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Immersed in Fire: The Use of Virtual Reality as an Attitude Assessor and Boundary Object in Wildland Fire Management

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**IMMERSED IN FIRE: THE USE OF VIRTUAL REALITY AS AN ATTITUDE
ASSESSOR AND BOUNDARY OBJECT IN WILDLAND FIRE MANAGEMENT**

By

Casey Olechnowicz

B.S. Old Dominion University, 2016

A THESIS

Submitted in Partial Fulfillment of the

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(Forest Resources)

The Graduate School

The University of Maine

May 2018

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Thesis Advisor: Dr. Jessica Leahy

An Abstract of the Thesis Presented
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Interest in using prescribed burning as a forest management tool to promote forest health and regeneration is growing in Maine. The goal for this research was to better understand the way that the public perceives prescribed burning practices in wildland-urban interfaces, with an emphasis placed on how immersive imagery, closely related to virtual reality (VR), compares to traditional communication methods. We specifically focus on the social acceptability of prescribed burning and analyze how the level of immersive imagery is related to that acceptability (Ahn, 2015; Bricken, 1990; Fogg, Cuellar, and Danielson, 2009; Smith 2015; Wiederhold, Davis, and Wiederhold, 1998). The information derived from this research can be a useful tool in public involvement and communication efforts for forest managers, scientists, and policy makers.

Additionally, this research identified potential solutions for bridging public and manager communication boundaries. Immersive imagery is a relatively new technology and its uses within forest management have only recently begun to be explored. This research built upon the concept of boundary spanning objects, where an object – in this case immersive imagery – can create an effective exchange of ideas and information between stakeholder groups. Within the boundary literature, three factors are frequently identified as being particularly influential on the

perceptions of information communicated through a boundary object: saliency, legitimacy, and credibility (Cash et al., 2002). Combining this with the growing body of literature on immersive imagery for communication and decision-making purposes, this research attempted to identify public perceptions of immersive imagery. This research evaluated saliency, legitimacy, and credibility of immersive imagery and traditional communication methods, which contributes toward understanding immersive imagery's potential as a boundary-spanning object.

The methodological design for this research was to implement a 2x2 framework in which participants were shown visual imagery that varied based on level of immersion as well as level of smoke within the imagery. Each participant was given a pre and post-questionnaire tailored to whichever of the four groups they have randomly been assigned. The pre-questionnaire included questions that attempted to measure the participants environmental values, prior knowledge and experience, acceptability of prescribed burns, their views on smoke from prescribed burns, their perceived confidence and trust in managers, and questions relating to boundary objects. After viewing the randomly assigned imagery, participants took a post-questionnaire which composed of questions relating to sociodemographic variables, and the other same identical parameters.

We found that immersive imagery or VR has substantial potential in several arenas, but most notably as an effective boundary spanning object that seemed to increase participant's perceptions of credibility and saliency towards VR and wildland fire management. Additionally, the technology also showed a high amount of potential in reducing fear and anxiety towards prescribed burning.

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CHAPTER 1

INTRODUCTION

While prescribed burning is a frequently used tool in the western United States to reduce wildfire risk and promote forest health, it is one that is infrequent and unexplored at the location of this study, Maine. When one thinks of the prominent forest landscapes in America influenced by fire, rarely would the normally temperate and wet forests of Maine come to mind. The return interval of major fire disturbances in this region is of a considerable length of time, often occurring only every 500 years. This however, refers to stand replacing fires, and some researchers have indicated that certain portions of the state experienced fires in return intervals as little as 20 years (Figure 1: Stambaugh et al., 2015).

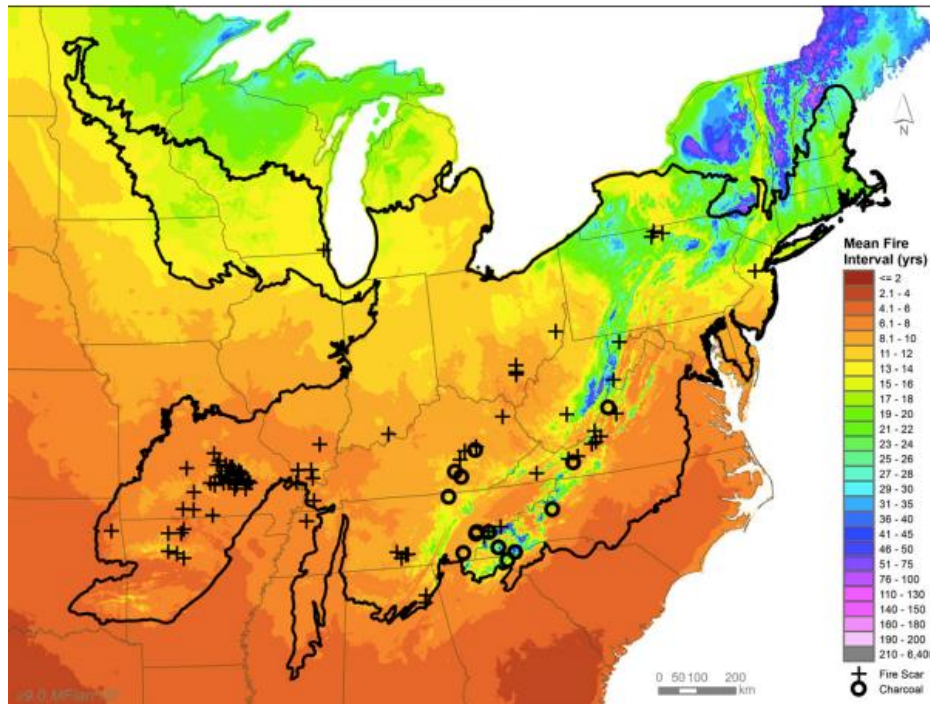


Figure 1- Fire Intervals in Maine

Despite a general lack of an ecological necessity for stand replacing fires in Maine, small-scale fires created naturally or as a result of human disturbance are still relatively common throughout

the state. Decades of fire suppression throughout the state has called into question the need for forest managers in Maine to perform occasional prescribed burning fuel treatments that serve the dual purpose of both simulating the natural ecological regimes of this region while also potentially preventing larger and more dangerous wildfires from occurring as a result of accumulated fuel loads (Brown and Smith, 2000; Irland, 2013). The last century of forest management in Maine has led to suppression and prevention of forest fires on a large scale. Records back to 1903 indicate that fires frequently consumed 50,000 acres of forest per year, and occasionally exceeded 100,000 acres per year. Fires since the 1960s have burned less than 5,000 acres per year and more typically about 1,000 acres (Gadzick et al., 1998). As urban sprawl increases throughout the country and the state of Maine, fuel treatments are increasingly needed as fires begin to occur near residential areas more frequently than in the past.

The use of prescribed burning as a forest management tool has been implemented by various agencies and organizations in Maine such as The Nature Conservancy in the Downeast region of Maine, the National Park Service in Acadia National Park, and by several other public and private agencies in the more fire prone ecosystems in Southern Maine. These organizations use prescribed burning as an ecological tool to simulate natural disturbance regimes within the forest, as a management tool to reduce accumulated fuel loads, or as a method to clear fields to prevent forest growth such as at a historical site that is being preserved or sites being utilized for agriculture. Maine as a whole is home to a number of pyrophyllic tree species, including most of the species of pine and oak in the state (Thomas-Van Gundy et al., 2015; Abrams, 1990; Abrams, 2000; Abrams, 2001; Keeley, 2012). Prescribed fire can also be used as a tool to promote rare plant growth, such as in the case of the endangered Northern Blazing Star, a plant indigenous to New England, including Maine. Prescribed fire has been shown to increase the reproduction of

this plant and reduce predation from other invasive plants (Vickery, 2002). As managers begin to forecast various scenarios in regards to climate change, there is some agreement among experts that, despite Maine expected to see an increase in precipitation, there will be an increase in extreme weather events including late season drought events that could potentially increase wildfire risk within the state (Karl et al., 2009 and Hamilton, 2010).

Nevertheless, there remains very little research performed on these issues in Northern New England, particularly in Maine, and there is research that indicates local context does indeed matter in terms of acceptance of fuels treatment scenarios (McCaffrey, 2006). The high forest density and especially the amount of private land ownership in Maine are unique features in comparison to the western United States, and may offer some alternative conclusions in terms of this regions pre-conceived attitudes and perceptions towards fuel treatment practices. Thus, this research analyzed the social acceptability of prescribed fire in Maine through a novel technology, Virtual Reality, while also assessing the potential of this technology to effectively span communication boundaries and barriers between scientists, managers, and the public.

CHAPTER 2

ASSESSING PRESCRIBED BURNING ATTITUDES USING IMMERSIVE IMAGERY

Introduction

Background

In this modern digital age, natural resource managers and scientists are beginning to explore the effectiveness of emerging technology to measure public attitudes towards pressing and often controversial environmental management strategies. Simultaneously, a few of these emerging technologies display potential in influencing environmental attitudes by replicating real world environments and management actions. One of the technologies that displays a high amount of potential in this regard is Virtual Reality (VR). VR is a relatively new form of technology that has traditionally been developed for gaming and training purposes, but has recently been explored for its effectiveness in assessing users attitudes and as a persuasion tool to influence attitudes (Fogg, Cuellar, and Danielson, 2009).

VR is defined as the computer-generated simulation of a 3-D image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment. Many researchers argue that VR in its definition must be “illustrative, immersive, interactive, intuitive, and intensive”, all of which have a strong correlation to the effectiveness of the technology in influencing attitudes, perceptions, and behaviors (Orland et al., 2001). While all of these variables are important aspects to the overall influence of VR technology, this study will analyze the immersiveness of the technology. Many researchers have indicated that level of immersion is a particularly vital component to the effectiveness of VR technology as a communication tool (Ahn, 2015; Bricken, 1990; Fogg, Cuellar, and Danielson, 2009; Riva et al.,

1998). We assess VR and traditional imagery (2-D) methods in an often-controversial forest management situation: prescribed burning.

The literature provides evidence that level of immersion within VR systems is crucial. It has also been established as essential to highlight how different forms of VR influence the level of immersion in a virtual environment. When it comes to changing attitudes and behavior associated with prescribed burning, research has often indicated that more interactive and immersive communication methods are the most effective (McCaffrey, 2006). VR technology can currently be broken down into four categories: smartphone based headgear, integrated VR, CAVE (Cave Automatic Virtual Environment), and 2-D photosphere. The two most advanced forms of VR in terms of technological capacity and level of immersion are the CAVE and integrated VR systems. These platforms are the most sophisticated and realistic, while providing the highest amount of immersion into the virtual environment. 2-D photosphere, otherwise known as 360-degree photography, is one of the more basic and cost-efficient ways to create a virtual immersive environment. It is currently being tested for its effectiveness in environmental communication projects such as an ongoing USDA Forest Service climate change project to increase climate change awareness with rural northeastern United States residents by showing them adaptive local agricultural landscapes

(<https://www.climatehubs.oce.usda.gov/hubs/project/if-you-were-there-360-demonstrations>).

There are some potential limitations to 360-degree photography in that it is not as immersive of a virtual environment as a CAVE system and is often limited to a single site that cannot be brought to participants. The final variation of VR technology would be the smartphone based headgear technologies such as Google Cardboard or Samsung GearVR, which varies heavily in terms of immersion into the system depending on the type of headgear technology. All of these have

potential for communication in the natural resource management sector, including within forest management. Despite some of the limitations associated with the cost and practicality (location-wise) of some of the variations of VR technology, scholars of decision-making and communication theory have identified significant benefits of conveying information through virtual systems versus traditional information delivery systems.

As the technology continually improves, research is beginning to test immersive virtual environments as effective measures of individual perceptions of natural environments (Smith 2015). This technology has proven to be useful when applied to other natural resource management areas, such as displaying environmental changes as a result of climate change, but very seldom has this technology been tested as a communication method for forest management or forest fuel treatments such as prescribed burning. This research will aim to effectively analyze and highlight communication methods like VR that can measure and even potentially influence public perceptions and attitudes towards forest management techniques like prescribed burning.

The residential areas most susceptible to fire risk and smoke production are referred to as the wildland-urban interface, areas where development mixes with forested landscapes that are more susceptible to potential wildfire outbreaks (Whitman et al., 2013). As a result of this phenomena, a crucial aspect of wildfire research has focused on the attitudes and perceptions of homeowners within this wildland-urban interface towards fuel treatments and their side effects, particularly prescribed burning and the smoke it produces. This emphasis on analyzing social acceptability prompts the exploration of new tools to increase the effectiveness of attitude assessments and the importance of tools that can be used to increase social acceptability such as VR.

With the significance of exploring VR technology and prescribed fire communication outlined, the information derived from this research can be a useful tool for forest managers, scientists, and policy makers by estimating the social acceptability of prescribed burning and smoke production while also analyzing what variables might influence this social acceptability, particularly how perceived immersion within a virtual environment will influence it.

Goals and Objectives

The explicit goal of this research is to assess social acceptability of prescribed burning through VR and analyze how a number of variables supported by the literature influence social acceptability. This will be examined through a 2x2 experimental design in which there are two levels of immersion (2-D visual imagery and a 360-degree immersive imagery presentation) and two levels of smoke (normal smoke output from a prescribed fire and altered imagery with increased smoke output). The objectives of this study are:

1. To understand how level of immersion in a VR system is related to the social acceptability of prescribed burning.
2. To understand how smoke levels are related to the social acceptability of prescribed burning under different levels of immersion.
3. To understand how confidence and trust in managers is related to the social acceptability of prescribed burning under different levels of immersion.
4. To understand how knowledge, experience, and sociodemographics is related to the social acceptability of prescribed burning under different levels of immersion.

Conceptual Framework

Construal Level Theory

When it comes to analyzing VR as an attitude assessor and influencer, there are a few prominent communication theories that show where VR has significant promise. One theory we explored as a conceptual framework is Construal Level Theory, a commonly used theory in risk communication. The theory essentially states that an individual's perceived uncertainty, and temporal, social, and geographical distances with events or objects influence their risk perceptions and attitudes towards those things (Trope and Liberman, 2010). The theory argues that a greater perceived uncertainty or temporal, social, or geographical distance within a communication message is less likely to influence some sort of attitude or behavior than a message where the individual perceives a closer temporal, social, or geographical distance with that issue (Zwickle and Wilson, 2013). In the Construal Level Theory framework, a greater perceived temporal distance towards an issue is less likely to influence attitudes and behavior than a more proximal one as a result of the individual experiencing a greater sense of urgency associated with the information being communicated (Ahn, 2015). In the context of prescribed fire management this applies directly to many of the long-term benefits that are associated with fuels treatments. There are a large amount of resources invested into the implementation of these decisions with the reward often taking place in an unknown distant future. These attributes of Construal Level Theory identify key areas where VR can be a useful tool for managers or scientists.

