Helicopter in 360*, which presented the outcome of a natural disaster. (Referred to as "the Hurricane Harvey video")
    c. *Puzzle in Poland: Who Bent the Trees*, which presented a terrestrial elicitor. (Referred to as "the Bent Trees video")
- Human-made Elicitors:
    a. *Iron Mountain Facility Provided Data Storage Before the Cloud*, which presented an elicitor that embodies physical as well as conceptual vastness. (Referred to as "the Iron Mountain video")

b. *Fukushima, 6 Years On: Empty and Eerie*, which presented the outcome of an industrial disaster. (Referred to as "the Fukushima video")

c. *Inside the Wooden Worlds of Prayer Beads*, which presented a small yet highly intricate gothic boxwood artifact. (Referred to as "the Prayer Beads video")

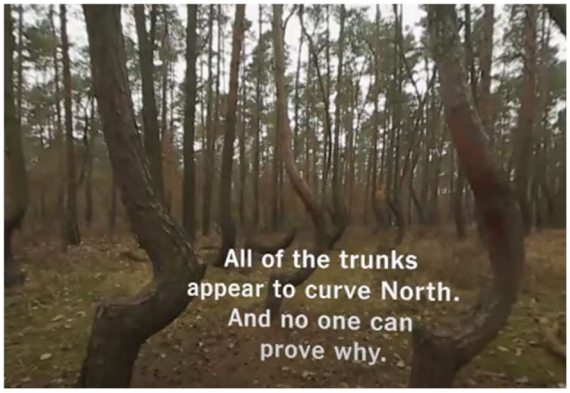
Plate 1: Scenes from the selected VR stimuli

Sun's Magnetic Cycles



Hurricane Harvey

Bent Trees



Iron Mountain

Fukushima

Prayer Beads

I selected immersive videos rather than more interactive simulations due to their fidelity and ease of participant use. Although interactivity can indeed support the formation of spatial presence (Wirth et al., 2007), I forwent simulations that required using hand-held controllers as participant expertise, time constraints, and variability between interactive stimuli would influence the results of this study.

3.3 Data Analysis

3.3.1 Quantitative Data Analysis

I investigate differences in participant levels of awe and state curiosity through descriptive statistics, mixed-effects logistic regressions, and rates of change.

3.3.1.1 Descriptive Statistics

I utilized descriptive statistics to determine average levels of awe, feelings of vastness, need for accommodation, curiosity, and exploration intentions (as well as their accompanying standard deviations). Additionally, I tallied the participants' qualitative responses toward their most awe-inspiring stimuli as well as their mentions of thinking about or searching for information on any of the elicitors. This approach gives an assessment of which elicitors were the most awe-inspiring and/or curiosity-provoking.

3.3.1.2 Inferential Statistics

For further insight into which elicitors were the most awe-inspiring and/or curiosity-provoking prior to conducting the qualitative analysis, I employed inferential statistics. After checking the normality (i.e., skew and kurtosis) of the dependent variables of awe, vastness, need for accommodation, curiosity, and exploration intentions, I determined that these variables were non-normally distributed. As such, I applied mixed-effects logistic regressions to the data to determine if the average odds of a participant reporting high levels of awe from the videos without considering moderating variables. To accomplish this, I first tested the assumptions of each ordinal model. Then, I ran an analysis of variance (ANOVA).

3.3.1.3 Rates of Change

I also determined the rates of change for each participant's levels of awe, vastness, need for accommodation, curiosity, and exploration intentions for each elicitor between the laboratory session and the follow-up questionnaire. These rates of change provided further insight on how motivations for exploration changed beyond the confines of the laboratory.

3.3.2 Qualitative Data Analysis

To analyze the qualitative laboratory questions, interview transcripts, and diary entries, I followed the procedures outlined in *Interpretative Phenomenological Analysis* by Smith and colleagues (2009). After utilizing an automated transcription service, I completed six steps for analysis:

1. Reading (and rereading) laboratory questions, dialog/interview transcripts, and diary entries without conducting annotations. This repeated reading promotes an understanding of questions responses. It also provides insight into interview

development, interviewer–interviewee rapport, and the narratives that bind together each portion of the interview.

2. Initial coding by adding descriptive, linguistic, and conceptual comments to each transcript using Nvivo 12, a qualitative research analysis software.
3. Through an inductive process of reorganizing codes and accompanying excerpts for each participant, I then used these codes to uncover initial themes. Turning these codes into themes will establish concise statements that synthesize what is important from the initial coding.
4. Identifying connections across themes by developing superordinate and subordinate categories and oppositional relationships between themes when applicable.
5. The iterative process then begins again by moving to next open-ended response or interview transcript
6. In the final step of data analysis, I draw connections across all cases and create a master table of themes. This table aids in establishing recurrent themes in participant experiences.

I repeated these steps independently for the laboratory open-ended responses, the follow-up open-ended responses, and the interview transcripts.

3.4 Participants

If particular virtual awe elicitors do increase curiosity, educators may leverage VR to raise student motivation for conducting authentic research. Researchers have tested various tactics to increase motivation in student research projects, such as alternate reality scenarios (Bonsignore et al., 2013), video games (Urban, 2019), and creative nonfiction

(Urban et al., 2020). Because awe-inspiring virtual experiences may be another tool for stakeholders in both formal and informal learning environments, I focused on undergraduate students in this dissertation. The selected virtual stimuli may foster students' situational interest (Hidi, 2001) and activate prior knowledge (Krapp et al., 1992), which are connected in their capacity to motivate learning (Schunk et al., 2014). Well-recognized literacy frameworks also stress the importance of immersion in student research projects (AASL, 2018; Kuhlthau et al., 2012).

I recruited 34 students enrolled in elective courses in Communication, Education, and Digital Storytelling at the University of Missouri as these topics intersected with this study's domain and fostered participant interest. I announced calls for participation via email through course instructors who could advocate for this research. Additionally, when possible, I visited classes to introduce the study. Participants who completed the laboratory session received either extra credit or $5 gift cards to a coffee shop. For the interview stratified sample, each participant was compensated with a $50 gift card upon completion of the interview. These gift cards were delivered electronically.

3.5 Laboratory Procedures

I met with each prospective participant one at a time in a laboratory setting. Prospective participants were screened at the laboratory. I accomplished this screening by first gathering demographic data and then asking the participant about their experience with either VR HMDs or 3D movie-going experiences. (See Appendix K.) I asked this latter question to determine whether the participant had experienced cybersickness in the past. The symptoms of cybersickness include headache, feeling dizzy or lightheaded, drowsiness, vision problems, and nausea or vomiting. (It is worth noting that I did not

specifically ask participants if they have experienced cybersickness in the past to avoid priming.) No participants described past experiences with cybersickness.

Next, after explaining the study, I provided the participant with an Institutional Review Board (IRB) consent form. Upon providing the form, I asked that the participant to relax in a chair as I demonstrated how to wear the HMD. After handing the HMD to the user, I watched as they donned the HMD, asking if they need to adjust the HMD straps in any way. 30 seconds after donning the HMD, the initial test video played. During this video, I confirmed whether the participant has any trouble viewing the initial test video. If no challenges emerged, I then allowed the HMD to continue to the next video, which began automatically. After the participant viewed the first three stimuli, I asked them if they needed like to take a short break. After this break, if necessary, I asked them to continue with the playlist. After the stimuli playlist was finished, I then direct the participant to a computer that the Google Form opened. I then asked the participant to complete the quantitative measures and open-ended qualitative prompts as well as a final form asking their interest in participating in the interview process. The total time in the laboratory for each participant was approximately 30 minutes. After laboratory data collection was complete with all 34 participants (as well as the follow-up questionnaire). (See Appendix L.)

3.7 Trustworthiness

This study aimed to ensure trustworthiness via a three-pronged approach: (1) transferability through consideration of how the results may change based on different contexts, (2) dependability through documentation, and (3) confirmability by discussing

the interpretation process with an interdisciplinary committee of scholars (Lincoln & Guba, 1985; Savin-Baden & Major, 2012).

To balance the possible undue influence of the monetary incentive, I recruited students taking electives in subject areas that intersect with this study. This targeted approach assisted in finding participants interested in the research topic itself and not solely the monetary compensation.

3.8 Ethical Considerations and Safety

Before beginning this study, I obtained approval from the IRB. The resulting consent form was provided to each participant before the laboratory session, and participants could end their participation at any time.

Identifying information is kept in password-protected, cloud-computing software. I will destroy identifying digital information after this project. Destruction will occur three years after concluding the study to allow time for journal manuscript preparation and any required revisions.

Because this research was conducted during the COVID-19 global health crisis, I took additional precautions to ensure the health and safety of myself and the participants. Cloth masks were worn at all times by myself throughout laboratory sessions, and prepackaged masks were available for participants.

For the *in-virtuo* observation, I cleaned the HMD before the participant's arrival as well as the data collection laptop computer. For the HMD, the cleaning process entailed using a dry cloth to clean the outside of the headset, anti-bacterial wipes to clean the straps and the facial interface foam, and a dry optical lens micro-fiber cloth to clean the lenses. Additionally, for added safety, I applied a washable silicone cover over the

facial interface foam. Last, I used non-abrasive anti-bacterial wipes to clean the HMD's hand-held remotes.

To mitigate the risks of cybersickness, I conducted welfare checks and ensure needed breaks. The use of VR equipment is also associated with injury from tripping, falling, or colliding with physical objects. To mitigate these risks, I cleared the lab space of hazards or obstacles that could harm participants. (See Appendix M.)

3.9 Researcher Positionality

It is important that you, the reader, recognize how this study emerged. This may reveal any potential biases that I possessed. First, I approached this study with the recognition that immersive technologies are powerful tools with the capacity to promote introspection, spark interest, and move individuals to act and learn. When leveraged with care, technologies like VR can strengthen the impact of learning content by allowing the user to embody a virtual space. It was my own experiences as a young (and, frankly, unmotivated) student and, more recently, as an education technology professional that has led me to this belief.

Today, I take the stance that information presented to users—whether analog or digital, eudaimonic or hedonic—is not bound to ink on a page or pixels on a screen. Thus, I believe that by exploring an individual's media experiences and perceptions from the first-person point of view, I may begin to discover her reality and her relationship with digital worlds (Savin-Baden & Major, 2012). As such, I am approaching this exploratory study with a hermeneutic phenomenological lens supplemented with quantitative data.

From my personal stance and the phenomenological paradigm that I inhabit, I acknowledge that my passion for interactive media influences my relationship to the research context and participants; I want students to enjoy learning from novel technologies, and I want students to experience awe. This desire stems from my own creeping feeling that awe has become increasingly difficult to attain as time ticks by and commitments increase. I often turn to new media to satisfy my own needs for adventure.

Despite these biases, I worked with participants in a collaborative manner to uncover their virtual experiences—whether they were positive, negative, or unabashedly disinterested. Although I attempted to bracket my experiences and beliefs, my position as a researcher may also influence participant self-reflection. To the best of my ability, however, I present the participants' experiences so that you may better understand their realities.

CHAPTER 4: FINDINGS

This chapter reports the study's findings. It first summarizes the pilot study. Then it outlines the data produced during final study. Then, it provides answers to the research questions under investigation. It concludes with emergent findings beyond these prescribed questions.

4.1 Pilot Study

4.1.2 Pilot Study Results

Before beginning the pilot study, I conducted two pretests with volunteers to determine the soundness of the procedures. With these pretests completed and instruments revised for minor errors, laboratory data collection occurred between September 20th and October 8th, 2021. In total, 17 students participated in the pilot study.

Participants found the Prayer Beads video as the most awe-inspiring (avg. score = 6.06 out of 7, SD =1.69). The mixed-effects logistics regressions (and assumptions testing) support this, suggesting that participants were 7.5 times more likely to rate the gothic boxwood video as more awe-inspiring than the Iron Mountain video, and 8.9 times more than the Fukushima video.

Participants found the Bent Trees video as the most curiosity-provoking (avg. score = 6.47, SD = 1.06). The mixed-effects logistic regressions suggest that the Bent Trees video is significantly different from all other videos—except the Fukushima video—in its ability to prompt high reports of curiosity. For example, participants are 34.5 times more likely to score high on feelings of curiosity from this video compared to the Sun's Magnetic Cycles video.

For the gothic boxwood video, the lab and interview responses suggest that a key theme of the awe-experience related to visual attention, particularly the multidirectional viewing experience and level of intricacy. When concerning on the Bent Trees video, the lab and interview responses embody how a sense of mystery can capture attention. Although these videos prompted different cognitive processes, the interviews indicate that both videos fostered self-diminishment—a key component of awe—due to their physical as well as conceptual qualities (e.g., the vastness of time.)

All laboratory participants expressed intentions to explore the awe elicitors in further detail. When asked what questions emerged from their viewing experience, eight questions concerned the elicitors' origins, making it the most prevalent response. For example, participants desired to know "more about the different theories" for the Bent Trees or the "history of the carvings and how we found out about them."

Prior commitments and lack of immediate relevancy, however, often stymied curiosity-sating behavior. Additionally, feelings of awe and curiosity from the VR experience reduced on average by 7% and 4%, respectively, over 24 hours. As such, only six participants (35%) confirmed that they searched (via Google) for information regarding the awe elicitors. The interviewees similarly expressed that the Prayer Beads and Bent Trees videos piqued their curiosity, but only half searched for further information.

The theme of immediate relevancy did appear for the two interviewees who explored the elicitors in further detail. Both searched for information on the day of the laboratory session.

When asked what would have pushed them to search for more information, the most prevalent laboratory response centered on greater mystery and context. Similarly, when asked what they would incorporate into VR designed to foster awe and curiosity, all interviewees stressed the importance of fantastical elements and drew from science fiction or fantasy titles.

4.1.3 Ensuing Revisions to the Final Study

The pilot study informed changes to the final data collection methods and procedures. These changes affected the quantitative scales, qualitative questions in both the laboratory sessions and follow-up questionnaires, the material provided to the participants, the interview schedule, and additional procedures. Chapter 3 includes these changes for the sake of readability, and I outline them here for transparency.

4.1.3.1 Inclusion of Additional Scales

I revised the quantitative measures to include three new dependent variables. Specifically, I included the two aforementioned Awe Experience Scale items that target vastness and the need for accommodation (Yaden et al., 2019). This inclusion allowed me to witness which elements of awe the videos prompted rather than relying on a single general awe scale. Second, the pilot showed that curiosity may not always lead to exploration. Therefore, I also included the aforementioned exploration intention scales.

4.1.3.2 Revisions to the Laboratory and Follow-up Qualitative Questions

Although the pilot study provided insight into why the VR scenes were "meaningful" or "interesting," the initial qualitative questions used in the laboratory session and follow-up questionnaires did not specifically pinpoint the awe-inspiring aspects of the content or how these qualities relate to knowledge gaps and curiosity.

Thus, I revised the first two laboratory questions (and follow-up questions) to focus squarely on awe. Also, I split the final follow-up question regarding awe into two prompts to focus the participant on one train of thought at a time. Last, to help hone participants in on the notion of awe before crafting their responses, the questionnaire in the final data collection introduced awe, drawing from Keltner's and Haidt's (2008) prototypical definition.

Also, I adjusted the cut-off period for the final data collection follow-up survey; for the final study, participant responses that are not received within three days were excluded. I extended this period as six responses were received outside of the prescribed 24-hour timeframe, but they did arrive within three days.

4.1.3.3 Inclusion of the Supplemental Search Material

With only six out of 17 participants confirming that they sought information about the VR scenes, I determined that it was necessary to further encourage exploratory behavior. To do this in the final study, I gave each participant a double-sided sheet of paper with resources about the presented VR scenes.

4.1.3.4 Revisions to the Interview Schedule

The pilot interviews provided insight into an interesting challenge in building awe-inspiring virtual content for educational purposes. Interviewees described how there may be two forms of awe experiences—one based more on emotion, another based more on new information. For the final study, in addition to asking participants to describe a time they experienced awe in their personal lives, I asked participants to relay a time when an educational setting, experience, or material has fostered feelings of awe. This

helped to show ways that virtual content might balance emotionally-fueled awe experiences with the didactic nature of learning content.

Next, to better understand the curiosity-provoking qualities of the videos, I asked participants which video fostered the greatest quantity of curiosity and why in the final study. Also, because of my focus on the effects of naturalistic settings and time on virtually-induced awe and curiosity, I included a question that asks participants to expand on why they think their quantitative levels of awe changed over time.

4.2 Summary of Final Data Produced

35 participants completed the laboratory portion of this study. However, three of the participants did not return their follow-up questionnaires within a three-day period and were thus removed from analysis. 71% of participants had previous VR experience. 69% of participants were female. 82% of participants were white or Caucasian. Most participants (34%) were sophomores. The average participant was 20 years of age. Quantitative data underwent descriptive statistical analysis and inferential statistical analysis through mixed-effects logistic regressions. From the laboratory sessions, two major themes emerged from the participant responses regarding their most awe-inspiring VR scenes: (1) *Access* and (2) *Knowledge-based Reactions*. Six subthemes developed from categorizing 62 descriptive codes, 10 linguistic codes, and three conceptual codes provide the foundation for these two major themes.

Again, for the follow-up questionnaire, quantitative data underwent descriptive statistical analysis. Ultimately, 10 participants searched for more information on the selected stimuli. Qualitative analysis first centered on participants' thoughts on the stimuli over time. Again, two major themes emerged: (1) *Interest in Striking Visuals* and

(2) *Interest in Mystery*. These two themes stem from 45 descriptive codes and five conceptual codes. Then, qualitative analysis shifted to considering the participants' reasons for seeking information about the stimuli presented or not. Beyond one theme embodying participant lack of free time, no further themes appeared. The interviews, however, provided insight regarding participants' information seeking motivations.

Eight of the ten information-seeking participants completed interviews. All interviews were conducted within one week of the participant's laboratory session. The two remaining participants were unable to complete interviews as they did not respond within the one-week timeframe. Combined, these interviews provided approximately four hours and twenty minutes of dialog. Participant names have been changed to maintain confidentiality. Through the inductive process of coding each interview, I discovered initial themes and then created concise statements that summarized these themes. In total, I produced 50 statements which collapsed into five over-arching themes: (1) *Perceptual Envelopment,* (2) *Accessing the Inaccessible,* (3) *The Unknown and the Unexplained,* (4) *Focus on Experience,* and (5) *Balancing Attention.*

4.3 RQ1. Out of a selection of virtual awe elicitors, which do participants find the most awe-inspiring and curiosity-provoking and why?

The quantitatively most awe-inspiring stimulus, a video that places viewers inside of prayer beads, did not lead to the highest reports of curiosity or subsequent information seeking. Instead, the limited information seeking stemmed from a separate video, which participants deemed the most curiosity-provoking. This curiosity-provoking video concerned a mysterious forest in Poland. The following section of this paper first details

participant reactions to these specific videos and then considers how these videos utilized characteristics found among the other stimuli.

4.3.1 Awe and the Prayer Beads

4.3.1.1 Quantitative Analysis

Descriptive statistics using awe emotion label ratings (M = 5.86, SD =1.31) and a vastness scale (M = 5.80, SD =1.39) indicates that participants found a video of gothic boxwood sculptures, also called prayer beads, as the most awe-inspiring for participants. Despite these higher scores for awe emotional label rating and vastness, the prayer beads ranked fifth in their ability to foster a need for accommodation (M = 3.74, SD =2.02). Instead, participants indicated that the Sun's Magnetic Cycles video caused the greatest need for accommodation (M = 5.20, SD =1.13). (See Table 3.)

Table 3: Descriptive statistics for awe reactions

Video	Emotion Label Rating (Avg)	Vastness (Avg)	Need for Accommodation (Avg)	Qualitative Selection*
Prayer Beads	5.86 (SD = 1.31)	5.80 (SD = 1.39)	3.74 (SD = 2.02)	5
Sun's Magnetic Cycles	5.43 (SD = 1.29)	5.57 (SD = 1.27)	5.20 (SD = 1.13)	8
Bent Trees	5.37 (SD = 1.37)	5.46 (SD = 1.38)	4.23 (SD = 1.90)	13
Hurricane Harvey	5.29 (SD = 1.30)	5.03 (SD = 1.52)	4.09 (SD = 1.93)	7
Iron Mountain	4.31 (SD = 1.60)	4.23 (SD = 1.54)	3.34 (SD = 1.57)	2
Fukushima	4.48 (SD = 1.54)	4.23 (SD = 1.61)	3.94 (SD = 1.81)	1

*Note: In one instance, a participant chose two awe stimuli in their response. To account for this discrepancy, only their first mentioned stimulus was counted.

The mixed-effects logistic regressions (and assumptions testing) using the emotion label ratings also suggests that the Prayer Beads video had significantly high odds in fostering awe compared to the other stimuli. Although both the Prayer Beads and Bent Trees videos both had two statistically significant comparisons, the boxwood video had the highest odds of fostering awe. For example, similar to the pilot study, participants were 10.99 times more likely to rate the gothic boxwood video as more awe-inspiring than the Iron Mountain video, and 9.03 times more than the Fukushima video. (See Table 4, which presents only the significant pairs but not the non-significant pairs for the sake of readability.)

Table 4: Mixed-effects logistic regression comparing odds of high levels of awe

Video Comparison	Difference in Log Odds	Odds Ratio	Tukey Adjusted p Value
Prayer Beads - Iron Mountain	2.40	10.99	<0.01
Prayer Beads - Fukushima	2.20	9.04	<0.01
Bent Trees - Iron Mountain	1.64	5.16	<0.01
Sun's Magnetic Cycles - Iron Mountain	1.57	4.81	<0.01
Bent Trees - Fukushima	1.45	4.25	0.02
Hurricane Harvey - Iron Mountain	1.38	3.98	0.02
Sun's Magnetic Cycles - Fukushima	1.38	3.96	0.02

When using the mixed-effects logistic regressions for vastness, the boxwood sculpture videos again had three significant comparisons. Participants were 12.43 times more likely to rate the Prayer Beads video as promoting more feelings of vastness than the Iron Mountain video, and 11.96 times more than the Fukushima video. Because the need for accommodation scores did not pass the goodness-of-fit test, it was not included in the regression analysis. (See Table 5.)

Table 5: Mixed-effects logistic regression comparing odds of high levels of vastness

Video Comparison	Difference in Log Odds	Odds Ratio	Tukey Adjusted p Value
Prayer Beads - Iron Mountain	2.52	12.43	<0.01
Prayer Beads - Fukushima	2.48	11.96	<0.01
Prayer Beads - Hurricane Harvey	1.29	3.64	0.05
Sun's Magnetic Cycles - Iron Mountain	1.95	7.04	<0.01
Sun's Magnetic Cycles - Fukushima	1.91	6.78	<0.01
Bent Trees - Iron Mountain	1.85	6.37	<0.01
Bent Trees - Fukushima	1.81	6.13	<0.01

4.3.1.2 Laboratory Qualitative Analysis

Access, the first theme from the laboratory qualitative analysis, may explain why the Prayer Beads video was particularly impactful. Awe-inspiring VR situates the user in seemingly impossible spaces to visit and/or leverages audiovisual techniques to give unparalleled access to information. These characteristics appeared across the stimuli, and the following section relays these qualities.

First, VR's ability to simulate physically inaccessible locales may prompt awe. Some participants described how this inaccessibility may be due to certain privileges (e.g., helicopter rides, expensive travel, or security clearance). For example, beyond having never heard of the bent trees in Poland, P35 mentions that they "liked feeling like I was in the environment of a place I will likely never actually visit." Other times, participants' descriptions embody the sheer impossibility of experiences that VR provides. For example, participants described being inside of the sun's magnetic field scene as "trippy" (P17) and prompted them to feel as if they were "taken away from the real world" (P33) or that they "would never get to have an experience such as that" (P27).

Similar sentiments appeared for descriptions of the Prayer Beads video. Participants felt as if "the video put me inside of the bead." (P9)

Second, the audiovisual affordances found within the VR environments may heighten the awe experience by providing access to information that is typically impossible to obtain. These effects include computer-generated imagery, detailed close-up shots, and other audiovisual capabilities. For example, the sun simulation allowed participants to see a star "taken apart and explained," (P5) which "made it more understandable." (P20) Others emphasized how the VR scene placed them in a position to examine a stimulus with greater detail. P19 fixated on the Prayer Beads video, describing how "The details were remarkable, and I felt like I got more information about each carving by getting 'up close and personal'." P28 echoes this description of the Prayer Beads video: "I got to see it up close and I actually got the chance to study what I was looking at."

The Prayer Bead video's high quantitative scores may suggest that it leveraged these qualities to the greatest extent, particularly its ability to simulate perceptual envelopment with intricate visuals and feeling small in an inaccessible space. To a lesser extent, participants also noted admiration for the beads' creators as well as their historical longevity and preservation, but feelings of transportation and visual attention outweighed these more conceptual sentiments.

4.3.1.3 Interview Themes: Perceptual Envelopment & Accessing the Inaccessible

The interviews provided further insight into the characteristics of awe-inspiring VR content. The first theme for the interviews concerns perceptual envelopment. The second theme embodies accessing the inaccessible. Again, because participants and

interviewees were exposed to several stimuli in quick succession, their responses often consider videos beyond the Prayer Beads video. Nonetheless, observing how interviewees characterize awe from VR may yield insight into the qualities of the Prayer Beads video.

Awe-inspiring VR fosters a sense of perceptual envelopment. This theme appeared from conversations with five of the eight interviewees. In some instances, this theme stemmed from VR's ability to simulate grand 360-degree views, thus aligning with typical descriptions of perceptual vastness (e.g., the view from a mountain top). Both Amanda and Bethany, for example, emphasized how VR simulated novel positions that provided a better understanding of the magnitude of a particular space. (This emphasis on grand views also appeared in Amanda's and Bethany's descriptions of powerful awe experiences in the physical world.) Reflecting on the Hurricane Harvey video, Bethany described how VR provided grand views:

> *I remember discovering that I was able to look up, down, and all around. I remember that it was on the side of the helicopter, so it almost felt like I was like hanging off of it, rather than inside it—which was even cooler because then I had more of a view of everything.*

Interviewees also described how awe-inspiring VR awe may be associated with a sense of being surrounded by an intricate environment—even very small spaces. Like her real-life experience of seeing mountains "up-close," Maria vividly remembered the number and variety of sculpted faces she could examine while inside of a prayer bead. For Katie, this ability to examine minutia allowed her to better feel the impact of a powerful entity—in this case, the destruction from Fukushima. She frequently used the

term “everything” and “everywhere” when describing the detritus from nuclear evacuation, and the “the shock value … when you saw all the children's things laying around.”

Ariel provided a more nuanced perspective on perceptual envelopment. She centered on how effective awe elicitors surround the user while avoiding feelings of confinement. Reflecting on the Iron Mountain video, Ariel described that the facility “wasn’t my kind of place,” and that it was “depressing,” “somber,” and made her feel “trapped, but not in a bad way.” On the other hand, reflecting on the Bent Trees video, Alison appreciated being surrounded by a specific atmosphere unencumbered by text:

> *I just remember being surrounded by all those curved trees—even when I looked up and down. I could see them everywhere, and I liked how the words were kind of 3D, almost in front of you so it didn't take away from like being an atmosphere. It wasn't like a text box. You could read what was happening in the descriptions, but I still felt like I was there…*

This sense of being surrounded or enveloped—but not confined—resonated with interviewees.