In addition to distance, Construal Level Theory also outlines two significant areas of psychological distance towards which VR could potentially be effective towards: abstract and concrete construals. Within this theory, concrete construals are the framing of messages as

occurring closer in time and geographical distance, as impacting the self, and having little uncertainty. Contrastingly, abstract construals are messages with greater perceived temporal and geographic distance, that effect others, and have high uncertainty (Zwickle and Wilson, 2013). There is an inconsistency within the literature regarding the effectiveness of abstract versus concrete construal messages and their influence on perceptions and behavior, however it is clear that VR can be an effective tool for reducing psychological distance towards an issue. In studies related to 3-D visualization of climate change outcomes, researchers have found that extremely realistic visual imagery can cause abstract concepts to be perceived as more concrete among viewers of the imagery (Sheppard, 2005). The technology could potentially create a concrete construal message out of a forest management issue that may oftentimes be fairly abstract, such as climate change because it is associated with having a great perceived psychological distance (Spence et al., 2010). Wildfire management can be thought of similarly, as the effects of wildfire and prescribed burning are often very uncertain, and the benefits are temporally distant to the general public.

Admittedly there is some debate among scholars regarding the effectiveness of using psychological distance as a way to influence behavior, especially when considering distance of place, as place attachment can have considerably different meanings depending on the individual (Brugger et al., 2015). Recognizable landscapes have been shown to elicit more effective behavioral responses in persuasive imagery research, but in large scale communication scenarios it can be incredible difficult to establish a recognizable local place that is consistent among all audience members (Sheppard, 2005). However even outside of place, if reducing distance within abstract scenarios like prescribed fire management leads to positive perception shifts and eventually behavior change towards that issue, then it can be advantageous to frame messages to

reduce those distances. With abstract management decisions VR can be particularly advantageous in making the perceptions of the risks or benefits associated with the management more concrete.

When it comes to using VR to influence environmental attitudes and behaviors, a few studies have attempted to explore its effectiveness. Ahn et al. (2014 and 2015) explored the use of VR to influence environmental behaviors related to paper conservation. By highlighting the connection between paper waste and a negative environmental outcome (heavy cutting of forests), VR was able to increase individual self-efficacy and internal locus of control regarding this behavior, both of which refer to an individual's perceived influence on the outcome of this environmental issue. This directly relates to the distant abstract benefits associated with sustainable forest management, which are aimed at generating future forest outcomes that are difficult to immediately see. Fire managers can use this behavior or attitude modification to influence management support, and scientists can also potentially increase positive perceptions regarding fire science. These theories and past research lend support to VR's potential in this area, and one of the variables that could arguably have the greatest influence on perceptions and attitudes is the level of immersion that comes with a virtual environment.

Social Acceptability

In the context of this study an attitude is defined as “a learned tendency to react favorably or unfavorably to a situation, individual, object, or concept; often articulated around support or opposition for an action or activity (Allen et al., 2009, pg. 5).” Social acceptability in the context of forest management is referred to as “public willingness to accept or tolerate management options.” (Wyatt et al., 2011, pg. 256). In the prescribed fire literature, there have been a large number of studies that have analyzed the social acceptability of fuels treatments, mostly in the

western United States. McCaffrey (2006) estimated that based on a number of social acceptability studies an average of 80-90 % of study respondents approve of prescribed burning with 30% indicating that they strongly approve. Smoke has been identified in the literature as being a significant potential barrier to social acceptability towards prescribed and controlled burning due to the potential human health impacts that it brings to a significant portion of the American public (McCaffrey, 2006).

Immersion

Level of immersion within a virtual environment has a significant influence on VR's effectiveness as a communication or persuasion tool (Ahn, 2015; Bricken, 1990; Fogg, Cuellar, and Danielson, 2009; Riva et al., 1998). Researchers have identified panoramic and 360-degree virtual environments as increasing perceptions of immersion, and thus increasing sense of place and engagement among participants (Appleyard, 1977; Furness et al., 1998; Sheppard, 2005).

Ahn (2015) analyzed the effectiveness of immersive virtual environments on reducing temporal and social distance within the Construal Level Theory framework. She tests this relationship in the human health sector between soft drink consumption and obesity, and finds that the vividness (immersion) of virtual experiences for users not only reduced their perceived temporal and social distance associated with soft drink consumption, but that the use of immersive virtual environments had significant links to long term behavior changes as opposed to traditional forms of communication like pamphlets. This indicates that the attitude shifts from more immersive virtual environments have longer term effects than attitude shifts from other forms of communication. Ahn (2015) further suggests that the use of more immersive virtual technology can significantly aid communication efforts in the context of health risks by allowing users to virtually experience health effects of soda beverage consumption without doing any

physical damage. This experience of the risk is suggested to have a much greater weight on the individual's perception of the health risk because personal and recent experiences have a greater weight than distant ones (Ahn, 2015). This phenomenon can also be applied towards creating a more positive perception of a risky management action through a more immersive virtual environment. Bricken (1990) also suggested that immersive virtual environments could constitute direct experiences that can be representative of real world scenarios the user would face in natural environments. This concept of VR replicating a direct experience has potential for increasing perceptions of the benefits with most fuels treatment scenarios while simultaneously lowering perceptions of risk towards fuels treatment.

Smoke

One of the largest barriers to public acceptance associated with prescribed fire is smoke, which can have damaging human health side effects that can range anywhere from heart and lung conditions, exacerbating of preexisting conditions like asthma, and irritation to many of the senses (McCaffrey, 2006; Olsen et al., 2014). Other potential side effects not related to health are reduced road visibility, and potential tourism impacts (Olsen et al., 2014) Researchers have found that most of the negative perception of smoke can be avoided with communication before the prescribed fire event, but one study found that, even with advanced notice, smoke from prescribed fire represented a human health problem for 30 percent of households effected by prescribed fire (McCaffrey, 2006). McCaffrey (2006) also pointed out that who benefits from the production of smoke has a great influence on citizen's acceptance of the smoke. For example, citizens of a particular community may be less inclined to accept the production of smoke if the cause is towards a management goal that does not align with their wishes or desires, or offers no tangible benefit to them. While smoke has commonly been identified as a potentially significant

barrier to the social acceptability of prescribed burning, experts in the field have noted that research on the acceptability and communication of smoke production is limited and remains a major literature gap related to studies on the social acceptability of prescribed fire (McCaffrey et al., 2013).

When it comes to prescribed fire management, one of the most influential variables on attitudes towards fuels treatments or other management decisions are risk perceptions due to the potential side effects of prescribed burning, particularly smoke. The previously mentioned Construal Level Theory articulates the shaping of risk perceptions through perceived psychological distance, and smoke is one of the side effects that would be the most proximal in the public's mind. The abstract benefits of prescribed fire are often long term, whereas the immediate risk associated with smoke is much more concrete and can often times outweigh the abstract benefit resulting in a negative attitude towards prescribed burning, particularly prescribed burning plans close in geographic distance to an individual's residence. Another proximal risk that researchers have identified in the public mind is the possibility of an escaped burn, which has been shown to be a major barrier to social acceptability of prescribed fire and is a concept that has strong ties to confidence and trust towards institutions and managers performing the controlled burn (McCaffrey, 2006; Winter et al., 2002; Winter et al., 2005). Other studies have shown the link between public risk perceptions associated with environmental air quality and smoke from a prescribed burn (Winter et al., 2002).

Confidence/Trust

There is ample research done on the attitudes and perceptions of citizens towards specific forest management practices, agencies, and policies, particularly as forest managers increasingly attempt to involve local communities in large-scale management decisions (McDaniel, 2014;

Toman and Shindler, 2006; Winter et al., 2004). A slight majority of the literature, albeit not all studies, indicates a slightly positive perception of prescribed burning practices within local communities as long as an effective line of communication exists between forest managers and the public regarding the positive benefits of fuel treatment practices like prescribed burning (Carpenter et al 1986; Kumagai and Daniels 2002; Smith and Clark 1994; and Taylor 1988). Acceptance to prescribed burns in the literature has been strongly tied to confidence in the resource managers performing the burn and a belief in the positive outcomes of the burn. In a sense, many researchers studying social acceptability of prescribed fire have identified confidence and trust in managers and agencies as a significant predictor of approval towards fuels reduction management (McCaffrey, 2006; Winter et al., 2005; Toman et al., 2014; McCaffrey, 2015). These two factors, perceived benefits and confidence in managers, have been noted as positive indicators of affect, which relates to the subconscious negative and positive feelings invoked by something (Wilson et al. 2011). While perceptions may lean positive for burns if trust exists, research has indicated levels of skepticism from the public towards managing rather than suppressing non-planned fires started by humans or those started by natural causes like lightning (Taylor 1988; Kumagai and Daniels 2002).

The literature also indicates that the trend of a slight acceptance towards prescribed burning performed by forest managers hinges upon the community trust in those forest managers and the information that is communicated to the public. This is similar with many natural resource management areas where the public is more likely to accept and be engaged with a management decision if they are informed and involved with the decision prior to its implementation (McCaffrey, 2006; Toman et al., 2014; McCaffrey, 2015). This may seem like common sense logic, but there remain concerns among researchers and practitioners regarding

the effectiveness of different communication methods to relay this information to the concerned parties and build confidence and trust across multiple stakeholder groups. These results only serve to highlight the significance of analyzing immersive imagery technology and its potential influence on confidence and trust in managers.

Researchers have highlighted past experiences with managers as being essential to building confidence and trust, and this is an area where VR technology could potentially be the most effective (Toman et al., 2014; McCaffrey, 2015). If VR technology positively influences participant's perceptions of experience towards prescribed fire management, than level of immersion could potentially act as a mediating variable by increasing confidence and trust which has in turn been shown to positively influence social acceptability.

Knowledge

The literature reveals a direct positive correlation between the amount of information citizens have about the ecological benefits of wildfire and the likelihood that they will support fuel treatment practices like prescribed burning (Blanchard and Ryan, 2004; Cortner et al., 1984; Kumagai and Daniels, 2002; Shelby and Speaker, 1990). Additionally, literature indicates that some of the strongest linkages found between prescribed fire and public acceptance are knowledge and familiarity with prescribed burning (McCaffrey, 2006, see also: Blanchard and Ryan, 2004; Carpenter et al., 1986; Dupey and Smith, 2018; Loomis, 2001; McCaffrey, 2002). In one of the only acceptability of prescribed burning studies performed in the northeast, where prescribed burning is relatively uncommon, Blanchard and Ryan (2004) found that knowledge was one of the most significant predictors of support towards prescribed burning practices. Contradictory to other studies measuring social acceptability of prescribed burning, some researchers found no significant difference between the social acceptability of individuals who

have a high level of knowledge about prescribed burning and those who have no knowledge of prescribed fire (Taylor and Daniel, 1984). With somewhat inconclusive results found in the literature, knowledge remains a key variable of interest.

Innovative technologies like immersive imagery have been shown to increase subjective knowledge whilst also reducing the knowledge-behavior gap that has been identified by many researchers across natural resource disciplines (Ahmad and Nordin, 2014; Kollmuss and Agyeman, 2002). However, one does wonder if the links between an increase in subjective knowledge and behavior change are more strongly tied to experience than knowledge, as other studies state that knowledge alone is a poor predictor of social acceptability and is unlikely to change social acceptability on its own (Wyatt et al., 2011).

Experience

As previously stated, familiarity and experience are often found to be positively linked with social acceptability towards prescribed fire (McCaffrey 2006, Carpenter et al. 1986, Loomis 2001, and McCaffrey 2002). There are additionally theoretical frameworks that lend support to the notion that experience has a strong linkage with social acceptability, willingness to support, and even behavior. Communication theories linking attitudes and behavior, such as the Theory of Planned Behavior or the Elaboration Likelihood Model, rely on the assumption that there is a link between changing an individual's perception towards an issue and that individual supporting or engaging in a particular behavior. While some social psychology theories link attitudes and behavior, some researchers believe the linkage is more nuanced than assuming a change in attitudes will lead to behavior or support of a behavior, and that behavior can play a significant role in shaping behavior (Ajzen, 1991).

Kollmuss and Agyeman (2002) identify several barriers to this attitude and behavior gap, and one of the most prominent is the difference between the effects of direct and indirect experiences. The authors state that direct experiences, like personally witnessing a fuels treatment for example, have a much stronger influence on individual behavior (or likelihood to support a behavior) than indirect experiences such as learning about fuels treatments in a classroom setting. Indirect learning may lead to an increase in a desired attitude towards an environmental issue, but it may not be a lasting attitude or one that has a correlation to a change in behavior (Kollmuss and Agyeman, 2002). Spence et al. (2011) for example, found that citizens who reported having directly experienced impacts of climate change had much lower uncertainty about the issue and showed an increase in perceived risk, saliency, and behavioral intention associated with the issue. In the context of prescribed burning, Blanchard and Ryan (2004) found in Massachusetts a direct correlation in experience with prescribed fires and acceptability towards them, while Winter et al. (2005) found no significant relationship between experience with prescribed burning and social acceptability towards the practice. While experience is not a sure guarantee of social acceptability, this is an area where VR can potentially be effective by bridging a gap between indirect and direct experiences if the virtual environment is immersive enough to imitate a direct experience with a fuels treatment.

Sociodemographics

Most research regarding human dimensions of wildfire and prescribed burning predominantly focuses on the Western American landscape and typically involves local ecosystems that are dominated and ultimately shaped by frequent wildfire regimes. The current literature has mixed conclusions as to the differences in attitudes and perceptions towards wildfire and prescribed burning based on changes in region and demographic information, and it

should be noted that some notable experts in the field have remained skeptical that these factors will change attitudes and perceptions of forest management practices (Toman et al 2014; Bright and Carroll, 2004). One research study in particular from Bright and Carroll (2004), attempted to analyze differences in social acceptability responses between different population densities along the wildland-urban interface in Illinois. Needless to say, they found very few significant differences in social acceptability responses between urban and rural demographics regarding prescribed burning.

Along with rural-urban differences, one of the other social demographic variables that is of considerable interest to the study is that of gender. Throughout the social acceptability of prescribed fire literature there is no mention of any significant results associated with gender. However, within social psychology and risk communication literature there have been consistent findings that have shown significant differences in risk perceptions between men and women, particularly in the United States (Finucane et al., 2000). One theory that epitomizes these results is the White Male Effect, which is a trend in risk studies that white men often perceive risks on a much lower level than women and minorities do. Finucane et al. (2000) assert that this notable trend is a result of sociopolitical factors rather than biological ones and is also not a result of education or rationality. The effect has been found even among studies comparing risk perceptions of men and women experts and scientists, and the Finucane et al. (2000) study hypothesized that it is much more closely tied to the difference in world views and power in decision making contexts that white men often have compared to women and minorities (note that this result is specific to the United States only). One interesting aspect of this effect that has been shown by researchers is that men statistically are also more likely to have trust in authoritative decision makers compared to women who are more supportive and trusting of

community-based decision making processes (Finucane et al., 2000). Along with rurality and gender, the responses to the variation in immersion (2D imagery and VR) and visual imagery (smoke levels) will also test the influence of other various demographic variables including home state, rurality, student majors, and education level.

Methodology

Approach

The methodological approach implemented a 2x2 framework in which participants were shown visual imagery that varied based on level of immersion as well as level of smoke within the imagery (Table 1). The level of immersion is considered low with participants who were shown 2-D imagery and high with participants who were shown immersive imagery. Variation in smoke levels consisted of 2 groups: one with participants who viewed normal footage or photographs of a prescribed burn and one with participants who viewed footage or photographs in which the smoke levels were digitally enhanced to be more obscured and give the impression of heavier smoke production.