Awe-inspiring VR also mimics the benefits of travel by promoting feelings of discovery in new and extraordinary places, especially spaces that feel inaccessible. This theme appeared while speaking with Ariel, Emma, and John. Although this theme appeared more prominently in interviewees’ design recommendations, it did emerge when reflecting on some of the selected stimuli. For example, when asked which video was the most awe-inspiring for her, Ariel enjoyed how the VR headset transported her to Poland:

Looking around, I felt like I was there, and that was a place I had never heard of—somewhere I'm probably never going to go in my life. I had no idea. I had no prior knowledge about those trees before, and it just really surprised me. I thought that was really cool.

John also emphasized how VR provides access to otherwise inaccessible spaces—particularly those that feel supernatural. Describing his most awe-inspiring VR scene, which placed him inside the sun, John reflected: "It almost feels like I'm in space." When asked to expand on why this video was more awe-inspiring than the others, he explained that while the other videos were novel, the sun video provided a sense of being somewhere he hadn't been before:

So, it was the most awe[-inspiring] video—and I would say better—and it was just because it was cool. When I was in the helicopter [video], that was very cool, but it was more realistic. [I mean] they're both realistic, but I've been in a plane before—my cousin was a pilot took me up once. So, it was stuff I'd already seen before. The star, I really haven't seen [or been] inside. I haven't felt that.

Emma also mentioned being disengaged while watching the Hurricane Harvey video. She described how the space depicted was not particularly new or inaccessible for her. She had accessed similar spaces before. She explained:

There just wasn't a ton of engaging footage in it. I was like, "I've been to Texas before. I've been on a plane. I'm seeing what the top of like grass looks like, what a big lake looks like from above—so I wasn't really engaged in it.

John summarized how awe may be related to the physically impossible or occurrences outside of everyday life. Comparing the Sun video with the data storage video, he explained that:

> *If I was walking around every day, I would expect to see something like the [data storage facility] a few times in my lifetime. I'm never going to be able to be an astronaut and go into a star physically. I guess that's where the line is with them being different videos.*

4.3.2 Curiosity and the Bent Trees

4.3.2.1 Quantitative Analysis

Participants found a video presenting a grove of bent trees in Poland as the most curiosity-provoking. The state curiosity scales (M = 5.74, SD =1.40) and exploration intention scales (M = 5.11, SD =1.92) support this finding. Participants indicated that they knew nearly nothing about any of the selected stimuli. (See Table 6)

Table 6: Descriptive statistics for curiosity reactions

Video	Curiosity (Avg)	Exploration Intentions (Avg)	Previous Knowledge (Avg)
Bent Trees	5.74 (SD = 1.40)	5.11 (SD = 1.92)	1.57 (SD = 1.15)
Sun's Magnetic Cycles	5.11 (SD = 1.75)	3.34 (SD = 1.68)	2.29 (SD = 1.53)
Fukushima	5.09 (SD = 1.40)	4.14 (SD = 1.91)	1.94 (SD = 1.54)
Hurricane Harvey	4.60 (SD = 1.75)	2.83 (SD = 1.67)	2.26 (SD = 1.57)
Prayer Beads	4.54 (SD = 1.72)	3.57 (SD = 1.90)	1.14 (SD = 0.55)
Iron Mountain	3.71 (SD = 2.09)	2.97 (SD = 2.12)	1.43 (SD = 1.07)

Again, the mixed-effects logistic regressions support the descriptive statistics findings regarding the Bent Trees video's ability to provoke curiosity. For example, out of the three statistically significant comparisons, participants were 9.86 times more likely to state that the Bent Trees video piqued curiosity compared to the Iron Mountain video. It is important to note, however, that the sun's magnetic cycles video had the highest odds of piquing curiosity compared to the Iron Mountain video. As noted earlier, this reaction may be due to order effects in addition to the relative lack of interest toward the Iron Mountain video noted in the qualitative findings. (See Table 7, which presents only the significant pairs but not the non-significant pairs for the sake of readability.)

Table 7: Mixed-effects logistic regression comparing odds of high levels of curiosity

Video Comparison	Difference in Log Odds	Odds Ratio	Tukey Adjusted p Value
Sun's Magnetic Cycles - Iron Mountain	3.54	34.50	<0.01
Fukushima - Iron Mountain	1.41	4.08	0.02
Bent Trees - Iron Mountain	2.29	9.86	<0.01
Bent Trees - Prayer Beads	1.37	3.93	0.02
Bent Trees – Hurricane Harvey	1.30	3.67	0.03

Regarding exploration intentions, the Bent Trees video again had the highest number of significant comparisons. For example, out of the four significant comparisons, participants were 10.71 times more likely to explore the Bent Trees topic compared to the Iron Mountain video. It is important to note, however, that the kurtosis for exploration intentions were overly flat (-1.3), thus exceeding normality and impacting these findings. (See Table 8, which presents only the significant pairs but not the non-significant pairs for the sake of readability.)

Table 8: Mixed-effects logistic regression comparing odds of high levels of exploration intentions

Video Comparison	Difference in Log Odds	Odds Ratio	Tukey Adjusted p Value
Bent Trees - Iron Mountain	2.37	10.71	<0.01
Bent Trees – Hurricane Harvey	2.32	10.14	<0.01
Bent Trees - Sun's Magnetic Cycles	1.78	5.94	<0.01
Bent Trees - Prayer Beads	1.60	4.96	<0.01
Fukushima - Iron Mountain	1.32	3.72	0.04
Fukushima – Hurricane Harvey	1.26	3.52	0.04

4.3.2.2 Laboratory Qualitative Analysis

At first, it might appear that there is a distinct division between awe-inspiring versus curiosity-provoking VR content. These quantitative findings suggest that the connection between awe and curiosity—and the possibility of awe-fueled information seeking—is less substantial than expected; the most awe-inspiring video did not prompt the greatest levels of curiosity. Yet, the qualitative data is murkier.

When explaining why certain stimuli were awe-inspiring, laboratory participants often focused on knowledge deficits, such as never having heard of the stimulus or the mystery surrounding a stimulus. This was the case for many of the videos—not just the Bent Trees stimulus. If awe is a knowledge emotion, this reaction makes sense. Awe elicitors drop jaws and cause goosebumps because they represent the incomprehensible or something never witnessed. Unlike the other stimuli, however, the Bent Trees video only left a breadcrumb trail of explanations for their origins. Additionally, the video had sparse contextual information due to its lack of audio narration. This lack of information

promoted the greatest curiosity. By providing alternative explanations regarding this awe elicitor's existence, a sense of dissonance may have piqued the learners' hunger for more information. Participants described wanting "more time explaining the theories," (P10) "more in depth understanding of the theories," (P22) and "if there are more theories out there." (P18) For the Bent Trees video, participants also wondered about the extent of empirical research on the subject (P10, P12, P18), the sources and acceptance of the theories presented (P5, P7), and questioning of an extraterrestrial explanation (P12, P17).

In fact, this curiosity may have eclipsed some participants' awe reactions when they provided their qualitative laboratory responses. For example, immediately after exposure to the stimuli, participants responded to the following open-ended question: "After watching this video that you found most awe-inspiring, what questions do you have about the content presented? (e.g., Was there something that you're interested to learn more about, was there anything that confused you, etc.)" Participants sometimes quantitatively ranked the Prayer Beads video as the most awe-inspiring but subsequently discussed the Bent Trees video. This muddling of responses was also compounded by a few participants who described multiple stimuli when asked to consider their single most awe-inspiring stimulus. The interview analysis provides some insight into why these two emotions are difficult to parse.

Th4.3.2.3 Interview Themes: The Unknown and the Unexplained

The interviews support descriptions of awe as a knowledge emotion that often promotes curiosity. The presented stimuli accomplished this by either presenting unknown information or unexplained phenomena. Although not all interviewee

reflections centered on the grove of trees in Poland, their responses reveal the connection between awe and curiosity that the Bent Trees video leveraged.

Five out of eight interviews contained themes on how the most curiosity-provoking awe elicitors presented previously unknown information. Interviewees often mentioned their surprise of never having heard about the awe elicitor in question. This sentiment appeared in the linguistic codes during analysis. Katie frequently used the term "shocked" to describe her disbelief at never having heard of the Fukushima disaster. Ariel used phrasing like 'I never knew' or 'I never realized' when summarizing her experience with the bent trees in Poland. Or, as John stated when describing the Fukushima disaster, "Wow, that stuff can actually happen."

Sometimes, interviewees explicitly connected between awe and surprise. When explaining why the Iron Mountain video did not prompt awe, Ariel, Katie, and Maria said that it was because the subject was unsurprising. Reflecting on the underground storage facility, Alison realized a direct connection between awe and surprise: "…that's what makes me in awe of things, I guess: new things I'm interested in, never heard of, or are brand new to me. Just what inspires me and shocks me."

Beyond shocking or surprising viewers, awe-inspiring VR piques curiosity by presenting unexplained phenomena. This theme appeared for four of the eight interviewees. With its eerie music and multiple explanations as why the phenomena occurred, interviewees focused on the mysterious Bent Trees of Poland video. The lack of a succinct answer in this video prompted the curiosity—or incredulity—of all four interviewees. This video did not provide an explanation for the phenomenon. Emma explained:

I think that was the video that gave me the least answers, which is why I was the most curious about it. I felt like the other videos I watched, [they were] describing something and all the details about it—like who made it or what it was—and they went really in depth with the facts of the video. [The Polish trees video] was really open ended, and it was really like ominous, so that's why I was the most curious about it.

When asked what made this video awe-inspiring, she contemplated on her motivation to learn more: "That is what made it awe-inspiring for me. It left me feeling like I needed to know more about it."

The general rarity of unexplained phenomena also impacted interviewees. Bethany, Sam, and Maria highlighted this quality, which may align with conceptual vastness and the multitude of reasons for why certain phenomena occur. According to Bethany, the Bent Trees video exemplifies that "there are also unexplained things" in this world that are still beyond our intellectual grasp. Sam recognized this, too, describing how these trees epitomize genetics, evolution, and the ability for nature to change. Unable to wrap her head around the mystery of the trees, Maria chose to search not only for the reasons the trees bent but an explanation as to why we do not yet have an answer. Additionally, explaining her inability to decide between the Bent Trees and the Prayer Beads videos as her most awe-inspiring, Maria began to consider the rarity of unsolved mysteries:

…The beads are more amazing—that [the craftsmen] could do that—but the trees are more awe-inspiring because we don't know much about them and that intrigues me… I think [the videos are] tied because the trees are hard for me to

wrap my head around—that something like that happened. We have answers to so many things nowadays so it's intriguing that the trees are something that there are guesses on, but no one knows for sure.

4.4 RQ2. What, if any, information-seeking behaviors do participants adopt after exposure to virtual awe elicitors and why?

The following section of this paper describes how the findings support descriptions of awe as a knowledge emotion, but that this emotion does not necessarily lead to a desire for more information. It first provides findings from the follow-up questionnaire data, both quantitative and qualitative, as well as a summary from the interview analysis.

4.4.1 Follow-up Questionnaire Analysis

To better understand how feelings of awe and curiosity change over time, which may affect information seeking behaviors, participants completed follow-up questionnaires within three days of the laboratory sessions. Participants ranked their levels of awe, feelings of vastness, need for accommodation, and curiosity regarding each stimulus using the same scales from the laboratory session. Additionally, the questionnaire gathered qualitative data regarding their thoughts and exploratory behavior after exposure. Afterwards, participants who searched for information regarding the elicitors were interviewed.

Over the course of three days, participants reported that general feelings of awe reduced on average by 9.13%. For the more specific measurements of vastness and the need for accommodation, they reduced on average by 7.84% and 4.05%, respectively. Levels of curiosity, too, decreased on average by 9.94%. 81% of participants stated that

they thought about the videos presented after the laboratory session. Despite the lingering thoughts on the stimuli and the relatively small diminishment of awe and curiosity, only 10 participants described searching for more information on the stimuli. In some instances, participants searched for information on more than one stimulus. Participants utilized Google and Youtube searches as well as the provided supplemental information sheet.

According to the open-ended response coding, participants most frequently thought most about the Bent Trees video, followed by Prayer Beads video. It comes as no surprise then that, of the 10 participants who explored the topics on their own, seven chose to search for information about the bent trees. (See Table 9.)

Table 9: Qualitative codes on awe experiences overtime and search behaviors

Video	Mentions of thoughts	Mentions of searching
Bent Trees	14	7
Prayer Beads	8	3
Sun's Magnetic Cycles	5	2
Iron Mountain	4	1
Fukushima	4	1
Hurricane Harvey	2	0

Exposure to the stimuli led to a general desire for more information, specific interrogative questions, and sharing of information with peers. Responses also indicate that a lack of familiarity with the awe elicitor resonated with learners. Beyond these general sentiments of interest, two themes of note emerged: (1) Interest in Striking Visuals and (2) Interest in Mystery. First, awe elicitors with striking visuals-maintained interest over time. These visual elements ranged from the colorful nature of the sun simulation (P1, P4, P18, P32), the level of intricacy for the boxwood sculptures (P4, P22), and the feeling of being placed inside the elicitors (P1, P2). Second, awe elicitors

shrouded in mystery may maintain learner interest over time. This occurred primarily for the Bent Trees video. As one participant summarized, “The trees are what I initially found awe inspiring because it is unknown exactly why they bend. This fascinated me because while there are many things unknown today, there are a lot of phenomenas we do have answers to.” (P4)

As noted, most participants did not search for more information regarding the stimuli once outside of the laboratory. Participants described having a lack of free time to conduct any information seeking. For those 10 participants that did search for more information, their reasons varied greatly, ranging from sharing information with their friends (P11) to wanting to know the size of the elicitor in question (P16) to the immersive qualities of the VR headset (P2). To better understand participants' reasons for attempting to bridge knowledge gaps prompted by the stimuli, I invited all ten participants to interview sessions, and eight participants accepted this invitation.

4.4.2 Interview Theme: Focus on Experience

Interview analysis suggests that exposure physically or conceptually vast stimuli does not equate to the desire for more information after exposure. Interviewees often felt shocked from not knowing about an elicitor, but this shock did not typically motivate curiosity-sating behavior. Instead, some interviewees explicitly emphasized the importance of experiencing a new stimulus rather than the importance of contextual information. Some conducted information seeking online to re-experience the elicitor. The following section reports this finding.

Information behavior after exposure to the stimuli frequently centered on re-experiencing an awe elicitor. This subtheme appeared for four of the eight interviewees.

These interviewees focused on viewing an elicitor for a second time after the laboratory session, highlighting that their information needs may have been more centered on visual desires.

For John, awe comes from "something that's pleasing to the eye." He discussed how his search strategy followed the path of least resistance to re-experience visuals. Although he mentioned not learning much from the Bent Trees in Poland video (as opposed to the "more serious" videos), he stated that this video piqued his curiosity the most. To boot, it was the easiest to search:

> *If I looked up the key terms [on the supplemental hand out sheet], I would most likely find the video about the trees. If I looked up "information center" or "information vault," I might find something different than the video [I saw]. If I look up "inside a star," I'm not going to get the cool pictures that I got to see. It's just going to be more like straight-forward information. The trees were simple.*

Although John would have preferred seeing the inside of a star videos because "it was definitely breathtaking," searching for the trees was simply easier.

Sam also explained that the information seeking she conducted was based on the visual qualities of the elicitors and ease. Sam, who had difficulty selecting just one video as the most awe-inspiring, conducted searches on the gothic boxwood sculptures as well as the bent Polish trees. She explained that she had difficulty describing these elicitors to her boyfriend, so she used her phone to quickly search for images on to share her experience: "For the beads, I was more focused on the pictures." When asked why she didn't look up her most curiosity-provoking video, the Iron Mountain, she said:

I think I just want to devote more time to it. These were just quick searches. I want to sit down and actually look it up and read about it versus just wanting pictures. There's more to the Iron Mountain than pictures. But the beads are pretty—I don't know. When I go to an art museum, I'm more interested in the art than I am in 'when it was made' or 'who it was made by' and all that kind of stuff.

Bethany considered how awe may induce curiosity, but this experience may not evolve into an information need. She admitted to being confused about her most awe-inspiring video, which depicted the aftermath of Hurricane Harvey. However, Bethany did not conduct any information seeking to resolve this confusion. Unlike the trees in Poland, which she did look up, she did not have an information need regarding Hurricane Harvey. Her priority was experience. She explains:

There wasn't much information that I felt like I needed. Obviously, there's information to be found, but I had seen it. It sparked curiosity in the sense, like, "Oh my gosh. I want to go back on a helicopter," but a Google search isn't going to do anything for me. I see news coverage all the time of [tragedies like Harvey], but actually feeling like I was on helicopter was like completely different. I guess that's why I didn't really look it up.

As Bethany later described when discussing her awe-inspiring trip to the Grand Canyon and whether it prompted any information: "I mean, Google is cool, but I like to experience things."

4.5 RQ3. What do participants propose when envisioning awe-inspiring VR that motivates exploration?

Recognizing the possible balancing act between awe and experience versus information and inquiry, I asked interviewees to reflect on any awe experiences that they have had in educational settings. Their responses embody a feeling of discovery during travel, which emerged alongside three of the phenomenological interview themes: *perceptual envelopment*, *accessing the inaccessible*, and *the unknown and the unexplained*. I then asked participants to envision an awe-inspiring VR system designed to promote curiosity. The following section of this paper exhibits these memories and how they coalesced into design considerations.

4.5.1 Being There: Enhancing Perceptual Characteristics

A theme throughout the interviews was the need to enhance the sensory qualities of VR beyond 360-degree visuals. These technological desires ranged from omnidirectional treadmills and microchip implants in the brain to scenarios that engage tactile or olfactory systems. These recommendations, in and of themselves, are not surprising. Without some technological enhancements, users may not be able to suspend disbelief during virtual experiences. As Emma stated: “I don't think anything could have really made it feel like I was there—unless I was actually there.”

What is interesting, however, is how these proposals took different approaches to combine perceptual vastness with didactic information. Amanda and Sam provided these design considerations.

Amanda reflected on a university-sponsored field trip. During this trip, she canoed and camped for several days down a Missouri river. While canoeing, she and her peers would come across previously unknown wildlife and realize their place in the ecosystem. She emphasized that this trip allowed her to experience the vastness of

ecosystems without having to attend lectures, and it was, in her words, "probably more for the experience than the information." Ultimately, these feelings of conceptual vastness led her to change her major. When asked how she would create a VR system designed to foster both awe and curiosity, she did not concentrate on didactic information. Instead, she envisioned using technology to create the sensation of being in a canoe—replete with a rocking mechanism and smells of the river. She imagined recreating the height of the bluffs and the river extending before her. Allowing others to be present grand places, she explained, might make people feel more attached to the environment. This, in turn, could make them curious.

Sam remembered attending an immersive Van Gogh Exhibition in St. Louis with her mother. This exhibit gave patrons an understanding of Van Gogh's life while projecting his work onto walls, ceilings, and floors. These visuals were sometimes accompanied by narration, animation, music, and fragrances. When describing her proposed VR system, Sam drew heavily from this experience. She explained that awe-inspiring, curiosity-provoking technology requires surrounding the learner with content while still providing cognitive space to engage with individual elements. Even though she was enveloped by both complex visuals as well as traditional contextual information, she described having a sense of agency; patrons had the cognitive space to concentrate on a single piece of art or information at a time, allowing a sense of presence.

At first glance, these two experiences, a canoe trip and an augmented reality exhibit, could not be more different. Yet, they are similar in that they portray a sense of discovery in a place, a place that surrounds the person with a multitude of complex stimuli. These findings suggest that if awe-inspiring VR submerges the user in rich,

multisensory experiences, the user must still have a sense of agency and the space to take a breath and just be with the content presented—one crayfish or artwork at a time.

4.5.2 Traveling through Time and Space: Learning in Amazing Places

When proposing their awe- and curiosity-provoking VR systems, interviewees frequently mentioned traveling through time and space to inaccessible locations. Specifically, interviewees recommended VR systems to either simulate time travel or explore anatomy.

During their interviews, three participants stated that VR in educational settings should send students through time. Of those who suggested time travel to the past was Ariel. A pre-service teacher, Ariel expressed gratitude for a social studies teacher who taught her the history of St. Louis. She recounted how not only was the teacher's classroom interactive and decorated toward a specific curricular theme each week, but she would also take students on frequent excursions in the city. Even though she described herself as "not a history person," her VR proposal leveraged time travel:

> *I don't know about a specific topic, but maybe something that involves traveling. If you're in a history class, and you're learning about history—seeing it and being in the experience yourself—that would be a more exciting way to learn about it. … I would enjoy it if I was immersed in the experience there and watching it happen.*

Bethany also focused on time travel. She retold feeling the vastness of time in an Irish church during a choir field trip. Bethany, who is also a preservice teacher, recognized her privilege when recounting this field trip and was concerned about equitable access for others. When asked what she would propose for a VR system design

to promote both awe and curiosity, she wanted to simulate the 1963 March on Washington or the U.S. Civil War. As she said:

> *Give students a sense of what it was actually like to live in a time with whatever technology they had, what the people were wearing, what the people were saying to each other. That would be really interesting because that's not something—I mean, if it was about Ireland they could go to Ireland at some point—but a time period would be really cool because they can't actually do it.*

Beyond history, Bethany also remembered dissecting owl pellets as a child to reveal the anatomy of mice skeletons. Anatomy was another recurring theme in the VR proposals. Like the pilot study, two interviewees recommended using VR to reveal the inside of a human body—or even shrinking and entering the body. John, a nursing student, remembered a 3D animation of a human body—and compared it to studying an actual cadaver. He explained that the experiences were very different. With the simulation, "You get to see things you normally wouldn't." Other VR experiences, he indicated, could promote similar feelings of discovery. Maria expressed feeling awe in the form of intellectual humility in her high school chemistry and math classes, which she felt was "hard to wrap your head around." Maria, who is now a Health Sciences major, drew inspiration from the Sun's Magnetic Cycles video and proposed a VR experience that places learners inside the human heart.

4.5.3 Exploring Explanations for the Unexplainable

Many participants described their surprise toward the stimuli, and, likewise, some interviewees relayed how some unknown topics presented in educational settings shocked

them. This notion of discovering something—especially something unexplained—continued throughout some of the interviewees' VR proposals.

Like the Bent Trees video's inclusion of an extraterrestrial explanation, both Sam and Katie's design proposals centered on promoting "what if" questions. Sam's proposal would give different explanations for how Egyptians built the Pyramids of Giza. Although she described the absurdity of her proposal, her explanation taps into the idea of asking "What if" questions:

> *Maybe it'd focused on [how Neanderthals built the pyramids]. Some people say that the pyramids were put in by aliens, which is definitely a little racist ... [But] diving into that. I think that being one of the Seven Wonders of the World, it's hard to fathom how it was made considering it's so big. And, thinking of the technology we have now and what they didn't have ...I'm very curious about that, and I think a lot of people are, too. So maybe [it could be] focused on that and this virtual reality would take you to Egypt. It could take you through different scenarios of what could have happened...*

Whereas Sam reflected on ancient ruins, Katie also imagined a VR simulator that prompted "what if" questions in the present day. She suggested showing the precarity of checks and balances in governance and what would happen if this system did not exist. When asked what would make students say "whoa," she settled on:

> *What would happen if the checks and balance system was not in place—all the bad things that could happen. I think that would be good because then kids [might] start to wonder, "Well, what can we do to stop it?" ... The president could veto a widely popular bill, and that's just the end of it. All these people that*

were going to get so much help from this bill are now just left in the dust. We'll just say for the child's sake of understanding that the president's vetoing every single bill that comes to him. [He's] not even looking at them. [He's] just vetoing all of them and that's the end of it. No laws are being passed. Period.

Maria, focusing on her anatomy proposal, grappled with how to foster curiosity. She also settled on promoting feelings of mystery. "Showing something, describing it, and not telling people what is—and making them guess." Maria suggested that her anatomy simulation should provide the sounds of the human body, but not necessarily reveal where the user is located. Instead, they should ask questions and draw their own conclusions.

4.6 Emergent Findings

An unanticipated theme materialized from the interview analysis that add to this study's discussion of awe, information, and inquiry. This theme concerns *Balancing Attention* when using VR to foster awe and curiosity. This theme of *Balancing Attention* considers (1) the impact of cognitive adjustment on information processing during VR experiences, (2) information as an anchor for orienting the learner, and (3) how attending to information impacts feelings of presence.

4.6.1 The Impact of Cognitive Adjustment on Information Processing

Despite including an introductory video to acclimate participants to the laboratory procedures, order effects—and cognitive adjustment to VR—may have prevented attention to didactic information. Three interviewees described how the novelty of the first video, which simulates being inside the sun, heightened the spatial qualities of the elicitor as well as feelings of awe. They stressed, however, that this feeling of spatial

presence hindered the retention of information. Ariel explained that she was simply absorbing the environment rather than information when watching the Sun's Magnetic Cycles video. By comparison, the Prayer Beads video, which she watched later, was more memorable. Although she described her curiosity being provoked by both as well as a sense of "Being There," order effects may have influenced her memory:

> *The space one was the first one that popped up, so I was just taking it all in. I feel like I didn't really get a chance to listen to what they were saying. I was almost distracted by where I was at. I was like, "Whoa. This is cool. I'm in space." I don't remember much of the information that they were talking about. Whereas, with the prayer ones, I remember more information and being curious about that. I don't know if that's because it was like later in the experience or, if the space one, I was just like caught up in where I was at.*

Acclimation to the VR headset during the sun video also prevented retention of specific facts for Amanda. This memory deficit stymied her ability to craft terms for information seeking, all in spite the fact that this video was the most awe-inspiring for Amanda. She explains what would have pushed her to explore the subject in further detail:

> *Probably just being more focused on it when I first watched it—remembering what it talked about. I remember also being curious about that one, [but] I just didn't know as much about it because, whenever it first started, I wasn't really paying attention a lot. I don't know why—the first video, I was just still getting used to it. I think I definitely want to search more about it—if I remembered more.*

In these instances where order effects prevented retention of information, attention shifts not only to environmental qualities of the simulation but to the qualities of VR technology generally. Ariel continued by comparing the laboratory experience to her previous exposure to VR:

> *The one I used was not high tech as that one [in the study]. The one I used before, you could kind of just look straight, but this one, I was able to look around, so I was just like really trying to take it all in the first one.*

John also hinted that the novelty of the experience—heightened by order effects—enhanced his feelings of awe as well as wonderment with VR generally: "The awe stuck out the most [with the Sun video]. I was happy because I was like, "I'm like this is a cool VR set," [and] how the world's changing to VR." It is worth noting, however, that this astonishment with technology—although potentially inhibiting exploration—may not be a bad thing. As John said: "[With the Sun video] being the first video I saw, I mean it was better than all the other videos in my personal opinion."

This emergent finding also provides a possible explanation as to why the Prayer Beads video did not produce the greatest levels of a need for accommodation. Cognitive adjustment to the VR experience may have led participants to rate a higher need for accommodation from this first video. Additionally, this video presents the relatively complex topic of solar magnetism. Yet, interestingly, parity exists between reactions to the Prayer Beads and Sun's Magnetic Cycles videos. Spherical awe elicitors—those videos that adeptly leveraged the 360-degree capabilities of VR—were more likely to leave an impression on participants. This may stem from feeling small *within* an object.