		<u>Level of Immersion</u>	
		<i>Low (2-D)</i>	<i>High (VR)</i>
<u>Smoke Levels</u>	<i>Normal</i>	2-D Visual Image unaltered	360-degree Immersive Imagery unaltered
	<i>High</i>	2-D Visual Image with an estimated 50% smoke opacity enhancement	360-degree Immersive Imagery with enhanced smoke footage

Figure 2– Research Design

Participants took a presurvey before viewing the immersive imagery demonstration or viewing the 2-D photographs, and a postsurvey after viewing the imagery. The surveys attempted to measure both social acceptability towards prescribed fire and constructs shown by the literature to be closely tied to social acceptability of prescribed burning (Appendix A).

Population and Recruitment

As one of the first VR studies in wildland fire social science, the population for the study consisted of University of Maine students from three undergraduate courses, which included two required lower division courses in the School of Forest Resources and one upper division elective course within the Department of Wildlife Ecology, Fisheries, and Conservation Biology. These courses were selected based on faculty members who expressed a desire to have their students participate in the study following outreach by the researchers to a variety of natural resource faculty members who teach large undergraduate natural resource courses. The population was limited to natural resource courses in order to prevent a wide variation in responses to survey questions that measured student's environmental values and prior knowledge and experience associated in prescribed burning. The use of students is well established in studies analyzing cause and effect relationships of treatments, and determining whether an effect exists (Guo and Schneider, 2015; Visser, Krosnick, and Lavrakas, 2000). Due to the exploratory nature of student samples, future research will be needed to replicate findings and determine whether the same effects are found among other populations.

Following a recruitment plan approved by the Institutional Review Board for human subjects, the researchers coordinated with faculty members at the university teaching the undergraduate courses to incorporate the study into the class either as a requirement (see syllabus language in Appendix B) or as extra credit in the class (see extra credit language in Appendix B),

with alternative options provided for whichever approach the faculty members of the courses preferred. Students who were interested in participating in the study signed up for time slots online to come to the Innovative Media Research and Commercialization Center on campus. This research involved 104 total participants, evenly distributed between VR and 2-D photography groups.

Instrument Design

The survey (Appendix A) was designed to measure a variety of variables, including environmental values, knowledge and experience towards both fire and VR, acceptability of smoke, confidence and trust in managers, and social acceptability of prescribed fire. The questions on the pre and post questionnaires consist of multiple-choice responses for social demographic questions and a 7-point likert scale for all other questions, from strongly disagree (1) to strongly agree (7). The participants taking the survey were randomly sorted into either the 2-D or immersive imagery levels as well as the regular and high smoke levels.

The two forms of visual imagery were taken from USDA Forest Service photographs showing prescribed burns, and prescribed burn footage customized by Ethan Turpin at the University of California, Santa Barbara Bren School for a 360-degree presentation (ethanturpin.com). The 360-degree presentation was projected in the APPE-2 space at the Innovative Media Research and Commercialization Center using a series of 4 projectors that each displayed a different perspective of the same prescribed fire on a wall (Appendix C). The presentation is exactly 2 minutes and 30 seconds long. The 2-D photographs were 5x7 inches in size, and were screenshots taken from several stages of the same prescribed fire shown in the 360-degree immersive imagery presentation (Appendix D). The footage and images were manually altered to represent two varying levels of smoke production from a prescribed fire.

While half of the participants viewed normal immersive or 2-D imagery of a prescribed burn, the other half viewed high smoke imagery, which was manually enhanced by the researchers. 2-D photographs were enhanced using consistent opacity scales, and the immersive imagery was enhanced to appear to have higher smoke by overlaying the prescribed burn footage with 360-degree imagery of smoke. Researchers attempted to achieve the same level of opacity associated with smoke in both treatments. The study took place on-site at the Innovative Media Research and Commercialization Center at the University of Maine with particular assistance and help given by the director of the facility, Gene Felice.

Instrumentation: Environmental Values

Environmental values were measured using a series of 8 questions adapted from adapted from Winter et al. (2004) and Steel et al. (1994) which aimed to measure participant's pro-environmental orientation.

Instrumentation: Knowledge

Knowledge was measured based on survey questions adapted from Brunson and Shindler (2004) and Cvetkovich and Winter (2004). For participants who were randomly sorted into the 2-D group there were three questions relating to knowledge about prescribed burns, wildland fires, and forest management. For participants who were randomly sorted into the VR category there were the same three questions plus an additional question pertaining to knowledge regarding virtual reality technology.

Instrumentation: Experience

Experience was measured based on survey questions adapted from Vogt, Winter, and Fried (2005) which aim to measure perceived experience of participants with prescribed fire, personal fire damage, fire damage of anyone close to them, and fear or anxiety associated with

fire. For participants who received the VR treatment, there was an additional question pertaining to participants past experience with virtual reality technology.

Instrumentation: Smoke

Acceptability of smoke production was measured based on survey questions adapted from Engebretson et al. (2016) and Shindler and Toman (2003), which aim to measure participants perceived health risks associated with smoke, and the level of acceptability towards smoke produced from prescribed fires with various management goals attached to the prescribed burns.

Instrumentation: Confidence/Trust

Confidence and trust was measured based on survey questions adapted from Vogt et al. (2005), Winter et al. (2004), and Shindler and Toman (2003), which aim to measure participants perceived confidence and trust in managers performing the prescribed burns.

Instrumentation: Social Acceptability

Social acceptability was measured on the survey based on questions adapted from Winter et al. (2004) and Brunson and Shindler (2004) which aim to measure participants perceived risk from the impacts of prescribed burning including how prescribed burning impacts scenery, firefighting costs, wildlife conditions, and human health risks as well as the perceived benefits of prescribed burning.

Results

Sample Demographics

The participants in this study (n=104) consisted entirely of university students (Table 1). The population had slightly more men (n=59) than women (n=45), most likely a result of the

high number of natural resource majors such as forestry, which tend to be male dominated disciplines. A majority of participants were 21 years of age or younger (n=87), and fairly evenly distributed between class years with most students being first years (n=39). A large portion of participants also indicated that they were from states within New England (n=77). Finally, participants were very evenly split between identifying themselves as being from either a rural area (n=47) or a suburban one (n=43) with few students stating they were from urban areas (n=10). The only major difference between the two imagery sample groups was that the 2-D group had fewer women (n=18) than the VR group (n=27).

Population Characteristics

Imagery	Female (%)	Mean Age (Year)	Natural Resource Major (%)	From New England (%)	Rural (%)	Suburban (%)	Urban (%)
<i>2-D</i>	34.6	20.2	98.1	74.9	44.2	42.3	11.5
<i>VR</i>	51.9	20.4	98.1	73.0	46.2	40.4	7.7
Total	43.3	20.3	98.1	74.0	45.2	41.3	9.6

Table 1. Population Characteristics

Immersion

The first objective of this research was to assess how level of immersion is related to social acceptability towards prescribed burning, in other words, how does social acceptability change under high and low levels of immersion. Before we tested this relationship, we needed to confirm that the two sample groups (2-D and VR) were not statistically different to begin with, which was assessed by running an independent samples t-test for presamples. No statistical differences were found for the two samples prior to treatment. Now that comparability of the two

samples has been established, we expected the following results following the imagery treatment:

- H1: Social Acceptability of prescribed burning will increase more among the VR participants than among the 2-D participants.
- H2: Social acceptability ratings will be higher in the VR treatment than the 2D treatment because the level of immersion makes it more concrete according to Construal Level Theory.

In order to test these two hypotheses, a paired samples t-tests were run to assess any significant pre and post differences, and an independent samples t-test was run to assess significant differences in the acceptability scores post treatment. Only one statement had a marginally significant result for 2-D participants (Table 2): prescribed burning creates more smoke now, less in the long term. Participant's acceptability towards this statement increased by a mean difference of 0.35 on the likert scale.

Table 2. Social Acceptability

Social Acceptability ^a						
Statement	Imagery	Mean (\bar{x})	Pre/Post SA Difference	Std. Deviation	p-value (Paired Samples)	p-value (Independent samples)
<i>Prescribed fire has little overall effect on the intensity or frequency of wildfires.</i>	2-D					NS
	<i>Pre</i>	2.87	0.20	1.69	NS	
	<i>Post</i>	2.67				
	VR					
<i>Prescribed fire reduces fuel loads in most natural areas.</i>	2-D					
	<i>Pre</i>	5.29	-0.02	1.54	NS	
	<i>Post</i>	5.27				
	VR					
<i>Prescribed burning creates more smoke now, less in the long term.</i>	2-D					
	<i>Pre</i>	4.73	0.35	1.44	p<0.10	
	<i>Post</i>	5.08				
	VR					
<i>Prescribed burning reduces fire-fighting costs.</i>	2-D					NS
	<i>Pre</i>	5.10	0.00	1.17	NS	
	<i>Post</i>	5.10				
	VR					
<i>Prescribed burning restores forests to a more natural condition.</i>	2-D					
	<i>Pre</i>	4.83	-0.04	1.12	NS	
	<i>Post</i>	4.79				
	VR					
<i>Prescribed burning improves future wildlife conditions.</i>	2-D					
	<i>Pre</i>	5.15	-0.19	1.10	NS	
	<i>Post</i>	4.96				
	VR					
<i>Prescribed burning allows for uncontrollable fires.</i>	2-D					NS
	<i>Pre</i>	3.13	0.09	1.03	NS	
	<i>Post</i>	3.04				
	VR					
	<i>Pre</i>	3.08	0.04	1.39	NS	

Table 2. Social Acceptability

	<i>Post</i>	3.04			
<i>I have fears about human health risks associated with prescribed burning.</i>	2-D				
	<i>Pre</i>	2.94	-0.06	1.06	NS
	<i>Post</i>	3.00			
	VR				
	<i>Pre</i>	3.31	0.14	1.44	NS
	<i>Post</i>	3.17			
<i>I have concerns over reducing scenic quality with prescribed burning.</i>	2-D				
	<i>Pre</i>	3.38	-0.16	1.29	NS
	<i>Post</i>	3.54			
	VR				
	<i>Pre</i>	3.65	-0.14	1.48	NS
	<i>Post</i>	3.79			
<i>I have concerns over reducing wildlife habitat with prescribed burning.</i>	2-D				
	<i>Pre</i>	4.25	0.23	1.29	NS
	<i>Post</i>	4.02			
	VR				
	<i>Pre</i>	4.33	0.15	1.21	NS
	<i>Post</i>	4.17			
<i>I have concerns about wildland fires in my state.</i>	2-D				
	<i>Pre</i>	2.85	-0.05	1.65	NS
	<i>Post</i>	2.90			
	VR				
	<i>Pre</i>	3.23	0.06	1.47	NS
	<i>Post</i>	3.17			
<i>I have concerns about prescribed burns in my state.</i>	2-D				NS
	<i>Pre</i>	2.67	-0.12	1.69	NS
	<i>Post</i>	2.79			
	VR				
	<i>Pre</i>	3.17	0.11	1.44	NS
	<i>Post</i>	3.06			

^a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Overall no responses changed significantly following the VR treatment. VR had a slightly more consistent trend of positively influencing acceptability scores than 2-D photographs did, as only 3 statements decreased in acceptability scores following the VR treatment, while all others marginally increased. The first statement interestingly, only decreased within the VR group, although the result was fairly marginal and not statistically significant

(Mean difference of -0.07). With the independent samples t-test no statement significantly differed between the 2-D and VR groups. Additionally, few trends were found between the two groups that would support our previous hypotheses, as several statements displayed lower acceptability or lower increases within the VR group and several displayed lower acceptability within the 2-D group, all of which did not display any significance difference other than the aforementioned statement regarding smoke for 2-D participants. However, overall among all participants social acceptability towards prescribed burning was slightly positive prior to treatment.

Smoke

The second objective for this research was to establish how smoke levels were related to social acceptability. Essentially, how does social acceptability change among varying levels of smoke and immersion. Before we tested this relationship, we needed to confirm that the four sample groups (2-D low and high smoke and VR low and high smoke) were not statistically different to begin with, which was assessed by running ANOVA of mean social acceptability among pretreatment samples. When running ANOVA, no statements showed any significant differences among the four pretreatment sample groups. Now that comparability of the four samples has been established, we expected the following results following the imagery and smoke treatments:

- H3: Post survey acceptability ratings will be lower among the two high smoke groups (2-D high smoke and VR high smoke) than among the normal imagery treatment group.
- H4: Social acceptability ratings will be lower in the VR groups than the 2D groups post treatment, because the level of immersion makes it more concrete according to Construal Level Theory

To accurately assess these hypotheses, we ran ANOVA of mean social acceptability towards all four posttreatment groups. Among the four different sample groups (2-D low and high smoke, VR low and high smoke), no significant differences were detected to support either hypothesis pertaining to smoke acceptability.

While the one social acceptability of prescribed fire statement that pertained to smoke showed the only significant increase following an imagery treatment, we also attempted to measure smoke acceptability in general (Table 3). There were some surprising findings, including participants indicating a small decrease in the acceptability of smoke following the 2-D treatment for 3 of the statements. The VR group's acceptability of smoke moderately increased for every smoke acceptability parameter following treatment. The VR group indicated a higher smoke acceptability in post scores among all statements except for one: Smoke from prescribed burns ignited by land managers is accepted (post 2-D \bar{x} =4.90 and post VR \bar{x} =4.73). However, the pretreatment scores for the VR group were lower which may explain this difference (pre 2-D \bar{x} =4.69 and pre VR \bar{x} =4.48).

Smoke Acceptability ^a					
Statement	Imagery	Mean (\bar{x})	Pre/Post SA Difference	Std. Deviation	Significance
<i>I've had a previous health problem associated with smoke.</i>	2-D				
	Pre	1.37	-0.11	0.58	NS
	Post	1.48			
	VR				
<i>Smoke from prescribed burns ignited by land managers is acceptable.</i>	2-D				
	Pre	4.69	0.21	1.29	NS
	Post	4.90			
	VR				
<i>Smoke from naturally ignited fire on nearby land that is allowed to burn is acceptable.</i>	2-D				
	Pre	4.77	-0.02	1.18	NS
	Post	4.75			
	VR				
<i>Smoke from prescribed burns to achieve forest health objectives is acceptable.</i>	2-D				
	Pre	5.38	-0.17	0.83	NS
	Post	5.21			
	VR				
<i>Smoke levels are acceptable as long as the fire results in a healthier forest.</i>	2-D				
	Pre	5.27	-0.08	1.44	NS
	Post	5.19			
	VR				
	Pre	5.22	0.23	1.19	NS
	Post	5.45			

^a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Table 3. Smoke Acceptability

Confidence/Trust

The third objective for this research was to establish how confidence and trust were related to social acceptability under varying levels of immersion. In layperson terms, how does

confidence and trust change under different imagery treatments and how does confidence and trust influence social acceptability? Before we tested this relationship, we needed to confirm that confidence and trust were not statistically different to begin with among the two immersion levels, which was assessed by running an independent samples t-test among pretreatment samples. When running an independent samples t-test, no statements showed any significant differences among the pretreatment sample groups. Now that comparability of the four samples has been established, we expected the following results following the imagery and smoke treatments:

- H5: Confidence and trust scores will have a greater increase (pre-post) among the VR survey group than the 2-D survey group.
- H6: Confidence and trust will be higher posttreatment among the VR group than the 2-D group.
- H7: Confidence and trust will be significantly correlated with social acceptability towards prescribed fire.