4.6.2 Information as an Anchor

Interviewees described that without enough context to engage the learner, attention may be directed toward other, less didactic qualities of the stimuli. Reactions to a video presenting the aftermath of Hurricane Harvey shows the importance of information in anchoring learners during an educational VR experience.

Because the Hurricane Harvey video did not make it abundantly clear that it was presenting footage after a hurricane, Emma found herself disengaged from the video. Bored, she directed her attention to her surroundings and peripheral elements rather than the flood below the helicopter.

> *I was kind of bored. There [were] people talking, but I felt like I wasn't supposed to be learning from them. They were just talking amongst themselves about what they were seeing. There just wasn't a ton of engaging footage in it… This might be bad to say but half the time I was looking at the guys in the helicopter [and] what they were doing. I was just getting bored of looking at the scenery.*

When asked what would have made the Hurricane Harvey video more engaging, which she found to be the least awe-inspiring, Emma said she needed more information:

> *A lot of the other videos I felt had more textual information on the screen about what you were seeing and, with [the Harvey video] it was more just listening to the guy in my ear talk about it. I didn't really understand what he was talking about. He was just really describing vague things about what you were seeing—without added context of why it's important or what they're doing. I think what would have made it more engaging.*

Likewise, Bethany highlighted how, without enough grounding information, the novelty of VR's 360-degree viewing capabilities may override the intended purposes of the presented content. When asked how she felt when watching the Hurricane Harvey video, Bethany remembered being excited, thrilled, and having a sense of presence during the experience. With her love of airplanes, flying, and having never been in a helicopter, it was no surprise that the video was "really cool." Then, her emotions shifted. Seeing the houses flooded below, the video became "sad and kind of heartbreaking." I asked Bethany if she learned anything from this video:

> *Yes, but it wasn't information. It was more like—I remember that if I looked a certain way, I would see like people with cameras. They were talking. I can't remember exactly what they were saying, but I was learning about different jobs that people have. There are people that their job is to fly a helicopter and look at the flood and report back to someone else. I guess I forget that helicopter rides aren't just for "fun-sies." [They're] for real research and understanding.*

While Bethany's memory centered on the reasoning behind the helicopter ride itself, it does call attention to how the fun or novelty of VR might overshadow an otherwise didactic experience. It is possible that, with more contextual information, her emotions (and motivations for information seeking) might have been different.

4.6.3 Information Hindering Presence

Although it appears that some information is required to orient users to the purpose of a VR simulation, another emergent finding suggests that having less didactic information in a VR experience fosters greater feelings of presence. Discussing the Polish

trees, Emma, Ariel, Amanda, and John, illustrated how a lack of narration, didactic information, and answers allowed them to feel as if they were in a forest.

Emma stressed that memorable VR experiences include moments free of contextual information (e.g., superimposed text or narration). This, she explained, allows the user to feel present with the elicitor. Emma had vivid memories of the Polish trees video, her most awe-inspiring video, due to her sense of presence in the environment. This sense of presence stemmed from wide shots (and her ability to view in 360-degrees) of the bent tree forest without any context. However, she pinpointed the difficult balancing act of making VR informational while also engaging:

> *With the videos, it's kind of hard because you feel like you're watching an informational thing; there's text on the screen, there's someone narrating it. So, if it was just a more natural set-up, I guess it would feel [more natural]. The helicopter [video] probably felt the most like I was actually there because there wasn't all of that information being given to me. Which is interesting, because I was also the least engaged in [the Helicopter video], so I don't know how that makes sense!*

Ariel also mentioned how limited didactic information increased feelings of presence with the Bent Trees in Poland, her most awe-inspiring video. Ariel, who enjoys being in nature, expounded on her sense of being in the digital environment. Ariel stated, "I felt like I was in nature." This feeling of presence was due to the lack of audio narration in said video. She continued:

> *I liked how in [the Polish trees video] there was minimal information. While, for the other videos, it's not as if I didn't like the narration—but the lack of noise or*

narration made me feel like I was really in that environment because [there] was—I don't know what the background noise was—but there was like [birds] chirping and some eerie kind of feeling. I wasn't just being spoken to. I still felt like I was there...

John stated that the Bent Trees video—as well as the Sun's Magnetic Cycles video—made him feel as if he were "living in the moment," "happy to be in the moment," and "glad to be in the moment." He compared these videos to the Fukushima video, which he found to be more informative and curiosity-provoking. Yet, it didn't feel "as good." John explained that his curiosity during this video was imbued with sadness. For John, it might be that curiosity and information seeking—as a future-oriented state and action, respectively—do not equate with feelings of presence.

Uncovering further how users conceptualize *experiencing* an awe elicitor versus *information* about an awe elicitor may help us to better understand not only the limits of awe as a knowledge emotion but how to pique learner curiosity with VR.

CHAPTER 5: DISCUSSION

5.1 Summary of Results

This study asked how and to what extent virtual awe elicitors foster curiosity and exploration. The analysis indicates that exposure to specific awe-inspiring VR scenes piqued participants' curiosity, especially those that presented phenomena that prompted thoughts surrounding the origins of unknown or unexplained awe elicitors. However, subsequent self-motivated exploration about awe elicitors only occurred in limited circumstances.

Analysis began by quantitatively determining that, out of a selection of virtual awe elicitors, participants found a simulation of being placed inside of a prayer bead as the most awe-inspiring and a simulation of visiting a grove of bent trees as the most curiosity-provoking. Participants explained that the prayer bead was the most awe-inspiring due to its ability to foster a sense of perceptual envelopment and visiting inaccessible spaces. Participant descriptions suggest that these qualities were not limited to the prayer bead video, but this stimulus may have leveraged these qualities to the greatest extent. On the other hand, participants explained that the grove of bent trees in Poland was the most curiosity-provoking because it prompted feelings of the unknown and unexplained.

The analysis then uncovered what, if any, information-seeking behaviors participants adopted after exposure to virtual awe elicitors and why. Laboratory and interview qualitative analysis revealed that the stimuli prompted curiosity, often from the shock of not knowing about a phenomenon. However, such reactions did not necessarily lead to a desire for more information. Only 10 participants explored the topics presented

on their own, seven of which explored the bent trees in greater depth. This subsequent information seeking centered on re-experiencing the elicitors, especially their visual qualities.

The interviews revealed that leveraging awe as an antecedent for inquiry requires instilling a feeling of discovery during travel. Beyond envisioning advanced extended reality technology, participants proposed that feelings of discovery could emerge by placing users in amazing and otherwise impossible spaces. Such spaces included the cosmos, inside the human body, and past or future eras. Last, participants imagined simulations that did not inundate the user with explanations of the phenomenon in question. Instead, their proposed system would allow the user to discover its qualities or origins on their own or offer what-if questions.

Emergent findings centered on participants' attentional direction during the VR experience. First, participant responses indicate that attention to didactic information was minimized when cognitively adjusting to the VR headset. Instead, during these periods of adjustment, interviewees focused on the perceptual qualities of the experience. Interviewees also directed their attention to purely visual qualities when the stimulus in question did not provide enough information to anchor the experience. Last, interviews revealed that having less didactic information in a VR experience fostered greater feelings of presence.

5.2 Implications

5.2.1 Theoretical Implications

Because of its stimulus-driven processing and outward orientation, awe belongs to a family of knowledge emotions that include curiosity (Keltner & Shiota, 2003; Silva,

2010). Knowledge emotions are affective states involved in the knowledge acquisition process (Morton, 2009; Schindler et al., 2017). The reformulation of rejection of mental schemas connects awe and knowledge acquisition. The findings of this study have theoretical implications for the notion of awe as a knowledge emotion and its relationship to exploratory behavior. These implications concern how scholars identify and define awe, how supernatural causality prompts curiosity, and how goal-driven behaviors compete with self-transcendence.

5.2.1.1 Awe as a Fuzzy Family of Emotions

This study's findings support the notion that awe has fuzzy definitional boundaries and is best considered along a spectrum of experiences. Because awe is difficult to sharply delineate into a distinct concept, it belongs to a family of emotions that has a variety of flavors, including threat, beauty, ability, virtue, and supernatural causality (Keltner & Haidt, 2003; Rosch, 1983). Depending on the methods selected to investigate awe, some features of the experience may be missing, well-established characteristics may be highlighted, or new elements may be applied (Fehr & Russell, 1984).

The seemingly inconsistent participant responses reinforce the importance of embracing a prototypical, fuzzy approach when investigating awe and its relationship to other emotions like curiosity. For example, at first, there appeared to be a disconnect between awe and curiosity in the participants' responses; the quantitatively most awe-inspiring stimulus, the prayer bead, did not prompt the greatest quantitative levels of curiosity or subsequent exploration. Such findings may support the position that

situational awe, like dispositional awe, is associated with a low need for cognitive closure (Shiota et al., 2007).

Synthesizing the data across the selected methods uncovered a murkier story. Although participants reported the greatest levels of vastness from the prayer bead, this stimulus did not cause the greatest need for accommodation. Furthermore, although participants quantitatively ranked the prayer bead as the most awe-inspiring, open-ended laboratory responses conveyed that the grove of bent trees was the most awe-inspiring stimuli. These qualitative reports on the bent trees being the most awe-inspiring stimulus reinforce accounts of experimentally induced awe leading to greater awareness of knowledge gaps and decreased tolerance for ambiguity (McPhetres, 2019; Valdesolo & Graham, 2014). These seemingly inconsistent findings stress the importance of taking a fluid approach to investigating awe and recognizing that some features of awe may be heightened depending on context.

5.3.1.2 Supernatural Causality: Awe's Curious Flavor

Embracing a nuanced approach when examining awe also means recognizing that some flavors of awe, like supernatural causality, may be better suited to prompting curiosity than other flavors. I selected this study's stimuli on relative valence as well as their relation to human-made or nature-oriented phenomena. The findings reinforce the importance of carefully selecting specific elicitors to promote specific awe flavors, whether for research or curricular purposes.

Because the prayer bead stimulus represents spiritual and artistic endeavors, this awe elicitor embodies beauty, virtue, and abilities. Such flavors may not readily prompt curiosity or exploration. Instead, human-made elicitors like historic artifacts or art may be

better suited for promoting conceptual vastness and ego diminishment. Because of their mystical qualities, historic or cultural artifacts can feel people with a spirit of the past and their relative smallness within time and space (Benjamin, 1935/2008; Cameron & Gatewood, 2000, 2003; Greenblatt, 1991; Latham, 2013). The prayer bead may have fixated on the feelings of beauty, virtue, and ability while also promoting both conceptual and perceptual vastness (Dudley, 2012). The resulting self-diminishment from such flavors, however, may not provoke curiosity

On the other hand, participant responses about the grove of bent trees exemplify awe imbued with supernatural causality. Supernatural causality encompasses the perception of gods or otherworldly manifestations, thus eliciting a feeling of the uncanny. Based on this study's findings, awe imbued with supernatural causality may be well suited for prompting users to ask questions and explore a phenomenon further.

By showing a strange and uncanny phenomenon, the bent trees video may have created a knowledge gap larger than the other stimuli. This knowledge gap fueled deprivation-elimination curiosity, pushing participants to close the gap (Litman & Jimerson, 2004). Furthermore, with three potential answers for why the awe elicitor exists, the participants had smaller perceived knowledge gaps and anticipation of learning something new (Litman & Jimerson, 2004; Litman et al., 2005).

Shifting information-seeking behaviors also speak to how supernatural causality may influence exploration. Feelings of deprivation sensitivity, the discomfort that persists until an information gap is closed, seemed to remain until participants realized their internet searches would yield no apparent answers to why the bent trees exist (Kashdan et al., 2020). Upon determining that they could not cope with the relative stress of finding

an explanation, participant curiosity may have shifted toward interest-induction curiosity, joyous exploration, or perceptual curiosity; at this point, the participants simply wanted to explore (rather than solve) the mystery and examine the sensory qualities of the elicitor (Collins et al., 2004; Kashdan et al., 2020; Litman & Jimerson, 2004).

5.3.1.3 Awe and Information Seeking as Competing Forces with the Ego

This study's findings suggest that exposure to virtual awe elicitors may create exploration intentions, but feelings of awe may only lead to information seeking in limited circumstances. One explanation for this gap between intent and behavior is that information seeking requires an inherently personal, ego-driven narrative; active searching is a future-oriented task leading the seeker toward an end goal. Self-transcendence requires reduced self-salience (Yaden et al., 2016), and information seeking is often focused on immediate goals (Kari & Hartel, 2007; Latham, 2014). Whereas awe enhances feelings of interconnectedness and broadens attention to reveal connections (Keltner & Haidt, 2003), mystery narrows the individual's attention to a singular task of explaining causality. Mystery may be a catalyst for turning the ego back on after awe. It shifts the learner from a state of outward orientation with an elicitor to a task-driven, ego-centric behavior like filling a related knowledge gap.

It may also be that, although awe can be considered a knowledge emotion, it does not necessarily lead to a search for *more* information. Based on his experimental VR awe research, McPhetres (2019) notes that teaching learners about awe elicitors has been shown to satisfy scientific interests piqued by stimuli, but didactic information does not reduce awareness of knowledge gaps. McPhetres suggests that further research is necessary to explore how broader, awe-induced knowledge gaps can be satisfied.

Schneider (2017) warns, however, that awe can never be fully schematized into knowledge structures. This may be true for both quick-boil forms of awe that result from vast VR elicitors or naturalistic, slow-simmer forms of awe (Schneider, 2017). Instead, we may only be able to simply live with awe and hope to experience it again; awe may not push us to parse apart an elicitor's nuances and find a causal explanation.

The gap between awe and information seeking also highlights the role of higher-order emotions in information seeking. Although interviewees did not typically search for more didactic information, they did focus on re-experiencing the awe elicitors again from the comfort of their homes (or phones). It has been suggested that although it may be impossible to search for happiness, people may use information sources to shore up memories of joyous feelings (Urban, in press). It may be that, at best, information seeking allows us to see visuals of stimuli that remind us of moments of awe.

5.2.2 Methodological Implications

5.2.2.1 Human-made Elicitors in VR-based Awe Research

Although this study presented a limited number of stimuli, participants' responses to the prayer beads stimulus may signal the need for future VR research to consider beyond nature-oriented elicitors when attempting to instill awe.

The inclusion of human-made elicitors in awe research, however, warrants caution. A key element of an authentic, aesthetic experience with a cultural artifact is the accompanying narrative and contextual information surrounding the object (Latham, 2015). Weaving story and context around digital representations of objects may be a key element of creating meaningful engagement (Champion, 2010). Information conveyed

through narrative may help to promote cultural presence, the feeling that people with a different cultural perspective occupied a virtual space (Champion, 2010, p. 72).

The results of this study, however, suggest that explanatory information may need to be held at bay to promote feelings of presence and, thus, awe. Instead, when selecting a human-made awe elicitor for research, researchers may want to choose stimuli that give the viewer unparalleled access to investigate the visual qualities of the object at hand. Furthermore, objects that create a sense of perceptual envelopment—mimicking the feeling of being inside an object or human-made space—may be better suited for promoting awe. By promoting both perceptual curiosity and envelopment, learners may become interested in learning more about an awe elicitor, even if only, at first, they are focused on visual qualities.

5.2.2.2 The Limits of Quantitative Measures to Investigate Awe

The methodological implications for this study include the importance of embracing awe's fuzzy definition through qualitative means, such as phenomenology. Keltner and Haidt (2003) warn that awe has been an elusive concept for researchers to study through closed-ended and quantitative approaches. Interviews and accompanying analysis through the three phenomenological themes of *parts and wholes*, *the identity in manifold,* and *presence and absence* yielded findings that I would have otherwise missed.

The first theme of *parts and wholes* embodies how pieces or moments of a phenomenon constitute a whole experience. Recognizing that pieces constitute a whole, phenomenology provided me with a metaphorical magnifying glass to examine discrete elements of interviewees' experiences. Participants focused on minute details, like the sound of birds chipping in a grove of virtual trees, the tiny faces of saints and wise men

in a gothic sculpture, or the placement of superimposed text on specific scenes. Interviews allowed me to peel back such moments and learn from the interviewee about how subtle aspects of awe-inspiring VR can increase or decrease feelings of presence.

The second theme of phenomenology, the *identity in manifold*, describes how a phenomenon under scrutiny may be expressed in various ways, including time. For this study, the identity in manifold revealed itself through a type of temporal oscillation—what participants found to be awe-inspiring immediately after the laboratory experience versus during the interviews. Phenomenologically-informed interviews allowed me to witness how participants' quantitative and qualitative responses sometimes clashed over time, highlighting the fluidity of awe and reactions to it.

The third theme of phenomenology is *presence and absence*; humans intend to objects when they are present as well as when they are not. First, by asking interviewees about their memories of the selected stimuli and previous moments of awe in educational settings, this study was able to capture features of virtually-induced awe that were not present in the laboratory. These memories included awe-inspiring interactive art exhibits, planetariums, and children's educational television programs, among others. These memories revealed the important qualities of virtually-induced awe, such as perceptual envelopment and a sense of transportation to inaccessible spaces. Second, by asking participants to use their imagination to envision awe-inspiring technology, the importance of allowing autonomy and a sense of discovery during travel experiences were uncovered.

5.2.3 Practical Implications

5.2.3.1 Implications for Designers

This study has two implications for designers of awe-inspiring VR intended to promote curiosity: (1) simulating presence within fantastical, inaccessible spaces and (2) balancing didactic information when presenting awe elicitors.

First, VR designers could benefit from creating environments that simulate travel and promote feelings of childlike wonder—or memories of it. Awe and travel are historically interconnected and underpinned by the romanticist movement, particularly notions of taming nature alongside the awareness of one's insignificance within time and space (Picard, 2012). Although an awe-inspiring travel destination in and of itself may prompt strong emotions, it is the recognition of those emotions that evokes personal memories. There may be a temporal aspect to the awe experience during travel, including an initial physiological response, a comparison with past experiences, and a schema-changing component oriented toward the future (Coghlan et al., 2012). This comparison to past experiences may be unrelated to the site, such as childhood memories (Picard, 2012; Lerner & Keltner, 2000).

When asked about their awe experiences in educational settings, participants' responses embodied feelings of childlike wonder, and their design suggestions focused on fantasy. These design suggestions sometimes stemmed from memories of favorite moments with media—ranging from *The Magic School Bus* to *Ready Player One.* Because myth, fantasy, or science fiction moves people beyond their daily concerns, and instead, into a state of wonder (L'Engle, 1982), designers might leverage these qualities when designing virtual spaces. Such spaces may instill a feeling of being small, like a child.

Second, this study's emergent findings indicate that designers must carefully consider how much didactic information to include in awe-inspiring VR experiences. To instill awe in a virtual environment, users must feel as if they are in the presence of the elicitor. Interviewee responses suggest, however, that attention toward explanatory or didactic information was sometimes distracting and reduced spatial presence. Voluntary and involuntary attention direction may explain such responses (de Rijk et al., 1999). Involuntary attention describes the process by which certain media-induced stimuli force concertation on objects. Such stimuli may include a constant stream of highly detailed information. Voluntary attention, on the other hand, allocation represents user-directed concertation based on interest or enjoyment.

Participant responses toward the prayer bead and the sun's magnetic cycles stimuli may be due to involuntary attention. The prayer bead grabbed participants' attention by continuously presenting minuscule visual details in 360 degrees, which may explain the high reports of general awe. Involuntary attention may also explain participants' quantitative awe, vastness, and need for accommodation reactions to the sun's magnetic cycles stimulus. This video utilized highly complex, colorful computer graphics against a 360-degree backdrop of star-filled space. Such visual complexities may promote perceptual vastness and the need for accommodation. By showing a seemingly infinite number of details, the mind cannot accommodate all of the qualities of a stimulus.

In contrast, superimposed text or narration may involuntarily redirect attention away from the vastness of an elicitor. Such information sources may induce cognitive overload (Paas et al., 1994). For example, interviewees noted feeling present during the

bent trees experience because it did not include narration, and noise can cause excessive cognitive load (Wright et al., 2014). Because feelings of self-transcendence require and facilitate increased connectedness to one's surroundings (Yaden et al., 2016), it is possible that participants' egos were diminished during the VR experiences that had limited didactic information. Therefore, designers attempting to instill both presence and awe as well as educate users should provide sufficient time for processing vast visuals before including didactic information.

5.2.3.2 Implications for Educators

The importance of awe in learning is evidenced by scientists who state that it fuels their careers, but, unfortunately, students do not often feel awe in the classroom due to the prescriptive nature of curricula (Cuzzolino, 2019). Despite the relatively limited instances when participants searched for information about the stimuli, educators may still benefit from adopting awe-inspiring VR. This is especially true when field trips or place-based learning is unfeasible and educators must choose which VR experiences to adopt.

Selection criteria may help educators in deciding which VR experience to deploy before inquiry-based curricula. Based on the findings, selection criteria may include (1) perceptual envelopment in highly complex visual details, (2) placement in an inaccessible space, (3) presentation of unexplained phenomena, and (4) limited didactic information. Additionally, educators could enhance their awe-infused curricula by allowing time for reflection after VR experiences.

Educators might first carefully select high-fidelity VR experiences that instill a sense of perceptual envelopment. The experience should ideally give 360-degree viewing

capabilities of a continuous stream of complex visual details that instill feelings of being small. Second, the experience should simulate otherwise inaccessible spaces, especially fantastical places, such as being surrounded by the cosmos or inside a cell. Third, the experience could center on a phenomenon that does not yet have a definitive answer for its existence. Ideally, the selected phenomenon will prompt the user to search for causal explanations. Fourth, the educator and/or VR experience should only give enough information to anchor the user's experience so that they are aware of the simulation's purpose. Alternatively, the user may have access to multiple causal explanations, but it should not give definitive information as to how or why the awe elicitor came into existence.

As noted, reflection may be central to awe experiences, and educators could enhance awe-infused inquiry by allowing moments for student contemplation throughout the VR experience. Just as finding opportunities for discussion or journal writing allows students time to understand and appreciate the extraordinary study abroad experiences (Jeffries & Lepp, 2012), the same may apply to simulated travel. Grounded in my conversations with the interviewees, techniques for promoting reflection may include staggering the didactic information throughout the VR experience or curriculum, providing enough time for students to explore the object or place in question according to their own interests, and fostering student-led conversations about the experience.

Unconventional approaches to fostering awe in the classroom, such as using VR, should be encouraged but with certain caveats. First and foremost, educators and researchers who look to leverage awe responses need to remain vigilant of classroom limitations. Powerful awe experiences may be more serendipitous and, thus, harder to

construct within the confines of a prescribed curriculum. Second, as seen throughout this study, not all elicitors prompt the same awe responses. Some elicitors, like historical artifacts, are culturally situated. Furthermore, because students may have differing awe dispositions or interests in specific topics, focusing on a single awe elicitor within a curriculum may not account for varying personal tastes.

Lastly, it may be incumbent on educators to provide context and further information when using VR that presents uncanny awe elicitors. Because this study found that supernatural causality may promote inquiry, some educators could be tempted to present seemingly supernatural phenomena to students. Instilling a *sense* of supernatural causality or the uncanny should not come at the expense of allowing students to rely on intuitive explanations for phenomena. As one participant mentioned, some individuals rely on supernatural causation to explain the creation of the Giza pyramids. Because non-reflective thinkers may be more likely to accept supernatural causation after an uncanny encounter (Bouvet & Bonnefon, 2015), educators should be certain to provide didactic information that explains the phenomenon once students have finished any prescribed inquiry tasks.

5.4 Limitations to the Study

Although some recognize that immersive technologies may provoke self-transcendent experiences (Gaggioli et al., 2016; Kitson et al., 2018), empirical research in this domain rarely extends to learning. As such, this study is one of the first of its kind. Certain limitations, however, accompany this work, particularly concerning the laboratory setting and stimuli, the sample size, the order effects and scales, memory, and external recognition and rewards. However, with this research being a first step in

determining the relationship between awe and information seeking, I aim to ignite a dialog on how virtual awe elicitors may motivate student exploration in both informal and formal education.

5.4.1 Laboratory Setting and Stimuli Limitations

This study investigated how awe emerges in a laboratory setting and promotes exploratory behavior in naturalistic settings; I did not account for classroom considerations or the incorporation of VR into formal instructional practices. Additionally, by limiting this study to pre-made VR content rather than environments crafted by myself, I was prevented from conducting design-based research that could determine how specific elicitor attributes could be manipulated to better foster curiosity. Furthermore, the relative low fidelity of the stimuli may have impacted feelings of spatial presence.

5.4.2 Sample Size Limitations

Due to this study's small sample size, the quantitative analysis was largely exploratory, and I did not perform a formal power analysis, thus limiting my ability to detect effect. It is also important to note that although the only independent variables were the stimuli and, thus, overfitting was prevented, the approach does create the potential for multicollinearity risks, which are the relationships between the independent variables. Multicollinearity can prevent deciphering which independent variables (which stimulus) explain the variation in the dependent variables (awe or curiosity).

To account for the limitations of this exploratory quantitative analysis, I drew heavily from my qualitative data. Also, my decision to conduct in-depth interviews limited the number of study participants. Consequently, by relying on regressions with a

small number of participants, I was unable to quantitatively conclude causation. However, my aim was that, with the ensuing qualitative data, I could provide more information on the phenomenology of virtual aesthetic experiences and the potential for educational outcomes.

5.4.3 Order Effects and Scale Limitations

Due to the largely qualitative nature of this study and its small pool of laboratory participants, I was unable to properly conduct counterbalancing for order effects, which would have created six possible viewing groups. Thus, order effects may have influenced participants' reactions, particularly toward the first video presented, *The Secret of The Sun's Magnetic Cycles*, and the last video presented, *Inside the Wooden Worlds of Prayer Beads*.

The descriptive statistics showed that the sun's magnetic cycles video had the second highest reports of general awe and vastness as well as the highest levels of need for accommodation. This video also had two significant general awe odds ratios and two significant vastness ratios. Additionally, as noted in the Emergent Findings, some interviewees described that acclimation to the VR headset during the sun's magnetic cycles video prevented the retention of didactic information. Participants may not have anticipated being virtually transported to the center of the sun with accompanying colorful and complex graphics, despite my inclusion of a preliminary, neutral test video.

Surprise can be elicited by stimuli that are high in novelty (Silvia, 2009), and Keltner and Haidt (2003) draw a connection between awe and surprise, noting how surprise may be linked to similar feelings, such as wonder (Frijda, 1986) or a variant of interest (Izard, 1977). Novelty, however, when coupled with a low ability to understand a

stimulus, can also cause confusion (Silvia, 2010). The need for accommodation is not typically associated with confusion (Anderson et al., 2020), and surprise alone does not require the effortful assimilation of information into pre-existing schema (Valdesolo et al., 2017). Others have posited that awe does not always require alterations to mental schemas and have thus operationalized awe elicitors as surprising stimuli (Chirico et al., 2016; Chirico & Yaden, 2018; Chircio et al., 2018). With only one scale focused on the need for accommodation ("I felt challenged to mentally process what I was experiencing"), I am limited to speculative interpretations on how or if surprise related to participants' awe ranking.

The need for accommodation scale and accompanying order effects challenges also impacts the statistics surrounding the prayer bead video. Despite having the highest levels of general awe and vastness in the descriptive statistics analysis as well as having two significant general awe odds ratios and three significant vastness odds ratios, the prayer bead had the fifth lowest need for accommodation. Again, with only one need for accommodation scale, it is difficult to quantitatively determine how frequently the stimuli prompted the need for accommodation in participants.