To assess the first two hypothesis, a paired samples t-test was run to assess the difference between pre and post responses between the two imagery groups, while an independent samples t-test was run to assess the differences in post responses between the two imagery groups (Table 4).

Table 4. Confidence and Trust

Confidence and Trust ^a						
Statement	Imagery	Mean (\bar{x})	Pre/Post SA Difference	Std. Deviation	p-value (Paired samples)	p-value (Independent samples)
<i>I would highly rate forest managers that manage land in my state.</i>	2-D					
	Pre	4.98	-0.13	1.01	NS	NS
	Post	4.85				
	VR					
Pre	4.81	0.04	0.91	NS		
	Post	4.85				
<i>I have trust in my local agency to perform prescribed burns.</i>	2-D					
	Pre	5.29	-0.29	1.23	p<0.10	NS
	Post	5.00				
	VR					
Pre	5.00	0.08	1.08	NS		
	Post	5.08				
<i>I have trust in forest managers to perform prescribed burns.</i>	2-D					
	Pre	5.58	-0.41	1.33	p<0.05	NS
	Post	5.17				
	VR					
Pre	5.23	0.02	1.09	NS		
	Post	5.25				
<i>Forest managers build trust and cooperation with people so they feel like they are acting in their best interest.</i>	2-D					
	Pre	5.08	-0.37	1.31	p<0.05	NS
	Post	4.71				
	VR					
Pre	5.06	-0.23	1.13	NS		
	Post	4.83				
<i>Forest managers do a good job communicating with the public about forest issues.</i>	2-D					
	Pre	4.19	0.06	1.23	NS	NS
	Post	4.25				
	VR					
Pre	4.29	0.11	1.00	NS		
	Post	4.40				
<i>Forest managers do a good job of managing forestlands.</i>	2-D					
	Pre	5.15	0.04	1.01	NS	NS
	Post	5.19				
	VR					
Pre	5.10	0.03	1.03	NS		
	Post	5.13				
	2-D					
	Pre	4.12	-0.18	1.13	NS	

Table 4. Confidence and Trust

<i>Forest managers do a good job of notifying the public about upcoming prescribed burns.</i>	Post	3.94				
	VR					NS
	Pre	4.23	-0.13	1.43	NS	
	Post	4.10				
<i>Forest managers do a good job protecting private property from wildland fires.</i>	2-D					
	Pre	4.77	0.00	1.14	NS	
	Post	4.77				
	VR					NS
	Pre	5.06	-0.14	1.07	NS	
	Post	4.92				

^a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Among participants in the 2-D group, confidence and trust in managers and prescribed burning consistently decreased for most statements, including a marginally significant decrease for 1 statement, and a significant decrease for 2 of the statements.

While participants in the 2-D group saw significant decreases in their confidence and trust scores, participants in the VR group saw minor increases in confidence for 5 out of the 8 statements, and minor decreases in the other 3 (with no significant decreases), which lends some credence to H5. While independent samples t-test showed no significant differences between VR and 2-D imagery treatments, post confidence scores were higher for the VR group among 6 out of 8 statements aimed at measuring confidence and trust.

Because of the stated correlation between social acceptability and confidence within the literature, we ran a correlation analysis between post confidence and trust scores and post social acceptability scores to test H7. In order to run a correlation analysis, a reliability test was needed to converge confidence/trust statements and social acceptability statements so we could simply compare two variables. When running a Cronbach's Alpha test based on the responses to the 8 confidence/trust statements a Cronbach's Alpha result of 0.889 was found, indicating a high

level of reliability between the statements and thus allowing us to merge the statements into one confidence and trust variable. With social acceptability, Cronbach’s Alpha was run twice, first for the set of statements in which lower responses indicate lower acceptability (social acceptability 1) and second for the set of statements in which lower responses indicate higher acceptability (social acceptability 2). For the first set a Cronbach’s Alpha of 0.816 was found, while for the second set a Cronbach’s Alpha of 0.863 was found thus allowing us to create two merged social acceptability variables. The next step was to run correlations tests between the two social acceptability variables and the confidence variable. A significant correlation was found between social acceptability and confidence when running Spearman’s Rho (Table 5).

Spearman’s Rho Correlation of Confidence/Trust and Social Acceptability			
	Confidence/Trust	Social Acceptability1	Social Acceptability2
Confidence/Trust	1.00	0.54**	-0.44**
Social Acceptability1	0.54**	1.00	-0.49**
Social Acceptability2	-0.44**	-0.49**	1.00

Table 5. Spearman’s Rho Correlation of Confidence/Trust and Social Acceptability

**Denotes significance at $p < 0.01$

The results show a moderate correlation between confidence and trust and social acceptability among all participants, verifying results shown throughout prescribed fire social science literature and H7.

Knowledge

Objective 4 for this research outlines the goal of understanding the relationship between knowledge and social acceptability under varying levels of immersion. Before we tested this relationship, we needed to confirm that the sample groups (2-D and VR) knowledge were not

statistically different to begin with, which was assessed by running an independent samples t-test among pretreatment samples. When running this test, no statistical differences were found among the pretreatment sample groups. Now that comparability of the samples has been established, we expected the following results following the imagery:

- H8: Perceived knowledge scores will have a greater increase under the VR imagery treatment than the 2-D imagery treatment.
- H9: Perceived knowledge scores post imagery treatment will be greater for the VR group than the 2-D group.

In order to effectively test these hypotheses, we ran a paired samples t-test to assess pre and post differences for the two groups, as well as an independent samples t-test to assess post differences between the two sample groups (Table 6).

Knowledge ^a						
Statement	Imagery	Mean (\bar{x})	Mean Difference	Std. Deviation	p-value (paired samples)	p-value (independent samples)
<i>How knowledgeable are you about prescribed burns in your state?</i>	2-D					
	Pre	3.06	-0.06	1.47	NS	
	Post	3.00				NS
	VR					
	Pre	2.79	-0.23	1.20	NS	
	Post	2.56				
<i>How knowledgeable are you about wildland fires in your state?</i>	2-D					
	Pre	3.31	0.13	1.01	NS	
	Post	3.44				
	VR					p<0.05
	Pre	2.96	-0.23	1.06	NS	
	Post	2.73				
<i>How knowledgeable are you about forest management strategies in your state?</i>	2-D					
	Pre	4.14	0.16	1.10	NS	
	Post	3.98				
	VR					NS
	Pre	3.83	0.11	1.31	NS	
	Post	3.94				

^a Likert scale from 1=Not at All to 7=Very

Table 6. Knowledge

Surprisingly, we found that post imagery knowledge in the VR group was consistently lower than the 2-D group, and significantly lower when pertaining to knowledge regarding wildland fire (post 2-D \bar{x} =3.44 and post VR \bar{x} =2.73, $p<0.05$), contrary to our hypothesis. Knowledge scores also consistently displayed lower increases or greater decreases for the VR group than the 2-D group.

Experience

Objective 4 for this research outlines the goal of understanding the relationship between experience and social acceptability under varying levels of immersion. Before testing this relationship, we needed to confirm that the sample groups (2-D and VR) perceived experience

was not statistically different to begin with, which was assessed by running an independent samples t-test among pre treatment samples. When running this test, no statistical differences were found among the pretreatment sample groups. Now that comparability of the samples has been established, we expected the following results following the imagery:

- H10: Perceived experience scores will have a greater increase under the VR imagery treatment than the 2-D imagery treatment.
- H11: Perceived experience scores post imagery treatment will be greater for the VR group than the 2-D group.

In order to effectively test these hypotheses, we ran a paired samples t-test to assess pre and post differences for the two groups, as well as an independent samples t-test to assess post differences between the two sample groups (Table 7).

Experience ^a						
Statement	Imagery	Mean (\bar{x})	Mean Difference	Std. Deviation	p-value (paired samples)	p-value (independent samples)
<i>I've experienced prescribed burns near my home.</i>	2-D					
	Pre	2.13	-0.17	1.28	NS	
	Post	1.96				NS
	VR					
<i>I've had friends, family, or neighbors impacted by fire damage.</i>	2-D					
	Pre	3.06	-0.06	0.73	NS	
	Post	3.00				NS
	VR					
<i>I've been personally impacted by fire damage.</i>	2-D					
	Pre	1.38	0.04	0.56	NS	
	Post	1.42				NS
	VR					
<i>I've felt fear or anxiety related to fire.</i>	2-D					
	Pre	2.08	0.04	0.63	NS	
	Post	2.12				NS
	VR					
	Pre	2.46	-0.38	1.05	p<0.05	
	Post	2.08				

^a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Table 7. Experience

Among participants in the 2-D group perceived experience was not significantly changed by the imagery treatment, while for the VR group perceived damage to family, friends, or neighbors (pre \bar{x} =3.52 and post \bar{x} =3.10), as well as fear or anxiety related to fire (pre \bar{x} =2.46 and post \bar{x} =2.08), both decreased significantly. This could indicate a potentially useful of application of VR in decreasing fear or anxiety related to natural hazards like fire, although VR did not seem to significantly change participants perceived experience with prescribed fire. The independent

samples t-test also showed no statistical differences between 2-D and VR post responses for perceived experience. The mixed results (increase in experience among some statements for VR and decrease for others), fail to lend support to either of our hypotheses.

Sociodemographics

Objective 4 also pertained to the effect of social demographic variables on social acceptability under varying levels of immersion. Prior to testing, we expected the following results regarding the effect of sociodemographics:

- H12: Participants who indicate they grew up in rural areas will indicate a greater acceptability towards prescribed burning than urban participants despite literature findings.
- H13: Women will indicate lower social acceptability towards prescribed burning based on prior literature indicating a statistical trend of women having higher risk perceptions than men.

All participants were asked to respond to six social demographic questions which measured participants gender, age, class rank, major, home state, and population density in their hometown. Age, class rank, major, home state, and population density were all statistically tested using one-way ANOVA to determine if any of these social demographic variables had any influence on the social acceptability of prescribed burning or smoke from controlled burns. All 5 had no significant relationship or correlation with social acceptability, including population density contrary to our expectations. The only social demographic that appears to have had any influence on social acceptability was actually gender, which was analyzed through a chi-square test of independence in post treatment responses (Table 8). For all statements, there were 58 participants who indicated that they were male and 45 who indicated that they were female.

Gender Differences Towards Social Acceptability (Posttreatment)^a					
Statement	Gender	Mean (\bar{x})	Mean Difference	X²	Significance
<i>Prescribed fire has little overall effect on the intensity or frequency of wildfires.</i>	M	2.62	-0.69	13.7	p<0.05
	W	3.31			
<i>Prescribed fire reduces fuel loads in most natural areas.</i>	M	5.40	0.51	8.81	NS
	W	4.89			
<i>Prescribed burning creates more smoke now, less in the long term.</i>	M	5.36	0.67	11.6	p<0.10
	W	4.69			
<i>Prescribed burning reduces fire-fighting costs.</i>	M	5.34	0.56	9.00	NS
	W	4.78			
<i>Prescribed burning restores forests to a more natural condition.</i>	M	5.21	0.54	9.23	NS
	W	4.67			
<i>Prescribed burning improves future wildlife conditions.</i>	M	5.33	0.57	12.2	p<0.05
	W	4.76			
<i>Prescribed burning allows for uncontrollable fires.</i>	M	3.16	0.29	6.18	NS
	W	2.87			
<i>I have fears about human health risks associated with prescribed burning.</i>	M	2.76	-0.71	6.03	NS
	W	3.47			
<i>I have concerns over reducing scenic quality with prescribed burning.</i>	M	3.34	-0.66	6.99	NS
	W	4.00			
<i>I have concerns over reducing wildlife habitat with prescribed burning.</i>	M	3.50	-1.32	18.4	p<0.01
	W	4.82			
<i>I have concerns about wildland fires in my state.</i>	M	2.90	-0.30	10.3	p<0.10
	W	3.20			
<i>I have concerns about prescribed burns in my state.</i>	M	2.95	0.08	7.56	NS
	W	2.87			

^a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Table 8. Gender Differences Towards Social Acceptability (Posttreatment)

When comparing differences in responses between male and female participants, it is evident that almost on every statement women indicate less social acceptability and greater risk perceptions towards prescribed burning and smoke than men do, with significant results occurring for 5 social acceptability statements. When the influence of VR on social acceptability was compared between men and women respondents, no significant differences or trends were discovered, indicating that the different forms of imagery did not influence the differences in social acceptability responses.

Discussion and Conclusion

Examining the results of this research study reveals some fairly significant trends, some of which confirm consensus within the prescribed fire social acceptability literature, and others which appear to be novel and not yet fully explored yet. While the immersive imagery treatment failed to distinguish itself from 2-D imagery in terms of mean social acceptability ratings before and after treatments, the results of this research confirm some controversial results in previous literature regarding certain social demographic variables, including an interesting gender difference that was not noted in previous literature. Perceived fear and anxiety associated with fire in general was also found to significantly decrease after participants witnessed a VR presentation of prescribed fire. Smoke levels were not related to changes in social acceptability in either 2-D or VR treatments, meanwhile the variables measuring confidence, trust, knowledge, and experience once again highlight their importance in gaining social acceptability towards fuels treatments like prescribed burns. These results have implications for both fire managers and future research in this arena. Like most studies of social acceptability of prescribed burning, our

result indicated slightly positive perceptions and attitudes towards prescribed burning among all participants. Interestingly, our study noted little effect of smoke on participants acceptability towards prescribed fire.

The first objective of this study was to assess how level of visual immersion would influence the social acceptability of prescribed burning. We found the immersive imagery presentation had no significant benefit over 2-D in influencing attitudes. Potentially the system was simply not sophisticated, immersive, or inclusive enough, as many scholars argue that in order for VR to be effective it needs to be completely immersive and include a participatory component, which this study did not (Ahn, 2015; Bricken, 1990; Fogg, Cuellar, and Danielson, 2009; Riva et al., 1998).

There were a few variables that the immersive imagery did alter compared to 2-D, particularly participants perceived experience. Participants in the immersive imagery presentation saw a significant decrease in their perceived damage family members experienced through fire, and a significant decrease in fear and anxiety related to fire, and a significant increase in their perceived experience with virtual reality, while 2-D had no significant results related to experience.

One of the interesting results regarding the influence of immersive imagery on perceived experience was its effect on reducing fear and anxiety related to fire while also reducing the perceptions of damage that family members, friends, and neighbors faced from fire. There are many studies in medicine and psychology that detail VR's potential for exposure therapy for treating shock, anxiety, post-traumatic stress, and fear which is an extremely interesting result to show up in the context of a prescribed fire study (Meyerbroker, 2014). The ability to reduce fear and anxiety in participants relating to fire is a result that may need more long-term study to

analyze if that is a consistent trend and if it will have any long-term trends regarding attitudes and behavior towards prescribed fire or wildfire.

The second research objective was understanding the role that smoke levels might play in influencing smoke acceptability within an immersive environment. Between participants who viewed imagery that was unaltered and those who viewed enhanced smoke imagery, there were little to no trends and no significant differences between their social acceptability responses. Pre and post survey results also remained relatively the same among participants. The social acceptability statistics of smoke was found to be slightly positive overall among all participants. This finding is not consistent with much research within the field that has found smoke to be a key barrier to social acceptability. McCaffrey (2006) cites that smoke is a serious health problem to an estimated 30% of the population. McCaffrey (2006) also indicates that the source of the smoke is key, and how that benefits those who are affected.

There are two possible explanations that we hypothesize are influencing this result. The first is that two of the questions relating to smoke acceptability are asking if smoke is acceptable for the purposes of resulting in a healthier forest, which is a management goal that would align with this population who are natural resource majors and indicated positive perceptions and values towards the environment in the survey. The other two questions are in the context of land managers, but are still phrased as though forest managers are lighting the burns for ecological purposes rather than extractive ones. For example, “smoke from prescribed burns to achieve forest health objectives is acceptable.” McCaffrey (2006) has identified that public support regarding the objectives behind a prescribed burning and its subsequent smoke production can lead the public to be much willing to tolerate the production of smoke. The second explanation would be that the student population sampled here is not indicative of what responses of the

general public would look like regarding smoke. In fact, 84.6% of respondents indicated that they strongly disagreed that they had ever had any previous health problems associated with smoke, a much smaller figure than the one indicated by McCaffrey (2006).

The results relating to confidence and trust only serve to justify many claims by experts in the field that confidence and trust in managers, agencies, and process are some of the most accurate predictors of social acceptability towards prescribed fire (McCaffrey, 2006; Winter et al., 2005). Within our research low scores of confidence were significantly correlated with low scores of social acceptability and vice versa for high scores of confidence. These results held true for both social acceptability towards prescribed fire and smoke. Our results also refuted findings from Taylor (1988) and Kumagai and Daniels (2002) who stated that the public was very skeptical to accept managers allowing burns from natural ignitions to be controlled rather than suppressed. Our participants indicated on average a moderate acceptance towards the statement: “Smoke from naturally ignited fire on nearby land that is allowed to burn is acceptable” (mean=4.86 in post responses among all participants), indicating a high level of trust in managers on average, to either control a naturally ignited fire or respond to it if it escapes. We should note that this is an exploratory study of a university student population, so studies like the ones from Taylor (1988) and Kumagai and Daniels (2002) could very well still be more indicative of the public as a whole than ours, future research will be needed to analyze these differences.

Along with confidence and trust, knowledge was also supported by this study to be indicative of social acceptability. The importance of knowledge for acceptance is well documented in the literature, as is familiarity towards prescribed fire, which can be considered part of both knowledge and experience (Shelby and Speaker, 1990; Kumagai and Daniels, 2002; Blanchard and Ryan, 2004; Dupey and Smith, 2018). Interestingly enough, participants stated

that they believed their perceived knowledge actually decreased marginally after seeing the immersive imagery, while 2-D participants perceived knowledge marginally increased. This could be a result of the vividness of the immersive system, and participants who had no prior experience regarding prescribed burning may not have at all expected the footage they saw which may cause some second guessing about ones perceived knowledge towards the subject. Considerations may need to be made regarding what type of prescribed fire footage was shown, particularly as in the case of our study the fire was not taking place in a familiar ecological region and was quite volatile rather than a gentle understory controlled burn. One can see the many potential solutions that can be created by increasing the knowledge of a community base regarding fire and prescribed burning and at the same time increasing confidence and trust to perform the prescribed burns.

Some of the interpretations of experience were discussed earlier regarding virtual reality and fear/anxiety. Experience of prescribed burns though was a large predictor of social acceptability, which mirrors much of the literature (Carpenter et al. 1986; Loomis 2001; McCaffrey 2002; McCaffrey 2006; and Toman et al., 2014). One interesting aspect about the theoretical concepts relating to experience in the literature, is the influence on behavior that familiarity and experience have, which might indicate that if managers are attempting to get stakeholders to engage in a certain activity (allow a burn on their land or on adjacent for example) that creating a direct experience for stakeholders might be an effective way to bridge the communication-behavior gap that is so frequently discussed by scientists and managers.

Out of all of the social demographic variables, childhood rurality and gender were the two that we hypothesized might make the largest impact on social acceptability. This is in contrary to past prescribed fire studies which indicated that rural-urban identification made no

difference in social acceptability, and this was the same result that was found within our study. It would seem however, that those who live or grew up in rural areas on the wildland-urban interface would be more likely to experience prescribed burns, and thus be more likely to support them. This was not found by our study however, and this might indicate that the other variables that were shown to influence acceptability like trust and knowledge play a larger role.

Gender, however was found in our study to significantly impact several items measuring social acceptability, as women proved to have much higher risk perceptions associated with prescribed fire than men did. This supports literature in the risk communication and social psychology fields, however this is a result that has not been discussed at length within social acceptability of prescribed fire studies. Due to the exploratory nature of this particular research study, this is one of the results that might be the most interesting to pursue in future research related to this topic to see if similar trends hold true. The higher amount of women within the VR group, could have lowered post VR social acceptability responses as well, and an evenly distributed gender sample might have illuminated more of the effects of VR on social acceptability responses within the survey.

The goal of this study was to assess social acceptability of prescribed burning through VR, and analyze how level of immersion, level of smoke, confidence in managers, knowledge, experience, and sociodemographics influence social acceptability. Based on the survey results, the following findings were found related to our goals and objectives:

- Participants who viewed the immersive imagery did not have significantly different social acceptability responses than those who viewed 2-D imagery.

- Participants who viewed imagery with higher smoke levels were not significantly more or less likely to have lower social acceptability responses than those who viewed unedited imagery.
- Participants who had higher confidence and trust in forest managers and in prescribed burning as a management tool were significantly more likely to view prescribed burning as socially acceptable.
- Experience was significantly influenced by the immersive imagery, gender was shown to have a significant effect on social acceptability, and perceived knowledge was shown to decrease as a result of the treatments.

Although this was an exploratory study with a student population, the results displayed here offer some interesting prospects for future research. This is particularly the case related to gender differences, which have seldom been explored within this field of study. In order to verify that these trends exist within the social science of prescribed fire, further research will absolutely be required to determine whether trends like ones we found related to gender, VR, smoke, and other social demographic variables exist within the public at large. The nature of the VR of this study is another limitation, as the 360-degree room is not entirely flexible, and can be difficult in recruiting participants to travel to the immersive environment for both research purposes and management purposes. Despite these limitations, this research offers reaffirmation to others researching the social acceptability of prescribed fire, while also reaffirming to managers the vital role knowledge, experience, and especially confidence and trust play in creating a socially acceptable management strategy.

CHAPTER 3

IMMERSIVE IMAGERY AS A BOUNDARY OBJECT FOR PRESCRIBED FIRE COMMUNICATION

Introduction

Background

Over the last several decades forest managers have indicated the need to understand and incorporate local attitudes and values into management decisions while building trust for those management strategies (Toman and Shindler, 2006; Winter et al., 2004; McDaniel, 2014). The complexity, uncertainty, and risk associated with many of these decisions, especially those related to fire, have created unique communication challenges for many forest managers. These management decisions often have little immediate tangible benefit, and the economic and environmental services provided by those forest management actions are often distributed over a longer time period. Some fire related forest management techniques such as prescribed burning or controlled natural burns have a high amount of perceived risk associated with them from the public and it can be difficult to communicate the abstract benefits associated with them when they take place on such long time scales (Toman and Shindler, 2006). While the benefits may be perceived as abstract, the risk can be perceived as far more concrete when the public imagines the negative impacts that could be associated with risky management effecting themselves, their family, or areas they highly value (Trope and Liberman, 2010; Zwickle and Wilson, 2014).

There remains an evident gap between the perceived risks from experts and the public, as well as a gap between the prioritization of the values of managers and the public (Wagner et al., 1998; Kocher et al., 2012). Another stakeholder highly involved in this discussion of value

considerations is the scientific community, who has obviously had significant communication gaps between themselves, managers, and the public. Many traditional methods of communication have done little to reduce this differentiation in values, or to gain public acceptability of forest management techniques that show only incremental public benefit (Toman et al., 2006).

In particular, many aspects of prescribed burning have a high-perceived risk to human health including the potential for an escaped burn, elevated smoke levels, and impacts to aesthetics or wildlife (McCaffrey et al., 2015). Even if traditional methods of information transferring create a public understanding of some of the ecological benefits associated with controlled fires, social acceptability of prescribed fire remains a critical area of research for managers and scientists. The risks associated with prescribed burning such as a potential escaped burn, wildlife habitat damage, or human health risks associated with smoke production are much more proximally close events and can sometimes outweigh the perceived long-term benefits of managed fire (McCaffrey et al., 2015). The human health risk associated with fire or smoke may cause a low amount of public acceptability towards the management technique despite its well-established ecological benefits and the lowered risk of actual wildfires from this specific fuels reduction treatment (Agee and Skinner, 2005).

A rapidly growing technology that could serve to bridge communication about prescribed burning and other forest management is immersive imagery, which includes Virtual Reality (VR). VR is defined as the computer-generated simulation of a 3-D image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment. Many researchers argue that VR in its definition must be illustrative, immersive, interactive, intuitive, and intensive, all of which have a strong correlation with the effectiveness of the technology in influencing attitudes, perceptions, and behaviors (Orland et al., 2000).

Immersive imagery is a closely related concept referring to the visualization of realistic images in immersive environments such as VR goggles or 360-degree rooms, which is the immersive environment that was chosen for the purposes of this research. Immersive imagery is a relatively new technology whose uses within forest management have only recently begun to be explored.

We explore the concept of boundary spanning objects, where an object (in this case VR or immersive imagery) can create an effective exchange of ideas and information between stakeholder boundaries, in this case the boundary between fire scientists/managers and the public. Within this body of literature three factors are frequently identified as being particularly influential on the perceptions of information communicated through a boundary object: saliency, legitimacy, and credibility (Cash et al., 2002). Using a growing body of literature on VR and immersive imagery in the context of communication and decision-making, we attempt to identify perceptions of immersive imagery by using university students as an initial population in a 2x2 pre-post survey design where students perceptions of the saliency, credibility, and legitimacy of immersive imagery were tested before and after students were shown either a 360-degree immersive imagery presentation of a prescribed burn or traditional photographs of the same prescribed burn. This allowed us to compare the pre and postsurvey results of student perceptions of immersive imagery and traditional 2-D imagery in relation with the three constructs outlined by Cash et al. (2002).

Goals and Objectives

Our research goals are to understand the perceptions and understanding of VR technology as it relates to fire management, evaluate VR's potential as a boundary object, and explore the influence of VR on the perceptions of forest managers. While VR has a potentially high amount of utility in multiple natural resource disciplines, fire management was chosen because as

wildfire and fuels management have a high amount of perceived risk associated with them, allowing for productive opportunities for targeted virtual communication messages. The purpose of this research was also to understand the perceived saliency, credibility, and legitimacy associated with VR technology and 2-D photographs and the information communicated by it. The information gathered through this study will potentially highlight areas in which VR may improve the communication gap between stakeholder boundaries. We also explore some underlying assumptions the public may have regarding emerging technology and its potential role in both forest and fire management. The objectives of this research to accomplish these goals prior to data collection are as follows:

1. To understand the perceived saliency, credibility, and legitimacy towards VR technology as it compares to traditional 2-D photographs.
2. To explore virtual reality as a potential boundary object between fire scientists, managers, and the public.
3. To make recommendations to fire scientists and managers on how to effectively use virtual reality to assess social acceptability and influence perceptions towards prescribed burning and forest management.

Conceptual Framework

Boundary objects are tools or physical objects providing mutual understanding of perspectives on both sides of the boundary as it relates to an issue (Cash et al., 2002). The end goal of a boundary-spanning object according is to create a common understanding regarding a problem, which in the context of this research would be prescribed burning (Cash et al., 2002). The example given by the authors is the use of models, assessments, or reports to communicate

scientific information from specific fields to a non-scientific audience. Cash et al. (2002) define three variables that have a considerable influence on the individual or decision-makers perception of the information given: credibility, saliency, and legitimacy.

One of the most significant measures of the success of boundary objects is to increase one or more of these three criteria and increase positive perceptions towards the information that is being communicated or the institution communicating the information (Cash et al., 2002; Cash et al., 2006; Feldman and Ingram, 2009; Blades et al., 2015). Not considering saliency, credibility, or legitimacy can lead to an ineffective communication exchange across boundaries, thus leading to an ineffective boundary object (Feldman and Ingram, 2009). Communication of scientific information across stakeholder boundaries is both more persuasive and more effective when it is perceived as salient, credible, and legitimate (Bendor, 2013). For communicating natural resource issues like prescribed burning, which can be more controversial in nature due to the perceived risk, communication tools like boundary objects can be extremely powerful.

Saliency

Saliency refers to the perceived relevancy of information being communicated, the boundary object communicating the information, or the institution disseminating the information (Cash et al., 2002). In the context of this study, this would mean that the information relating to prescribed burning may become more or less relevant to viewers when shown through VR than through other more traditional means, such as photographs of prescribed fires or displays of scientific data for example.

While studies relating to VR and saliency are limited, and practically non-existent in the context of fire management, researchers have explored how 2-D visual imagery relating to climate change can influence saliency along with self-efficacy. When assessing the effects of

imagery on saliency and self-efficacy associated with climate change, O'Neill et al. (2013) found that 2-D imagery served to increase perceptions of saliency, but undermined perceptions of self-efficacy towards climate change. The authors also noted that additional 2-D imagery of energy futures increased self-efficacy while lowering saliency, which led the authors to conclude that 2-D imagery can either increase saliency or self-efficacy, but can rarely do both. While this is an interesting result that displays the potential usefulness of using imagery to communicate issues relating to natural resource issues, there are some obvious limitations here that could potentially be solved through the alternate use of VR instead of 2-D imagery. The increased level of immersion associated with VR compared to photographs may lead to an increased level of salience. If imagery is specifically targeted to increase the perception of saliency regarding the natural resource issue, imagery presented in an immersive environment may potentially increase participant self-efficacy due to the more inclusive and participatory nature of immersive imagery as opposed to traditional 2-D imagery used in the O'Neill et al. (2013) study.

Some research exploring VR has led to the conclusion that extremely immersive virtual messages can potentially elicit a mortality salience or, an individual's awareness of their own mortality. This mortality salience, if elicited effectively, has been shown to increase individual motivation to engage in or support specific behaviors (Chittaro et al., 2017). Alternatively, a failed attempt to elicit mortality salience by using fear appeals can lead to a common concept within risk communication referred to as the boomerang effect. This is essentially when a risk communication message creates a reaction opposite to its intended effect (Hart, 2014). This could occur with VR if the presentation relies too heavily on fear appeals to create a pro environmental behavior or perception, which could result in the audience rejecting the information being presented and a lowered sense of salience towards the message and VR

technology. A boomerang effect can also be an unintentional consequence of immersive messaging in which the subject of the message inherently creates a mortality salience. Immersive imagery presenting a prescribed fire may elicit unintentional feelings of fear or anxiety, which could result in a boomerang effect thus decreasing their perceptions of the saliency of immersive imagery as a communication tool. For example, if participants indicate an increase in perceived fear or anxiety related to prescribed fire following the immersive imagery presentation, then it could be said that the immersive imagery treatment created a boomerang effect as the imagery was intended to lower anxiety and fear related to prescribed burning.