5.4.4 Memory Limitations

The limits of memory are another consideration when reviewing this study's findings. To uncover how the selected lab stimuli compared to awe in educational settings, I asked participants to compare their experiences. Although the educational settings described by interviewees, like field trips or museum exhibits, are inherently constructed to promote specific learner responses, memories of these moments have the added complexity (and power) of time. Unlike quickly assessing responses after exposure

to stimuli, powerful awe experiences may be slower to develop but qualitatively richer and more persistent (Schneider, 2020). Attempting to compare immediate laboratory experiences to persistent memories may be akin to comparing apples and oranges.

5.4.5 External Rewards and Recognition Limitations

Self-motivated exploration of awe elicitors, ideally, should be unbound for external rewards or recognition (Ryan & Deci, 2000). As such, social desirability bias and participant compensation are two additional limitations to this study. Social desirability in research embodies participants' inclination to bias their responses in surveys and experiments to appear in a more favorable light (Crowne & Marlowe, 1960). As there was an inherent imbalance of power between me and the students selected for this study, social desirability bias is a factor that cannot be ruled out. This power imbalance may have impacted intrinsic motivations for information seeking. The potential for monetary compensation may have also impacted this study's findings. Although I misdirected participants by informing them that the selection for interviews was random, some participants may have realized that reporting information seeking could lead to an invitation for an interview.

Despite these limitations, this study is generative. By examining the connection between humans and digital worlds, new conversations about the future of positive digital experiences and education may emerge.

5.5 Conclusion and Future Research Directions

This study considered leveraging the emotion of awe—a perception-expanding, epistemic state—as a tactic to increase motivation for self-directed exploration, such as information seeking. Thus, it aligns with calls for experiments focusing on the effects of

awe on state-level curiosity (Anderson et al., 2020). It also represents a new research direction within information science, which typically concerns user uncertainty or frustration during searches rather than the pleasurable or the profound (Kari & Hartel, 2007; Latham, 2014).

Ultimately, I found that exposure to specific awe-inspiring VR piqued participants' curiosity, especially toward representations of phenomena with unknown or unexplained origins. However, self-motivated exploration about the VR awe elicitors only occurred in limited circumstances, particularly toward awe elicitors tinged with supernatural causality. Based on this proclivity for exploring supernatural elicitors, injecting mystery and fantasy into educational settings may be one way for educators to promote self-directed inquiry. Interviewees' desires for combining fantasy with mystery to produce awe-inspiring VR content supports this technique.

Fantasy taps into awe by transporting the learner to previously unseen worlds. Mystery, on the other hand, prompts a desire for causal explanations. Continued research on the relationship between awe and inquiry may require targeting specific facets of awe, as suggested by Chirico and colleagues (2018). This study limited its investigation to a variety of positive- and negatively-valenced nature-oriented and human-made awe elicitors. Future studies may adopt Keltner and Haidt's (2003) concept of a family of awe emotions and select stimuli that more readily embody threat, beauty, ability, virtue, and/or supernatural causality. Such an approach may help determine which forms of awe have a positive influence on absorption in information seeking.

This study recognized the limits of contrived awe and thus investigated the experience from a phenomenological perspective to understand its limits. Future research

may benefit from qualitative explorations of technology-mediated awe that occurs in naturalistic settings rather than in the laboratory. Although scholars are recognizing the affordances of immersive technologies for inducing and measuring positive experiences and self-transcendence (Gaggioli et al., 2016; Kitson et al., 2018 for a review), the use of technologies to induce awe in controlled settings still raises important questions. As Schneider (2020) asks, are such mediated awe experiences truly replicative of awe in naturalistic settings? Laboratory-based, controlled studies may indeed not reveal how the nuances of life and time intersect with awe.

There is one source for technology-induced awe, however, that does warrant attention: video games. Understanding how *naturally-occurring*, digitally-induced awe experiences, such as with video games, compare to awe in the physical world may be a fruitful area for future research. Additionally, video games provide an avenue for studying the relationships between information, cognitive load, and awe experiences. Video games often have complicated interfaces as well as an abundance of information and narrative choices (McQuiggan et al., 2008; Green & Jenkins, 2014; Novak, 2014). Furthermore, future researchers may leverage the vast digital landscapes of video games to investigate *in-virtuo* exploratory behavior related to awe. Such exploratory behavior could include player navigation associated with joyous curiosity in awe-inspiring video game settings. This approach could build upon and expand how to operationalize the need for accommodation beyond surprising the user. Researchers could also explore whether refuge-prospect theories of awe apply in digital worlds by leveraging survival-style video games. Researchers might examine how awe elicitors in

such games influence player behaviors and then determine how to measure these responses for future user experience studies.

I began this dissertation by drawing a picture for you of a wind-swept monastery on an island. I drew inspiration for this anecdote from my own travel experiences, and I included it to demonstrate how awe may push people to explore. Whether through technology or other means, this study has highlighted how awe and feelings of discovery intertwine with each other. Often, awe experiences are serendipitous, concern powerful, inaccessible places, and occur outside of everyday experiences. VR, with its transportive abilities, is one path for increasing awe. Ensuring that such technology provides time and space for learners to simply be present, diminish their egos, and become fascinated is the next step.

APPENDIX A: RESEARCH ALIGNMENT

Research Question	**Data Collection**	**Data Analysis**
Out of a selection of virtual awe elicitors, which do participants find the most awe-inspiring and curiosity-provoking and why?	• Laboratory Quantitative Self-reports: o Emotion Label Rating o Vastness Scale o Need for Accommodation Scale o State Curiosity Scale o Exploration Intention Scale	• Descriptive Statistics • Inferential Statistics: Mixed-effects Logistic Regressions
	• Laboratory Qualitative Questions: o Most Awe-inspiring Stimulus Question o Exploration Questions • Phenomenologically-informed Interviews	• Interpretative phenomenological analysis.
What, if any, exploratory behaviors do individuals adopt after exposure to virtual awe elicitors?	• Follow-up Quantitative Self-reports: o Emotion Label Rating o Vastness Scale o Need for Accommodation Scale o State Curiosity Scale o Exploration Intention Scale • Follow-up Qualitative Questions: o Exploration Questions • Phenomenologically-informed Interviews	• Rate of Change • Interpretative phenomenological analysis.
3. How might designers improve awe-inspiring VR content to foster motivation for inquiry?	• Phenomenologically-informed Interviews	• Interpretative phenomenological analysis.

APPENDIX B: EMOTION LABEL RATINGS

How do you feel about this video? Please indicate to what extent that you felt these emotions during *each* of the VR videos. There are no right or wrong answers.*

1 = Absolutely inaccurate, 2 = inaccurate, 3 – Slightly inaccurate, 4 = Neutral, 5 = Slightly accurate, 6 = Accurate, 7 = Absolutely accurate

- Awe:

1	2	3	4	5	6	7

- Contentment:

1	2	3	4	5	6	7

- Excitement:

1	2	3	4	5	6	7

- Fear:

1	2	3	4	5	6	7

- Joy:

1	2	3	4	5	6	7

- Love:

1	2	3	4	5	6	7

- Pride:

1	2	3	4	5	6	7

- Sadness:

1	2	3	4	5	6	7

- Surprise:

1	2	3	4	5	6	7

*The following scales collected responses for each of the six stimuli.

APPENDIX C: VASTNESS SCALE

1 = Absolutely inaccurate, 2 = inaccurate, 3 – Slightly inaccurate, 4 = Neutral, 5 = Slightly accurate, 6 = Accurate, 7 = Absolutely accurate

- I felt that I was in the presence of something grand.*

1	2	3	4	5	6	7

*The following scale collected responses for each of the six stimuli.

APPENDIX D: NEED FOR ACCOMMODATION SCALE

1 = Absolutely inaccurate, 2 = inaccurate, 3 – Slightly inaccurate, 4 = Neutral, 5 = Slightly accurate, 6 = Accurate, 7 = Absolutely accurate

- I felt challenged to mentally process what I was experiencing.

1	2	3	4	5	6	7

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*The following scale collected responses for each of the six stimuli.

APPENDIX E: STATE CURIOSITY SCALES

How curious are you about each video? Please indicate your curiosity about each video. There are no right or wrong answers.

1 = Absolutely not curious, 2 = Not curious, 3 – Slightly not curious, 4 = Neutral, 5 = Slightly curious, 6 = Curious, 7 = Absolutely curious

1. The Secret of The Sun's Magnetic Cycles

1	2	3	4	5	6	7

2. See Harvey's Path from a Helicopter in 360

1	2	3	4	5	6	7

3. Puzzle in Poland: Who Bent the Trees?

1	2	3	4	5	6	7

4. Iron Mountain Facility Provided Data Storage Before the Cloud

1	2	3	4	5	6	7

5. Fukushima, 6 Years On: Empty and Eerie

1	2	3	4	5	6	7

6. Inside the Wooden Worlds of Prayer Beads

1	2	3	4	5	6	7

APPENDIX F: INTENTION TO EXPLORE SCALES

Please indicate the extent that you agree with the following statement: **"I intend to explore more information about this video."** There are no right or wrong answers.

1 = Strongly disagree, 2 = Disagree , 3 = Slightly disagree, 4 = Neutral, 5 = Slightly agree, 6 = Agree, 7 = Strongly agree

1. The Secret of The Sun's Magnetic Cycles

1	2	3	4	5	6	7

2. See Harvey's Path from a Helicopter in 360

1	2	3	4	5	6	7

3. Puzzle in Poland: Who Bent the Trees?

1	2	3	4	5	6	7

4. Iron Mountain Facility Provided Data Storage Before the Cloud

1	2	3	4	5	6	7

5. Fukushima, 6 Years On: Empty and Eerie

1	2	3	4	5	6	7

6. Inside the Wooden Worlds of Prayer Beads

1	2	3	4	5	6	7

APPENDIX G: LABORATORY QUALITATIVE QUESTIONS

This study aims to better understand the relationship between awe and curiosity. You have ranked the videos based on your levels of awe and curiosity to learn more about them.

There are many definitions of awe, but we define it as a powerful experience of wonder and sometimes fear when confronted with conceptually or physically vast objects or stimuli outside of everyday experiences. When it occurs, the individual sometimes experiences goosebumps or feels their jaw drop.

Please take a couple of minutes to respond to the following questions in a few sentences. Again, there is no right or wrong answer.

1. Which single VR scene presented was the most awe-inspiring for you and why?

2. After watching this video that you found most awe-inspiring, what questions do you have about the content presented? (e.g., Was there something that you're interested to learn more about, was there anything that confused you, etc.)

3. Do you have any intention to seek information that answers these questions? If so, how will you find that information?

Thank you! Your responses have been recorded. Please alert the researcher that you have completed the questionnaire.

APPENDIX H: SUPPLEMENTAL SEARCH MATERIAL

If you would like to explore the subjects of the VR experiences presented to you today, feel free to check out the following resources.

The Secret of The Sun's Magnetic Cycles

Wikipedia: "Solar Cycle"	*NASA: "What Will Solar Cycle 25 Look Like"*	Possible search terms: • Solar cycles • Magnetic fields • Solar storms • Sunspots • Plasma flows

See Harvey's Path from a Helicopter in 360

Wikipedia: "Hurricane Harvey"	*NPR: "Houston: Its Buildings Are Partly to Blame"*	Possible search terms: • Category 4 Hurricane • Tropical cyclones • Climate change • Urban development • Displacement

Puzzle in Poland: Who Bent the Trees

Wikipedia: "Crooked Forest"	*Explorer's Web: "Poland's Crooked Forest"*	Possible search terms: • Tree shaping • Pomerania, Poland • Drunken trees • Framing, grafting, pruning, and timing. • Wood warping

Iron Mountain Facility Provided Data Storage Before the Cloud

Wikipedia: "Iron Mountain"	Butler Historical: "Iron Mountain"	Possible search terms: • Secure storage facilities • Data storage • Data centers • Records management • "The Underground"

Fukushima, 6 Years On: Empty and Eerie

Wikipedia: "Fukushima Daiichi nuclear disaster"	BBC: *"Fukushima: What happened at the nuclear plant?"*	Possible search terms: • Tōhoku earthquake and tsunami • International Nuclear Event Scale • The Pacific Ring of Fire • Nuclear exclusion zones • Radiation poisoning

Inside the Wooden Worlds of Prayer Beads

Wikipedia: "Gothic Boxwood Miniatures"	*Met Museum: "Small Wonders: Gothic Boxwood Miniatures"*	Possible search terms: • Gothic boxwood miniatures • Sixteenth-century carvings • Northern Renaissance • Prayer nuts • Iconography

APPENDIX I: FOLLOW-UP QUESTIONNAIRE

Emotion Label Ratings (Follow Up)

It has been 24 hours since our laboratory session. Take a moment and reflect on the six different VR videos you experienced.

Remember: There are no right or wrong answers! Also, be sure to complete all four pages and then press Submit. Thank you!

How do you feel about this video? Please indicate to what extent that you felt these emotions during *each* of the VR videos. There are no right or wrong answers.*

1 = Absolutely inaccurate, 2 = inaccurate, 3 – Slightly inaccurate, 4 = Neutral, 5 = Slightly accurate, 6 = Accurate, 7 = Absolutely accurate

- Awe:

1	2	3	4	5	6	7

- Contentment:

1	2	3	4	5	6	7

- Excitement:

1	2	3	4	5	6	7

- Fear:

1	2	3	4	5	6	7

- Joy:

1	2	3	4	5	6	7

- Love:

1	2	3	4	5	6	7

- Pride:

1	2	3	4	5	6	7

- Sadness:

1	2	3	4	5	6	7

- Surprise:

1	2	3	4	5	6	7

*The following scales collected responses for each of the six stimuli.