Another important concept highlighted within the literature is the importance of “immediacy” in increasing perceptions of saliency (White et al., 2010; Ingram et al., 2016). Immediacy in terms of natural resource management refers to the immediate short term or day-to-day impacts that management tool has on the natural environment. While public perceptions of immediacy will vary greatly person-to-person depending on what impacts are valued the most (ecological, economic, aesthetic, etc.), this concept highlights the importance of short-term and immediately tangible benefits to increasing perceptions of saliency (White et al., 2010; Ingram et al., 2016). This can be an especially difficult concept to communicate through immersive imagery, especially as it pertains to a management tool like prescribed burning. While there can be some significant immediate benefits of prescribed burning easily communicated through virtual imagery, such as the clearing of understory vegetation, other benefits like long-term impacts on vegetation growth, invasive species and pest control, and forest composition changes can be much more difficult to communicate with immediacy.

There is ample evidence within the literature that the use of VR could increase the saliency of the information displayed. This has already been shown to be extremely effective in

decision-making contexts for landscape planning and climate change communication (Orland et al., 2000; O'Neill et al., 2013). These results by various fields show the high amount of potential in VR systems increasing the relevance of natural resource information by communicating it through a more immersive medium.

Credibility

Credibility refers to the trustworthiness of information that is being communicated, the boundary object communicating the information, or the institution disseminating the information (Cash et al., 2002). Credibility is almost always tied to trust and believability, while uncertainty can often play a large role in undermining perceptions of credibility (Ingram et al., 2016). Through a virtual environment information can be communicated with a high level of interaction for individuals within the virtual environment, which can potentially work to build trust with the audience while also visually displaying accurate representations of the information being communicated. In that sense, the level of perceived accuracy by audience members will determine the VR's ability to increase credibility of the information being communicated.

In addition to credibility being affected by perceptions of accuracy and uncertainty, credibility has also been shown to influence the acceptance of scientific tools and the acceptance of scientific advice (Ingram et al., 2016). This increase in acceptance of scientific knowledge communicated has also been shown to have a strong influence on the acceptance of related scientific practices, even if those practices are relatively new for the affected stakeholder group, such as carbon storage (Vogel et al., 2007; Ingram et al., 2016). This linkage highlights the relationship between credibility and saliency, as management tools are perceived as more credible the likelihood the tools are accepted and deemed as relevant may also increase. Another key link between credibility and saliency is related to perceptions of relevancy, as research has

shown that scientific information communicated through a boundary object has a lower likelihood of being perceived as credible if the information is older, and thus more likely to be perceived as outdated (White et al., 2010). However, these connections do not solely exist between credibility and saliency. Legitimacy additionally has a large influence on saliency and credibility, and all three are closely tied together with each carrying certain tradeoffs that can have ripple effects on the effectiveness on the boundary object as a whole.

Legitimacy

Legitimacy refers to the perceived fairness of the information that is being communicated, the boundary object communicating the information, or the institution disseminating the information (Cash et al., 2002). For the information presented through VR to be perceived as legitimate there are a few negative perceptions the information being communicated must avoid. Garnstrom (2012) found four major communication barriers that risked legitimacy between scientific and public stakeholder groups: media polarization, differing opinions between scientific and public stakeholder groups, hierarchy, and a lack of a communicational structure between the public and scientists. If the information communicated through VR is perceived as being an accurate representation of a prescribed burn, then it will likely avoid a drop in perceived legitimacy among participants. One aspect of legitimacy not covered by the Garnstrom (2012) study however is perceived fairness and representation of values among the information being communicated. Participants in the virtual environment, who have a strong pre-disposition against prescribed burning in general, may find the information communicated through VR as unacceptable and not a representation of the type of forest management that they would prefer to see.

Several scientific studies have identified legitimacy as the most important of the three variables outlined by Cash et al. (2002). One particular study, which attempted to identify how perceived saliency, credibility, and legitimacy towards ecosystem service knowledge influenced the impact the knowledge had on decision-making, found that legitimacy most significantly influenced impact while saliency and credibility had only marginal influences (Posner, McKenzie, and Ricketts, 2016). The study argued that this result increases the responsibility of researchers and managers to engage multiple stakeholder groups in order to increase the inclusivity of the knowledge creation and decision making process. Other research has highlighted that in order for boundary objects to increase perceptions of legitimacy, they must increase inclusivity and allow participants to influence the decision making process in some manner (Ingram et al., 2016).

Legitimacy may very well be one of the more difficult variables to influence through immersive imagery. Although immersive imagery is generally more inclusive and interactive than traditional communication, legitimacy often requires that stakeholders have an established role in the decision-making process, which can be difficult to communicate through immersive imagery that participants cannot directly influence, but only experience. Some studies pertaining to immersive imagery have found that embodied immersive learning (where participants are represented within and interacting with the immersive environment in order to produce new knowledge) increases perceptions of inclusiveness, which is strongly correlated with perceptions of legitimacy (Flood, Neff, and Abrahamson, 2015).

Boundary Objects and the Potential of VR

In regards to the three aforementioned variables of saliency, credibility, and legitimacy, the goal of a boundary object as mentioned previously is to increase one or more of these three

criteria and increase positive perceptions towards the information or institution communicating the information. This is where VR technology could potentially become a boundary object, if it succeeds in increasing one of the three Cash et al. (2002) variables in relation to fire management.

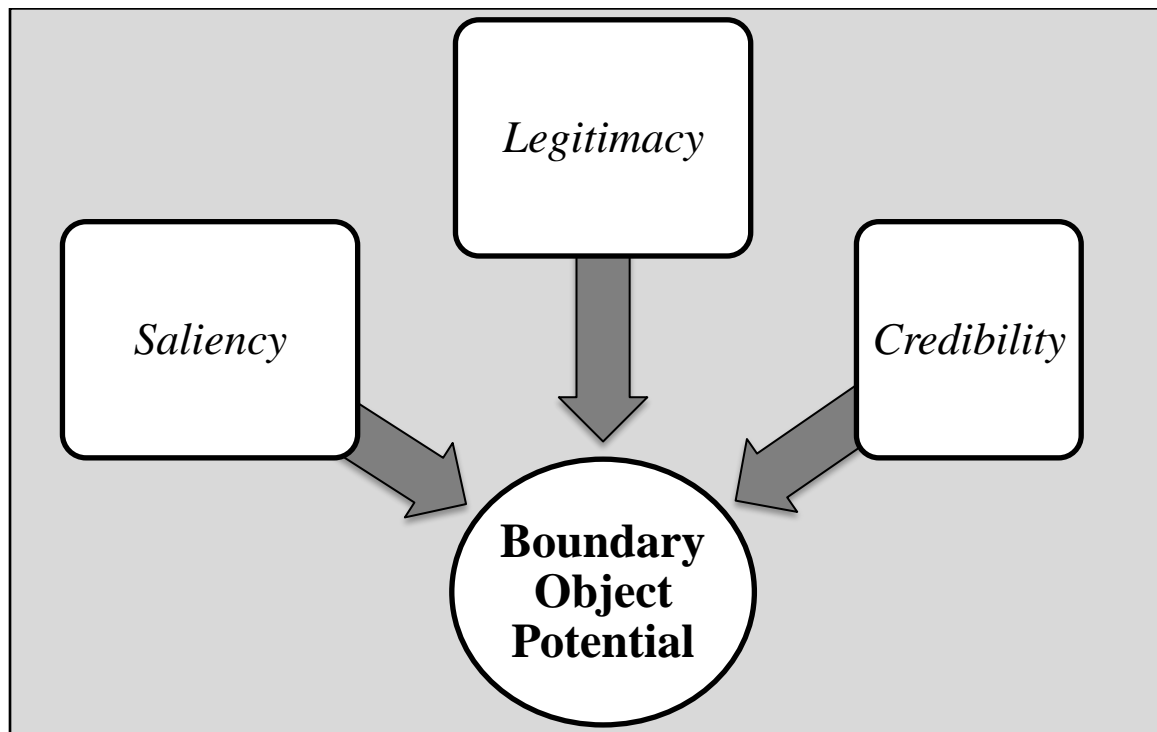


Figure 3 - Boundary Object Conceptual Model

While there remains a gap in the literature regarding VR's potential as a boundary object, literature exists on the use of VR in a decision making context where it is viewed as a boundary spanning object does exist. VR has been shown to be an effective tool for landscape planning, where it can be used to increase public engagement in a participatory process where planners can identify what values need to be considered in their management decisions (Ball et al., 2007). This allows for the inclusion of social values within forest management decisions along with traditional biophysical and economic values, and potentially increases the legitimacy of forest

managers to the public as a result of VR. Without consideration of these social values, Ball et al., (2007) suggest that local communities will be less likely to accept management plans and will view them as much less salient, credible, and legitimate. Given that fire management has known social acceptability concerns, testing VR's potential as a boundary object and public engagement tool is warranted.

In a forest management decision-making context, Gonzalez et al. (2007) attempted to use VR as a method to gauge expert perceptions of risk associated with various forest stands vulnerability to wildfire. Using VR and showing experts several different types of forests through the simulation, the authors were able to create a model that identified which characteristics of the various forest stands the experts identified as being particularly at risk. In this context, VR was bridging a communication boundary between scientific and management stakeholder groups, and creating mutual knowledge likely to be more salient, credible, and legitimate than knowledge produced simply by one stakeholder group alone. Some authors have argued that "Virtual worlds can provide high ecological validity without compromising experimental control, thereby increasing the generalizability of findings." (Kaphingst et al., 2009, pg. 3). This generalizability is what makes the information obtainable from multiple stakeholder groups and potentially demonstrates VR's effectiveness as a boundary object.

When studying the effects of virtual reality of environmental behavior and self-efficacy, Lu and Liu (2015) found a high amount of reported self-efficacy associated with augmented reality learning for marine resource issues among younger students. Augmented reality in the context of this study and others exploring its use in environmental education, refer to the combined use of both real and virtual learning environments (Wu et al., 2012). This highlights the potential of virtual reality in effectively educating the public on forest management

techniques with the intent that it will lead to a greater amount of support for those management strategies. That said, little research has been done with virtual reality in the context of forest management. While much of the research from other natural resource contexts are insightful into how the technology can be applied to forest management, more research needs to be done to determine the advantages and disadvantages of VR technology. The applications to fire management and prescribed burning in particular provide an important contribution towards this field of literature as well as to scientists and managers.

Methodology

Approach

The methodological approach was to implement a 2x2 framework in which participants were shown visual imagery that varied based on level of immersion as well as level of smoke within the imagery as displayed in figure 2. The level of immersion is considered low with participants who were shown 2-D imagery and high with participants who were shown immersive imagery. Variation in smoke levels was a key variable for another part of this study, and while not central to this chapter, it consisted of two levels of smoke or opaqueness in the 2-D photographic images. Tests between smoke levels showed few statistical differences so we combined the sample to contrast between two sample groups: low (2-D) and high (VR) immersion.

Smoke Levels	<u>Level of Immersion</u>		
		<i>Low (2-D)</i>	<i>High (VR)</i>
	<i>Normal</i>	2-D Visual Image unaltered	360-degree Immersive Imagery unaltered
	<i>High</i>	2-D Visual Image with 50% smoke opacity enhancement	360-degree Immersive Imagery with enhanced smoke footage

Participants took a presurvey before viewing the immersive imagery demonstration or viewing the 2-D photographs, and a postsurvey following them. The pre and postdesign was selected in an attempt to measure whether immersive imagery had an influence on saliency, credibility, and legitimacy and could be considered a viable boundary-spanning object compared to traditional photographic imagery.

Population and Recruitment

The population for the study consisted of University of Maine students from three undergraduate courses, two required lower division courses in the School of Forest Resources and one upper division elective course within the Department of Wildlife Ecology, Fisheries, and Conservation Biology. These courses were selected based on faculty members who expressed a desire to have their students participate in the study following outreach by the researchers to a variety of natural resource faculty members who teach large undergraduate natural resource courses. The population was limited to natural resource students in order to prevent a wide variation in responses to survey questions that measured student’s environmental values and prior knowledge and experience associated in prescribed burning.

While there are limitations in the generalizability of this study's results to the public, there is ample research that shows student samples can still be fairly successful in analyzing cause and effect relationships of mechanisms or treatments, and determining whether an effect exists (Guo and Schneider, 2015; Visser, Krosnick, and Lavrakas, 2000). Still, due to the exploratory nature of student sampling, future research should include more diverse populations.

Following a recruitment plan approved by the IRB for human subjects, the researchers coordinated with course instructors to incorporate the study into the class either as a requirement (see syllabus language in Appendix B) or as extra credit in the class (see extra credit language in Appendix B), with non-research alternative options provided for students that did not wish to participate. Students then signed up on-line for time slots to come to the Innovative Media Research and Commercialization Center on campus to view one of the forms of imagery and take the surveys. The sample sizes were 104 participants in total, with 52 participants in both the high immersion (VR) group and the low immersion (2-D) group.

Instrument Design

The survey (Appendix A) was designed to measure a variety of variables. The questions on the pre and post questionnaires consist of multiple-choice responses for social demographic questions and a 7-point likert scale for all other questions, from strongly disagree (1) to neutral (4) to strongly agree (7). The participants taking the survey were randomly assigned into either the high immersion (VR) group or the low immersion (2-D) group.

The two forms of visual imagery were taken from USDA Forest Service prescribed burn footage customized by Ethan Turpin at the University of California, Santa Barbara's Bren School of Environmental Science and Management (ethanturpin.com). The 360-degree presentation was projected in the APPE-2 space at the Innovative Media Research and Commercialization Center

using a series of 4 projectors that each displayed a different perspective of the same prescribed fire on a wall (Appendix C). The presentation is exactly 2 minutes and 30 seconds long. The 2-D photographs were 5x7 inches in size, and were screenshots taken from several stages of the same prescribed fire shown in the 360-degree immersive imagery presentation (Appendix D).

Instrumentation: Saliency, Credibility, and Legitimacy

Saliency, credibility, and legitimacy were measured based on a series of 7 survey questions identical in both the pre and postsurveys adapted from Winter et al. (2004) and Cvetkovich and Winter (2004). While the surveys from these studies were attempting to measure salient value scale, three statements seemed to accurately represent saliency, credibility, and legitimacy due to the phrasing of the statements which implemented definitions similar to Cash et al. (2002) such as relevant, credible, and values. Three questions attempt to measure the saliency, credibility, and legitimacy of either immersive imagery or photographs before and after participants view the imagery, one question attempted to assess perceptions of the two forms of imagery as notification tools, and lastly three questions attempted to measure perceptions of legitimacy towards forest managers for the two imagery groups (Figure 3).

Variables	Instrumentation
Measurement of <u>Saliency</u> :	Photographs [Virtual Reality] are a good method of communicating relevant information to the public about prescribed burns.
Measurement of <u>Credibility</u> :	Information communicated through photographs [Virtual Reality] about prescribed burns is scientifically credible.
Measurement of <u>Legitimacy</u> :	Photographs [Virtual Reality] are used to communicate information that aligns with your values, goals, and views.
Measurement of the Imagery as a <u>Notification</u> tool:	Photographs [Virtual Reality] can be an effective way of notifying the public about upcoming prescribed burns and other forest management plans.
Measurements of <u>Forest Manager Legitimacy</u> :	Forest managers share your values about how fire should be used in forests.
	To the extent that you understand them, forest managers share your goals for the use of fire in forests
	Forest managers support your views about fire in forests.