Vastness Scales (Follow Up)

1 = Absolutely inaccurate, 2 = inaccurate, 3 – Slightly inaccurate, 4 = Neutral, 5 = Slightly accurate, 6 = Accurate, 7 = Absolutely accurate

- I felt that I was in the presence of something grand.*

1	2	3	4	5	6	7

*The following scale collected responses for each of the six stimuli.

Need for Accommodation Scale (Follow Up)

1 = Absolutely inaccurate, 2 = inaccurate, 3 – Slightly inaccurate, 4 = Neutral, 5 = Slightly accurate, 6 = Accurate, 7 = Absolutely accurate

- I felt challenged to mentally process what I was experiencing.*

1	2	3	4	5	6	7

*The following scale collected responses for each of the six stimuli.

State Curiosity Ratings (Follow Up)

How curious are you about each video? Please indicate your curiosity about each video. There are no right or wrong answers.

1 = Absolutely not curious, 2 = Not curious, 3 – Slightly not curious, 4 = Neutral, 5 = Slightly curious, 6 = Curious, 7 = Absolutely curious

1. The Secret of The Sun's Magnetic Cycles

1	2	3	4	5	6	7

2. See Harvey's Path from a Helicopter in 360

1	2	3	4	5	6	7

3. Puzzle in Poland: Who Bent the Trees?

1	2	3	4	5	6	7

4. Iron Mountain Facility Provided Data Storage Before the Cloud

1	2	3	4	5	6	7

5. Fukushima, 6 Years On: Empty and Eerie

1	2	3	4	5	6	7

6. Inside the Wooden Worlds of Prayer Beads

1	2	3	4	5	6	7

Intention to Explore Scales (Follow Up)

Please indicate the extent that you agree with the following statement: **"I intend to explore more information about this video."** There are no right or wrong answers.

1 = Strongly disagree, 2 = Disagree , 3 = Slightly disagree, 4 = Neutral, 5 = Slightly agree, 6 = Agree, 7 = Strongly agree

1. The Secret of The Sun's Magnetic Cycles

1	2	3	4	5	6	7

2. See Harvey's Path from a Helicopter in 360

1	2	3	4	5	6	7

3. Puzzle in Poland: Who Bent the Trees?

1	2	3	4	5	6	7

4. Iron Mountain Facility Provided Data Storage Before the Cloud

1	2	3	4	5	6	7

5. Fukushima, 6 Years On: Empty and Eerie

1	2	3	4	5	6	7

6. Inside the Wooden Worlds of Prayer Beads

1	2	3	4	5	6	7

Exploration Qualitative Questions (Follow Up)

Please take a couple of minutes to respond to the following question in a few sentences. Again, there is no right or wrong answer.

Since we met in laboratory, have you thought about any of the presented videos that you found awe-inspiring? If so, what video was it, and what were your thoughts regarding it?

Have you searched for any information about this awe-inspiring video? For example, did you use the Supplemental Search Material, conduct a Google Search, check out a book at a library, watch a documentary, etc.?

What pushed you to conduct this search or exploration? If you did not look up more information, why didn't you? What would have pushed you to look for more information or learn more?

APPENDIX J: INTERVIEW SCHEDULES

Interview Procedure: *The purpose of this study is to understand your emotional responses to specific VR content, particularly your levels of curiosity. However, it also explores the concept of awe, that profound human experience when you witness something vast or grand and makes your jaw drop or gives you goosebumps.*

During this interview, you will be asked to respond to several open-ended questions regarding awe and curiosity. You may choose not to answer any and or all of the questions. The procedure will involve recording the interview and this recording will be transcribed verbatim. Your results will be confidential and you will not be identified individually.

Reflecting on the VR Experience

- You experienced six different videos. Reflecting on your VR experience, which video was the most awe-inspiring for you?
    - *Probing questions*
        - Can you describe the video for me?
        - What did you feel when you watched this video?
        - Why was it awe-inspiring?
        - What about this video stands out to you?
        - Did you learn anything from this video?
- We've discussed the video that you found to be the most awe-inspiring. Now, I would like you to consider the least awe-inspiring video. What video was that?
    - *Probing questions*
        - Can you describe the video for me?
        - What did you feel when you watched this video?
        - What about this video stands out to you?
        - Did you learn anything from this video?

Curiosity and Exploration Questions

- Can you describe if at any point you sought information about any of the scenes you watched?
    - *Probing questions*
        - Why did you search for that information?
        - How did you go about searching for that information?
        - When did you do this search?
        - Would you have sought out that information if you weren't in this study?

Awe Experience Comparison

- Can you describe a time when you have experienced awe?
    - How is it different from what you experienced virtually in the laboratory?

Awe and Curiosity Over Time

- Why do you think the videos you described stay relevant to you?

VR Design Questions

- I'd like for you to describe for me if there's been a time in an educational setting—so that could be in a classroom, a museum, a library, watching a documentary, whatever you think—that fostered awe for you?
    - *Probing questions:*
        - Why was this experience awe-inspiring?
        - How did your teacher/setting accomplish this? What did they/it do well?

- Pretend for a moment that you have millions of dollars, and you are going to create the most awe-inspiring *and* curiosity-provoking virtual reality experience for learners. What would this technology look like?
    - *Probing questions:*
        - What's the topic?
        - What would make the learners say "whoa"?
        - What are the learners seeing?
        - What are users doing in/with this technology?
        - What challenges do you foresee with this technology?
- Did you experience any issues with our VR session that I should know about?
- Any final thoughts about the experience that you would like to share?

Interview Procedure: *Remind student of $50 gift card.*

APPENDIX K: DEMOGRAPHICS QUESTIONNAIRE

All answers are confidential and you will not be able to be identified from the information you provide. Please mark the appropriate answer. Some questions may ask you to mark all answers that apply.

1. To which gender identity do you most identify?
    a. Female
    b. Male
    c. Gender Variant/Non-conforming
    d. Prefer not to answer
    e. Prefer to self-describe: _____
2. Which of the following best describes you?
    a. Asian or Pacific Islander
    b. Black or African American
    c. Hispanic or Latino
    d. Native American or First Nations
    e. White or Caucasian
    f. Another race not listed above: _____
3. What is your age? _____
4. What is your current academic level?
    a. Freshman
    b. Sophomore
    c. Junior
    d. Senior

NOT FOR PARTICIPANT USE

Does the participant have prior VR experience: Y/N

APPENDIX L: PROCEDURE PROTOCOLS

Space Availability

- Check with College of Education staff on available lab space.

Preparation

- Upon entering the lab space, ensure that participant stool is in place and free of any obstacles.
- Start the computer and open Google Form for the designated participant.
- Turn on Oculus and test buffering rates.
- Place Oculus on its charger while waiting for the participant.
- Place silicon interface cover on Oculus HMD.
- Wipe down all surfaces, including the Oculus and computer.
- Have a list of participant IDs ready for when participants arrive.
- Have copies of the consent form ready to hand out.
- Have extra pens that may be given to each student (rather than touching similar objects).
- Have a paper "In-Session / Do not Disturb" sign and tape to place on the lab door for when the participant arrives.

Participant Arrival

- Greet the participant.
- Show the Participant to their seat.
- Once the participant is seated, shut the door and place the "Do not Disturb Sign" on the door.

- **Script**: *"Thanks for coming in today. I really appreciate your participation in my study and if you can go ahead and please turn your phone off or put it on mute, we can get started. …*
- **"***I am conducting this study to understand user's emotional reactions to VR content and its potential for educational uses.*
- *For your participation today, you're going to watch about 10 minutes' worth of videos using a VR headset. Then, you're going to answer a questionnaire. Overall, with set-up and the questionnaire, your participation today should take approximately 30 minutes. Then, tomorrow, you will receive a follow-up email that will have three short questions. Last, I want to mention that by participating in this research you will receive:*
    - *Extra credit from your course instructor that announced this study*

      OR
    - *A $5 gift card to a coffee shop.*
- *Now, there is a second study that occurs outside of this space. If selected, we'll have an interview where I ask you some additional questions. For participation in this portion, if you're interested in that, you will receive a $50 gift card.*

Informed Consent Form

- Hand the participant a consent form.
    - Go through all points of the consent form.
- Ask the participant if they agree to consent and see if they have any questions.
- Be sure to indicate that a copy of the consent form is for them to keep.

Time Check

- ***Script: "****Just to double-check, do you have 30 minutes to set aside for participation today? Do you have class or work that you'll need to hurry to? I just want to make sure that now is a good time, and I don't want you to feel rushed at all. If it's not, we can always reschedule!"*
    - Wait for confirmation regarding time commitment.

General Instructions

- **Script**: "*For this study, I am interested in your emotions and levels of interest regarding the content in the VR videos I am about to present to you. You will first fill out some information about yourself. Next, you'll take a couple of minutes to hang out and relax. Then, you will watch three videos. Then, you will take another two-minute break. Then, you will watch the final three videos. After watching all of these videos, you will complete a questionnaire about your experience. Are you clear about what I'm asking you to do?"*

  [Answer any questions]
- **Script**: "*I do ask that you do not discuss this research outside of this room with others, as everything should remain confidential. Lastly, the questionnaires and main task are not a test, so please take this experiment in a relaxed manner. Nothing you do in this experiment will be used to judge you as an individual."*

Demographics and Screening for VR Experience

- **Script**: "*To start, please fill out this brief questionnaire about yourself. Once you reach the bottom of the form, please hand it back."*
    - Lead student to the designated computer.

- Upon receiving the computer, go to the next page of the form. Give the participant an ID number.

- **Script: "***So, just to know a little more about you, could you tell me if you've used a virtual reality headset before? If so, what was it like?"*
  - If their answer is no:
    - **Script**: *That's perfectly fine. Have you ever been to a 3D movie before?*
  - If their answer again is no, be certain to provide extra well-fare checks during exposure to ensure that they are not experiencing cybersickness.
  - Make a note of their answer in the form to control for prior experience.

Wearing the Headset Instructions

- **Script***: "Okay, you may now take a seat on this chair over here, and I'm going to walk you through putting the headset. However, I just want you to know that you may stop at any point if you need to, okay?"*
    - **Wait for confirmation**.
  - *So, place the headset in a position that's comfortable on your head.*
  - *Then, pull the Velcro straps into position. Put the rear strap into position just below the crown of your head.*
  - *Next, pull the top Velcro strap so that it's fairly tight.*
    - *You may see a little light coming through around your nose. This is normal. To reduce the amount of light, please gently pull down on the two levers above your ears."*

Oculus Start-up and Initial Video Instructions

- **Script***: "Please describe for me what you see.*
    - If the answer indicates that they are witnessing a white grid on a black background, they are good to proceed,
    - If the answer is No, troubleshoot with the headset to determine the issue.
- **Script***: "While there may be a little blur on this screen, it shouldn't be significant. Can you describe the clarity of the image."*
    - If the image is relatively clear, let the playlist continue.
    - If the answer is No, troubleshoot with the headset to determine the issue.
- **Script***: In this first video, we are just going to take 30 seconds and get you acclimated to the experience and also make sure that the video isn't too blurry. Then, when I ask you to, I'll just need you to select, pause. Do you understand what you need to do?"*
    - Wait for confirmation if they're ready.
    - If the image is relatively clear, proceed to play the rest of the YouTube playlist.
    - If the answer is No, troubleshoot with the headset to determine the issue.

Stimuli Exposure

- Observe them as they proceed with their videos. After the third video, ask them to stop.
- Wait for confirmation if they're ready.
- Observe them as they proceed with their videos. After the sixth video, ask them to stop.

- **Script**: *"Alright, that's all of the videos! You can take your headset off now, and I'm going to ask you to fill out a quick questionnaire, but, first, how are you feeling?"*
    - If they say they're feeling okay, proceed to the next steps.
    - If they are not feeling well, skip to Appendix K: Cybersickness Protocol.

Laboratory Data Collection Instructions

- Return to computer. Check to make sure that the correct participant form is open and on the correct page.
- **Script**: *"Now, please take a seat over here and fill out this questionnaire. If you have any questions or something is unclear, please let me know and I can help out. When you're finished, let me know."*

Debriefing, Follow-up Questions, and Future Participation

- On completion of the questionnaire, thank the subjects for their participation; clarify any further questions regarding the experimental procedures, data analysis, or use of data.
- ***Script***: *Great! So, again, thank you for your participation in this study. Tomorrow, you'll receive a follow-up email with just three short questions. Again, it's really important that you answer those questions."*
- *If you have any further questions, please feel free to contact me. Also, please remember this study is confidential so do not discuss it with others. If you are selected for an interview, you will receive an email.*
- *Thank you again so much!*

Clean-up

- Be sure to remove the "Do not Disturb Sign" from the door.

- Re-arrange the room as necessary.
- Remove silicon interface cover and clean with an anti-bacterial wipe.
- Using a dry cloth to clean the outside of the headset.
- Use an anti-bacterial wipe to clean the straps and the facial interface foam.
- Use a dry optical lens micro-fiber cloth to ***gently*** clean the lenses.
- Use a non-abrasive anti-bacterial wipe to clean the HMD's hand-held remotes.
- Use an anti-bacterial wipe to clean the computer.

APPENDIX M: CYBERSICKNESS MITIGATION PROCEDURES

- Before immersion, I will remind participants that they may stop at any point and that they should tell me if they are feeling any symptoms.
- During immersion, I will be able to check on the welfare of participants while still maintaining six feet of distance:
    - E.g., “We’re going to pause here for a minute. How are you feeling? Do you need anything?”
- After immersion, I will ask whether the participant is experiencing any symptoms of cybersickness.
    - E.g., “Are you feeling okay after the VR experience? Are you experiencing a headache, dizziness, nausea, vision problems, or sudden fatigue?”
- If the participant is experiencing symptoms, a lined trash can will be available in case of vomiting, and I will offer to accompany the participant to the nearest restroom. Saltines and ginger ale will also be made available.

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