Table 9 – Ch. 2 Survey Questions

Results

Sample Demographics

The participants in this population consisted entirely of university students (Table 9). Looking at the total samples, the study population had slightly more men (n=59) than women (n=45), most likely a result of the high number of natural resource majors such as forestry that participated in the study who typically have a higher male enrollment. A majority of participants were 21 years of age or younger (n=87), and most students were first years (n=39), with only one

participant who indicated they were a graduate student. Almost every participant was enrolled in a natural resource based major (n=102), and a large portion of participants were from states with New England (n=77) which was defined as Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island. Participants were also very evenly split between identifying themselves as being from either a rural area (n=47) or a suburban one (n=43) with few students stating they were from urban areas (n=10). The only difference amongst the two imagery sample groups was that the 2-D group had less women (n=18) than the VR group (n=27).

Population Socio-Demographics

Imagery	Female (%)	Mean Age (Year)	Natural Resource Major (%)	From New England (%)	Rural (%)	Suburban (%)	Urban (%)
<i>2-D</i>	34.6	20.2	98.1	74.9	44.2	42.3	11.5
<i>VR</i>	51.9	20.4	98.1	73.0	46.2	40.4	7.7
Total	43.3	20.3	98.1	74.0	45.2	41.3	9.6

Table 10. Population Socio-Demographics

Saliency

Perceptions of saliency prior to the imagery treatment were positive (2-D pre \bar{x} =4.74 and VR pre \bar{x} =4.94) on the Likert scale, while post treatment responses varied between 2-D (\bar{x} =4.10) and VR (\bar{x} =5.19) groups. A paired samples t-test was run to assess pre and post differences between the two imagery groups. A statistically significant decrease in the perceived saliency of 2-D photographs (pre \bar{x} =4.74 and post \bar{x} =4.10 respectively) was found to be significant at the $p<0.01$ level. There was a marginal, but not statistically significant increase in mean responses between pre and post VR saliency (pre \bar{x} =4.94 and post \bar{x} =5.19 respectively). After viewing

either imagery, participant saliency responses scored 1.09 points higher on the likert scale for the perceived saliency of VR as opposed to the saliency of 2-D photographs (2-D post \bar{x} =4.10 and VR post \bar{x} =5.19) (Table 10).

Saliency^a				
Imagery	Mean (\bar{x})	Mean Difference	Std. Deviation	Significance
2-D				
<i>Pre</i>	4.74	-0.64	1.68	<i>p</i> < 0.01
<i>Post</i>	4.10			
VR				
<i>Pre</i>	4.94	0.25	1.57	0.256
<i>Post</i>	5.19			

a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Results from the question: Photographs [Virtual Reality] are a good method of communicating relevant information to the public about prescribed burns.

Table 11. Saliency

A paired samples t-test was run to assess pre and post differences between the two imagery groups. A statistically significant decrease in the perceived saliency of 2-D photographs (pre \bar{x} =4.74 and post \bar{x} =4.10 respectively) was found to be significant at the $p < 0.01$ level. There was a marginal, but not statistically significant increase in mean responses between pre and post VR saliency (pre \bar{x} =4.94 and post \bar{x} =5.19 respectively). After viewing either imagery, participant saliency responses scored 1.09 points higher on the likert scale for the perceived saliency of VR as opposed to the saliency of 2-D photographs (2-D post \bar{x} =4.10 and VR post \bar{x} =5.19).

Credibility

Preimagery treatment credibility seemed to be slightly positive (2-D pre \bar{x} =4.48 and VR pre \bar{x} =4.79), while post treatment credibility seemed to be slightly negative for the 2-D group (\bar{x} =3.96) and positive for the VR group (\bar{x} =5.12) on the likert scale (Table 11). A paired samples t-test was run to compare pre and post responses for the two imagery groups.

Imagery	Credibility ^a			
	Mean (\bar{x})	Mean Difference	Std. Deviation	Significance
2-D				
<i>Pre</i>	4.48	-0.52	1.55	$p < 0.05$
<i>Post</i>	3.96			
VR				
<i>Pre</i>	4.79	0.33	1.20	$p < 0.10$
<i>Post</i>	5.12			

^a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Results from the question: Information communicated through photographs [Virtual Reality] about prescribed burns is scientifically credible.

Table 12. Credibility

Perceptions of credibility towards 2-D photographs decreased significantly (pre \bar{x} =4.48 and post \bar{x} =3.96), and perceptions of credibility towards VR increased at a marginally significant level (pre \bar{x} =4.79 and post \bar{x} =5.12). The difference was significant at the $p < 0.05$ level for the 2-D group, while being marginally significant at the $p < 0.1$ level for the VR group. This result was extremely similar to the saliency responses, and perceived credibility of VR scored 1.16 points higher on the likert scale post imagery than perceived credibility of 2-D photographs (post 2-D \bar{x} =3.96 and post VR \bar{x} =5.12).

Legitimacy

Preimagery and post treatment legitimacy seemed to be slightly positive (2-D pre \bar{x} =4.77 and VR pre \bar{x} =4.67; 2-D post \bar{x} =4.50 and VR post \bar{x} =4.85) on the likert scale (Table 12). A paired samples t-test was run to compare pre and post responses for the two imagery groups.

Legitimacy^a				
Imagery	Mean (\bar{x})	Mean Difference	Std. Deviation	Significance
2-D				
<i>Pre</i>	4.77	-0.27	1.60	0.23
<i>Post</i>	4.50			
VR				
<i>Pre</i>	4.67	0.17	1.18	0.28
<i>Post</i>	4.85			

a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Results from the question: Photographs [Virtual Reality] are used to communicate information that aligns with your values, goals, and views.

Table 13. Legitimacy

There were no significant differences between the perceived legitimacy of pre and post responses for both the 2-D (pre \bar{x} =4.77 and post \bar{x} =4.59) and VR (pre \bar{x} =4.67 and post \bar{x} =4.85) imagery groups. There did however, appear to be a similar trend that existed in perceived saliency and credibility responses where participants who viewed the immersive presentation increased their perceived legitimacy of VR (mean difference of 0.17) and participants who viewed the 2-D photographs decreased their perceived legitimacy (mean difference of -0.27), just on a more marginal level than the other two variables. Legitimacy of imagery was the only variable of the three measured in which preresponses were lower towards VR than towards 2-D, however in post responses perceptions of legitimacy towards VR were 0.35 points higher on the likert scale than perceptions of 2-D photographs (post 2-D \bar{x} =4.50 and post VR \bar{x} =4.85).

In addition to measuring perceptions of legitimacy towards imagery and information communicated through imagery, we also asked all participants (in both 2-D and VR groups) three questions about perceived legitimacy of forest managers. Perceived legitimacy towards forest managers was fairly positive both before (pre \bar{x} =4.78, 5.01, and 4.72) and after (post \bar{x} =4.89, 5.02, 4.92) the imagery treatment (Table 13).

Forest Manager Legitimacy ^a					
Variable	Imagery	Mean (\bar{x})	Mean Difference	Std. Deviation	Significance
<i>ForestMgr Legitimacy1</i>	2-D				
	<i>Pre</i>	4.88	0.02	1.15	0.90
	<i>Post</i>	4.90			
	VR				
<i>ForestMgr Legitimacy2</i>	<i>Pre</i>	5.08	-0.04	0.95	0.77
	<i>Post</i>	5.04			
	VR				
	<i>Pre</i>	4.94	0.06	1.20	0.73
<i>ForestMgr Legitimacy3</i>	<i>Post</i>	5.00			
	2-D				
	<i>Pre</i>	4.81	0.15	1.04	0.29
	<i>Post</i>	4.96			
	VR				
	<i>Pre</i>	4.63	0.25	1.44	0.22
	<i>Post</i>	4.88			

a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Results from questions: 1) Forest managers share your values about how fire should be used in forests.; 2) To the extent that you understand them, forest managers share your goals for the use of fire in forests.; 3) Forest managers support your views about fire in forests.

Table 14. Forest Manager Legitimacy

The differences between pre and post responses across all participants were fairly marginal, with the largest mean difference (0.20 for ForestMgr Legitimacy3) still not representing a statistically significant difference. To better assess differences in the two treatment group's responses, we ran an independent samples t-test to determine 2-D and VR differences in post legitimacy scores and similar to pre and post responses amongst all participants found no significant differences between the 2-D and VR groups. In fact, the post scores between the two treatment groups were fairly similar in nature, a much different result than the trend that existed for questions relating to 2-D and VR saliency, credibility, and legitimacy.

In addition to assessing all of the aforementioned variables, we also included a question asking participants their perceived effectiveness of the two forms of imagery as notification tools for the public (Table 14). Overall participants viewed both forms of imagery as very similarly effective as notification tools prior to the treatment (pre 2-D \bar{x} =4.94 and pre VR \bar{x} =4.92), but viewed VR as much more effective following treatments (post 2-D \bar{x} =4.13 and post VR \bar{x} =4.92). To compare the differences between pre and post treatments of the imagery groups a paired samples t-test was run.

2-D/VR Imagery as an Effective Notification Tool^a				
Imagery	Mean (\bar{x})	Mean Difference	Std. Deviation	Significance
2-D				
<i>Pre</i>	4.94	-0.81	1.87	<i>p</i> < 0.01
<i>Post</i>	4.13			
VR				
<i>Pre</i>	4.92	0.00	1.47	1.00
<i>Post</i>	4.92			

a Likert scale from 1=Strongly Disagree to 7=Strongly Agree

Results from the question: Photographs [Virtual Reality] can be an effective way of notifying the public about upcoming prescribed burns and other forest management plans.

Table 15. 2-D/VR Imagery as an Effective Notification Tool

While participant’s pretreatment viewed both 2-D and VR imagery as having the potential to be effective ways to notify the public about prescribed burning, post treatment the VR group (\bar{x} =4.92) viewed its imagery as being a more effective notifying tool than the 2-D group (\bar{x} =4.13). This is despite zero difference in pre and post responses for the VR group. The 2-D group saw a significant decrease (pre 2-D \bar{x} =4.94 and post 2-D \bar{x} =4.13), in perceptions of 2-D imagery as a notifying tool at the $p < 0.01$ level. Similar to many of the variables measured, the VR group scored 0.79 points higher on the likert scale than the 2-D group post imagery treatment.

Discussion and Conclusion

The goal of this study was to analyze perceptions of saliency, credibility, and legitimacy associated with VR, as well as VR's overall potential as a boundary object with the capability of effectively communicating information across multiple stakeholder groups. The findings of this study served to support the goal and objective of the researchers in analyzing the perceived saliency, credibility, and legitimacy of VR technology. VR for fire scientists and managers does indeed seem to show promise in bridging communication gaps with the public.

The first objective of the research was to understand the perceived saliency, credibility, and legitimacy of VR technology. Saliency, credibility, and legitimacy all increased among participants who viewed the immersive imagery and decreased among participants who viewed the 2-D photography. All scores in the postsurvey associated with immersive imagery were higher than scores for the 2-D surveys by mean differences of: 1.09 for saliency, 1.16 for credibility, and 0.35 for legitimacy on a 7-point likert scale.

The second objective of this research was to explore the potential of VR technology as a boundary object. Much of the literature has identified the success of a boundary object in increasing at least one of saliency, credibility, and legitimacy, these results do show the high amount of potential for VR (Cash et al., 2002; Blades et al., 2015).

Out of the three variables measured by this research, VR showed the least amount of potential with legitimacy, as responses to legitimacy towards VR and forest managers saw the smallest increase between pre and postsurveys, and the smallest score overall in post VR surveys. This is likely a result of the lack of inclusivity and participation within the immersive environment created for the purposes of this research. Studies have well documented the active role that American adults most desire to "play" within information exchanges across boundaries

(Toman et al., 2006; Steelman and McCaffrey, 2012). Within the context of this study, participants have no influence on the outcome of the virtual presentation, which is a consistently mentioned component of legitimacy. This does not discredit the potential of VR as a boundary object however, as one of the key aspects of a boundary object is the increase in one or more of saliency, credibility, and legitimacy, and the results of this research indicate potential in VR for increasing all three, particularly credibility. With previous research indicating that credibility has a significant influence on the acceptance of scientific tools and scientific advice, this highlights a particularly useful potential of virtual reality for fire managers and scientists (Ingram et al., 2016).

The third objective of this research was to make recommendations to scientists and managers on how best to effectively implement VR technology to both assess social acceptability and influence perceptions towards prescribed burning or other forest management techniques. Recommendations for managers and fire scientists looking to implement VR technology are contingent on some of the limitations we found with VR as a boundary object as well as the limitations associated with attempting to over concentrate on one of the three Cash et al. (2002) variables. While legitimacy had the most minimal impact from the immersive imagery presentations and is often highlighted as the most important of the three variables Cash et al. (2002 and 2006) outline, there are some risks of compromising the boundary object potential of immersive imagery by increasing engagement of participants within the virtual environment (Kunseler et al., 2015).

Saliency can be potentially compromised through increasing engagement by creating too much of a focus on participants desire for short-term needs which can contradict management goals in certain circumstances. For managers attempting to increase perceptions of relevancy of

their management practices, the literature identifies a few significant factors that can easily increase or undermine saliency. Perceptions of “goodness of fit” have been recognized by the literature as being vital for creating feelings of saliency regarding management practices (Ingram et al., 2016). This may be a significant barrier to saliency in the context of this study and prescribed burning, as the study took place in Maine where prescribed burning is a seldom-performed forest management strategy.

Another potential barrier to saliency can be the perceived “immediacy” that is often needed for participants to perceive relevancy. For the purpose of this research, participants in the study were shown only a small glimpse into an ongoing prescribed burn. If the presentation was to also include for example, a time lapse of post-fire growth, despite showing a tangible benefit of a prescribed fire this might actually serve to undermine perceptions of saliency if participants perceived this particular benefit as taking place too far in the future while reducing short-term benefits of a forest (such as recreation access, aesthetic quality, or wildlife habitat). The immediacy of benefits are not the only time related factor that can have a significant influence on perceptions of saliency, as the timing of the communication messages can have significant ramifications on the perceived relevancy of the information communicated (Ingram et al., 2016). This is especially true for prescribed fire, as the occurrence of wildfires nationally has been shown to result in an increase in public desire for prescribed fire as a management tool to decrease wildfire risk (Wibbenmeyer, Anderson, and Plantinga, 2016). In the context of boundary objects, communication can take advantage of salient national events like significant wildfires to increase the perceptions saliency towards management tools like prescribed fire. These salient events however, have also been shown to lead to ineffective management action. In certain cases in Southern California for example, recent wildfire events that received significant

media coverage lead to public pressure to perform prescribed burns in already burned areas which actually increased the risk of related natural events such as soil runoff or flooding risk (Wibbenmeyer, Anderson, and Plantinga, 2016). The potential of boundary objects is highlighted through this example however, as it can serve to bridge this serious communication gap by increasing the saliency of the management tool prior to the wildfire event ever occurring as long as there remains a communication network between managers, scientists, and the public.

Credibility can be compromised by creating an over-incorporation of participant knowledge (which in many cases is a result of historical knowledge), and create a lack of scientific underpinning. Finally, legitimacy can in some cases be surprisingly compromised through an increase in engagement if certain participants perceive a bias in the composition of stakeholders or a political bias as a result of the inclusion of participant values (Cash et al., 2002; Kunseler et al., 2015).

This research showed VR was effective in increasing saliency, credibility, and legitimacy of information, while also being perceived as a more effective notification tool than 2-D photographs. The one variable measured that VR did not seem to have much of an effect on compared to 2-D was regarding perceived legitimacy of forest managers.

There are some limitations associated with VR however, that should be considered if the technology is to be implemented by managers or scientists. The most obvious among them is practicality. VR systems can either be extremely expensive, or restricted to limited locations, making it difficult to gather the public or research participants to view the simulation. The VR systems that are the most practical cost-wise and can be easily transported are the inexpensive VR headsets, and oftentimes these systems are lacking in immersion, which has been highlighted to have significant effects for VR's effectiveness as a communication tool (Murray et al., 2007).

Other limitations include the low influence on legitimacy that immersive imagery had in this exploratory study. Research has found that not only is legitimacy one of the most important aspects of a boundary object's impact, but that boundary objects have a higher potential to fail when they do not capture multiple meanings, values, and perspectives (Akkerman and Bakker, 2012; Posner, McKenzie, and Ricketts, 2016). Managers should also consider that boundary objects in many cases need to be flexible in order to be most effective, in terms not only of practicality but also in terms of the types messages that they can send (Turnhout, 2009). Many virtual environment systems are more than capable of possessing this type of flexibility, however there would exist some obvious limitations in flexibility for a system like the 360-room used in this study.

Due to the exploratory nature of this study, we encourage future research to see if these results are replicable, can be improved upon, and are representative of public perceptions. This study explored bridging communication boundaries between scientists/managers and the public, and future research could also explore the potential to bridge boundaries that exist between scientists and managers. Future research might also be aided by testing other variations of VR technology, as there are limits to the 360-degree rooms (as noted by the lower amount of perceived legitimacy from our participants). Additional forms of VR could include immersive goggles or fully interactive CAVE rooms. Additional research should also explore forest and fire manager's perceived saliency, credibility, and legitimacy towards VR to determine whether this is a boundary object that managers are likely to implement and believe will be effective.

Despite the limitations, VR appears to have a high amount of potential in fire management where it may help scientists/managers understand public values and perceptions, and increase salience, credibility, and legitimacy related to issues like prescribed burning. VR

and immersive imagery also shows high potential in being a multifaceted tool for engagement, public notification, as well as both informational and manager saliency, credibility, and legitimacy. We recommend additional research and more consideration of VR and immersive imagery as a powerful communication tool with boundary spanning potential for fire scientists, managers, and the public.

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Image 1: [Map]. Taken from <https://www.firelab.org/document/historical-natural-fire-regimes-v2000>

APPENDIX A: QUESTIONNAIRE

Pre Questionnaire:

Environmental Values Section (adapted from Winter et al., 2004 and Steel et al., 1994)

1. Humans should have more love, respect, and admiration for forests. (*biocentric*)
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
2. Forest resources can be improved through human management. (*anthropocentric*)
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
3. Forests have a right to exist for their own sake, regardless of human concerns and uses.
(*biocentric*)
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
4. Wildlife, plants, and humans have equal rights to live and develop. (*biocentric*)
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
5. The primary use of forests should be for products that are useful to humans
(*anthropocentric*)
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
6. Forests should be used primarily for timber and wood products. (*anthropocentric*)
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
7. We should actively harvest more trees to meet the needs of a much larger human
population. (*anthropocentric*)
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
8. Plants and animals exist primarily for human use. (*anthropocentric*)
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Knowledge Section (adapted from Brunson and Shindler, 2004 and Cvetkovich and Winter, 2004)

9. How knowledgeable are you about prescribed burns in your state?
(Not at all) 1 4 (Neutral) 7 (Very)
10. How knowledgeable are you about wildland fires in your state?
(Not at all) 1 4 (Neutral) 7 (Very)
11. How knowledgeable are you about forest management strategies in your state?
(Not at all) 1 4 (Neutral) 7 (Very)
12. How knowledgeable are you about Virtual Reality technology?
(Not at all) 1 4 (Neutral) 7 (Very)

Experience Section (adapted from Vogt, Winter, and Fried 2005)

13. I've experienced prescribed burns near my home.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
14. I've had friends, family, or neighbors impacted by fire damage.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
15. I've been personally impacted by fire damage.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
16. I've felt fear or anxiety related to fire.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
17. I've had a previous experience with Virtual Reality technology.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Smoke Section (adapted from Engebretson et al 2016 and Shindler and Toman 2003)

18. I've had a previous health problem associated with smoke.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
19. Smoke from prescribed burns ignited by land managers is acceptable.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
20. Smoke from naturally ignited fire on nearby land that is allowed to burn is acceptable.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
21. Smoke from prescribed burns to achieve forest health objectives is acceptable.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
22. Smoke levels are acceptable as long as the fire results in a healthier forest.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Confidence/Trust Section (adapted from Vogt et al 2005, Winter et al 2004, and Shindler and Toman 2003)

23. I would highly rate the forest managers that manage land in my state.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
24. I have trust in my local agency to perform prescribed burns.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
25. I have trust in forest managers to perform prescribed burns.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
26. Forest managers build trust and cooperation with people so they feel like they are acting in their best interest.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
27. Forest managers do a good job communicating with the public about forest issues.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

28. Forest managers do a good job of managing forestlands.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
29. Forest managers do a good job of notifying the public about upcoming prescribed burns.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
30. Forest managers do a good job protecting private property from wildland fires.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Social Acceptability Section (adapted from Winter et al 2004 and Brunson and Shindler 2004)

Prescribed burning:

31. Prescribed fire has little overall effect on the intensity or frequency of wildfires.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
32. Prescribed fire reduces fuel loads in most natural areas.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
33. Creates more smoke now, less in the long term.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
34. Reduces fire-fighting costs.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
35. Restores forests to a more natural condition.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
36. Improves future wildlife conditions.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
37. Allows for uncontrollable fires.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
38. I have fears about human health risks associated with prescribed burning.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
39. I have concerns over reducing scenic quality with prescribed burning.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
40. I have concerns over reducing wildlife habitat with prescribed burning.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
41. I have concerns about wildland fires in my state.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
42. I have concerns about prescribed burns in my state.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Saliency, Credibility, and Legitimacy Section for Immersive Imagery (adapted from Winter et al 2004 and Cvetkovich and Winter 2004)

43. Virtual Reality is a good method of communicating relevant information to the public about prescribed burns.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

44. Virtual Reality can be an effective way of notifying the public about upcoming prescribed burns and other forest management plans.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

45. Information communicated through Virtual Reality about prescribed burns is scientifically credible.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

46. Virtual Reality is used to communicate information that aligns with your values, goals, and views.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Saliency, Credibility, and Legitimacy Section for 2-D Imagery (adapted from Winter et al 2004 and Cvetkovich and Winter 2004)

47. Photographs are a good method of communicating relevant information to the public about prescribed burns.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

48. Photographs can be an effective way of notifying the public about upcoming prescribed burns and other forest management plans.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

49. Information communicated through photographs about prescribed burns is scientifically credible.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

50. Photographs used to communicate information that aligns with your values, goals, and views.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

51. Forest managers share your values about how fire should be used in forests.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

52. To the extent that you understand them, forest managers share your goals for the use of fire in forests.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

53. Forest managers support your views about fire in forests.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

- (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
68. I've had a previous experience with Virtual Reality technology.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Smoke Section (adapted from Engebretson et al 2016 and Shindler and Toman 2003)

69. I've had a previous health problem associated with smoke.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
70. Smoke from prescribed burns ignited by land managers is acceptable.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
71. Smoke from naturally ignited fire on nearby land that is allowed to burn is acceptable.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
72. Smoke from prescribed burns to achieve forest health objectives is acceptable.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
73. Smoke levels are acceptable as long as the fire results in a healthier forest.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Confidence/Trust Section (adapted from Vogt et al 2005, Winter et al 2004, and Shindler and Toman 2003)

74. I would highly rate the forest managers that manage land in my state.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
75. I have trust in my local agency to perform prescribed burns.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
76. I have trust in forest managers to perform prescribed burns.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
77. Forest managers build trust and cooperation with people so they feel like they are acting
 in their best interest.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
78. Forest managers do a good job communicating with the public about forest issues.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
79. Forest managers do a good job of managing forestlands.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
80. Forest managers do a good job of notifying the public about upcoming prescribed burns.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
81. Forest managers do a good job protecting private property from wildland fires.
 (Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Social Acceptability Section (adapted from Winter et al 2004 and Brunson and Shindler 2004)

Prescribed burning:

82. Prescribed fire has little overall effect on the intensity or frequency of wildfires.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
83. Prescribed fire reduces fuel loads in most natural areas.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
84. Creates more smoke now, less in the long term.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
85. Reduces fire-fighting costs.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
86. Restores forests to a more natural condition.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
87. Improves future wildlife conditions.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
88. Allows for uncontrollable fires.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
89. I have fears about human health risks associated with prescribed burning.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
90. I have concerns over reducing scenic quality with prescribed burning.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
91. I have concerns over reducing wildlife habitat with prescribed burning.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
92. I have concerns about wildland fires in my state.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
93. I have concerns about prescribed burns in my state.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Saliency, Credibility, and Legitimacy Section for Immersive Imagery (adapted from Winter et al 2004 and Cvetkovich and Winter 2004)

94. Virtual Reality is a good method of communicating relevant information to the public about prescribed burns.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
95. Virtual Reality can be an effective way of notifying the public about upcoming prescribed burns and other forest management plans.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)
96. Information communicated through Virtual Reality about prescribed burns is scientifically credible.
(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

97. Virtual Reality is used to communicate information that aligns with your values, goals, and views.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

Saliency, Credibility, and Legitimacy Section for 2-D Imagery (adapted from Winter et al 2004 and Cvetkovich and Winter 2004)

98. Photographs are a good method of communicating relevant information to the public about prescribed burns.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

99. Photographs can be an effective way of notifying the public about upcoming prescribed burns and other forest management plans.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

100. Information communicated through photographs about prescribed burns is scientifically credible.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

101. Photographs used to communicate information that aligns with your values, goals, and views.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

102. Forest managers share your values about how fire should be used in forests.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

103. To the extent that you understand them, forest managers share your goals for the use of fire in forests.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

104. Forest managers support your views about fire in forests.

(Strongly Disagree) 1 4 (Neutral) 7 (Strongly Agree)

APPENDIX B – RESEARCH PARTICIPATION ACTIVITY

School of Forest Resources Research Participation Spring 2018

****Under 18? See note at end of document****

What is the research participation assignment?

There are two ways to meet this requirement. You may do either option 1 or option 2. **You may NOT do a combination of BOTH.**

Option 1: Participating in Study

You may complete this requirement by participating in the research study discussed in class. Participation includes taking a survey before and after watching a 3-5 minute presentation at the Innovative Media Research and Commercialization Center on wildland fire management.

Option 2: Research Reviews

Read and review two scientific articles selected from a predetermined subject. Students will demonstrate understanding of experimental research by completing an annotated bibliography about the research described in the articles (e.g., the independent and dependent variables, what the research found, etc). You must complete both reviews to fill the requirement.

Participating in research projects may help:

- Increase Your Understanding of Natural Resource Management: Participating in these experiments gives you a chance to see first-hand wildland fire management techniques.
- Increase Our Understanding of Human Behavior: You are helping our graduate and faculty researchers advance our understanding of human behavior. This research may be published in future natural resource journals.

What are the risks involved with the research projects?

- Each research project is extensively reviewed and approved by the university ethics committee before it is conducted. There are only minimal risks involving immersive imagery that will evoke visceral and close up images of fire, smoke and a burning forest and could trigger individuals who have had previous negative experiences associated with fire or smoke.

Signing Up for Studies

- ***You are responsible for signing up for the research.***
 - It is your responsibility to show up for research time slots you have signed up for. Remember that if you need to cancel one of the times that you have signed up for,

- you have to do this at least 24 hours in advance. You should e-mail the researcher (casey.olechnowicz@maine.edu) if you need to cancel up to 24 hours in advance.
- Keep track of your research participation (date, time slot, etc.) just in case.

Option (2) Research Reviews

- I. You will perform a two (2) to three (3) page journal article review on wildland fire management from approved journals. Your review should not only be a summary of the article but should also include your own thoughts and reflections about the methodology and findings of the study itself. These will be graded pass/fail, but **if you do not follow instructions, you will not receive credit.**

Article Reference (in APA format) - If unsure of APA format, visit <http://www.psywww.com/resource/apacrib.htm>

II. Format of your review

Introduction

For the introduction, you should discuss the background and major conceptual framework given for the study, as well as provide a summary of the questions, purposes, and hypotheses of the study.

- Clearly state the major research question(s).
- What is the purpose of the study?
- What are the concepts under investigation in this study?
- What major background research has been done on the topic in the past?
- State the hypothesis or hypotheses of the study.

Methods

- *Participants*: Who were the participants in the study (How many? Male or female? Other important characteristics to note?)
- *Materials*: What, if any, equipment was used for the study? What measures were used for the study?
- *Procedure*: What were the steps involved in collecting the data?
- Clearly identify the study's *independent and dependent variables*

Results

- What statistical analyses were performed?
- What were the major statistical findings?

Discussion

- Was the hypothesis of this study supported by the findings? Why or why not? If there was more than one hypothesis, which was supported and which was not?
- How do the major findings of this study relate to its' research questions?
 - Do they seem to follow with the purpose of the study?
 - What do they say about the concepts being examined?
- How do the major findings of this study relate to past research in this area?
- What are the strengths of the study?
- What are the limitations of the study?
- Discuss some possibilities for future research in this area of study.

** In this section, you should go above and beyond a simple summary of the article's discussion section. What do you think are the study's strengths and limitations? What do you think would be important to consider in future research?

****Under 18?****

If you are under 18, and taking this course for credit, you are unfortunately restricted to the research review option.

APPENDIX C – IMMERSIVE IMAGERY PRESENTATION



Figure 4. IMRC Photo 1



Figure 5. IMRC Photo 2

APPENDIX D – TRADITIONAL (2-D) IMAGERY



Figure 6. 2-D Photo 1



Figure 7. 2-D Photo 2



Figure 8. 2-D Photo 3



Figure 9. 2-D Photo 4

BIOGRAPHY OF THE AUTHOR

While Casey Olechnowicz was born in Hampton, Virginia, he calls Eliot, Maine home as a result of him spending much of his childhood there. Upon graduating from high school in 2012 he enrolled into the University of Oklahoma to study severe meteorology. By 2014, he realized he wanted to work more closely with people and human-environmental interactions and finished his Bachelors of Science in Geography at Old Dominion University in Norfolk, Virginia, with a minor in environmental issues and management. During Casey's undergraduate degree he worked a wide variety of jobs ranging from a certified pharmacy technician at Walgreens, to a tour guide for the Fish and Wildlife Service. All of this was leading up to his enrollment at the University of Maine in the School of Forest Resources in Fall 2016.

Following the completion of his graduate degree from the University of Maine, Casey intends to continue studying at the University of Maine to achieve his doctorate from the School of Forest Resources and pursue a career in academia. Casey is a candidate for the Master of Science degree in Forest Resources from The University of Maine in May 2018.