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Abstract

The following exploratory convergent mixed-methods study examined graduate students' experiences developing and facilitating 360º photo-based virtual reality (VR) tours titled *Labs and Landscapes* focused on forest conservation and climate change education, as well as tour impacts on public audiences. Graduate students in an agricultural and natural resources communication course at The University of Florida used 360º cameras, mobile devices, and online software to create VR tours about the UF/IFAS Austin Cary Research Forest. Then, the students guided public participants through the tours in three physical informal learning environments including a museum, brewery, and campus tabling site within the university community. Data collection included VR tour artifacts, audio recordings of students' VR facilitation and discourse with the public, post-surveys of public participants' tour impressions and climate change attitudes, and pre-/post-student reflections. Data sources were collected separately and mixed in interpretation. Results showed students increased their multimedia communication skills, knowledge of natural resource conservation, and confidence in communicating with public audiences. Additionally, survey results indicated public participants agreed the students successfully guided the tours, agreed it is important to learn about conservation and climate change, and had some disagreement with the statement that humans cannot prevent climate change.

Keywords

Virtual reality, climate change education, self-efficacy, science communication

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Introduction

Curriculum and teaching efforts aimed at preparing the next generation of professional science communicators should incorporate real-world active learning opportunities for students to practice their skills, as well as respectfully listen to diverse perspectives, empathize, and explore contentious scientific issues with public audiences (Bray et al., 2012). Science communicators are essential for interfacing between scientists and public audiences (Borchelt, 2001). Climate change is an ongoing and critical scientific issue that has proven to present communication challenges (Morrison et al., 2018). Natural resource scientists and land managers have specifically searched for ways to inform people about how climate change is impacting environments and land use and management practices (Schweizer et al., 2009). Place-based and informal science engagement utilizing visual science literacy methods such as virtual reality (VR) could be one way to increase public understanding of climate change and land conservation (Bucchi & Saracino, 2016). Therefore, the following study examined how developing and hosting VR tours could serve as a way for science communication graduate students to practice their multimedia and engagement skills through communication with the public about climate change.

Literature Review

Innovative Teaching for 21st Century Science Communication

Science communication graduate education programs at universities around the world are tasked with developing curricula, courses, and innovative teaching and learning experiences to prepare the upcoming generation of professionals (Burns et al., 2003; Loizzo et al., 2018; Loizzo et al., 2016). The upcoming generation of science communicators is expected to possess 21st century skills such as information literacy, digital literacy, critical thinking, collaboration, and creativity (van Laar, 2017). Science communicators should also be able to engage diverse public audiences in a variety of in-person and online, formal and informal settings for increasing science literacy, science-based decision-making, and attitude and behavior changes rooted in science (Burns et al., 2003). Science communication has shifted from a deficit model of unidirectional sending of information to a dialogic back and forth approach of scientists and community members alike sending and receiving messages and feedback in more comprehensive multi-directional exchanges of information, ideas, beliefs, and values (NASEM, 2017). Hence, science communication instructors and courses should implement and examine innovative teaching and learning experiences for fostering educational opportunities for students to develop 21st century communication skills and gain real-world experience interfacing with public audiences in discourse about critical scientific issues such as climate change (Nisbet & Scheufele, 2009).

Climate Change Communication

Many Americans report observing climate change in their local communities with increased severity of the weather, including floods, droughts, and wildfires (Kennedy, 2020). The increase of anthropocentric causes or human-related activity since the 1950s drastically impacted ecosystems due to the warming earth's atmosphere and ocean temperatures (Intergovernmental Panel on Climate Change [IPCC], 2014). Climate change is a global issue impacting communities differently based on location, and there are multiple ways to inform the public on climate change issues and mitigation strategies. For instance, community approaches to climate change education can promote wide-scale behavior changes for limiting global warming (IPCC, 2018). Teaching and communication strategies in a variety of social settings could potentially impact how people learn about mitigating climate change (Henderson et al., 2017). However, some audiences are fatigued by continuous messaging about the topic, making climate change communication challenging (Kerr, 2009; Morrison et al., 2018).

Virtual Reality (VR) for Informal Science Engagement (ISE)

Informal science education (ISE) environments encourage learning outside a school setting, inform audiences of current science issues, and promote life-long learning (Schein et al., 2019). Experiences in the first-person help students and the public learn new content, and immersive VR can help create electronic experiences to develop knowledge in a similar fashion (Winn, 1993). VR is often a computer-mediated environment and experience in which participants view a three-dimensional immersive programmed virtual world or 360º photographic imagery (Meinhold, 2020). VR has grown in popularity since the 1960s and is used for a variety of purposes in various sectors such as the military, architecture, art, education, entertainment, and health care (Meinhold, 2020). The expense and complications from hardware, software, and needed animation programming skills have slowed the trajectory of VR adoption (Kuchera, 2020). However, VR has trickled into the consumer market over the past ten years, and simplified, smaller-scale cameras and cloud-based image-stitching and viewing software are now available for less complex production (Mabrook & Singer, 2019; Nagy & Turner, 2019). Typically, a 360º camera or computer-generated environment, a viewing website, mobile app, or social media, and goggles are required to create and view virtual settings (Bailenson, 2018).

VR can take viewers to locations they would not have otherwise been able to visit, as well as introduce them to experiences they may not have the opportunity to have in real-life (Bailenson, 2018). VR has emerged in journalism and communication as a form of storytelling and documenting historical and current events and experiences (Mabrook & Singer, 2019). The use of immersive VR can also help individuals learn about complex environmental issues (Markowitz et al., 2018). Previous immersive VR studies explored climate change consequences through learning outcomes on ocean acidification (Markowitz et al., 2018) and water conservation through individual behavioral changes (Hsu et al., 2018). Boda and Brown (2020) pointed to the importance of including local contexts when engaging diverse audiences and applying new technology, like VR and 360º videos, promoting relevancy for individuals. Consequently, audiences can apply the content they learned with the latest technology in their local settings (Boda & Brown, 2020). In addition to using VR to teach environmental content, educators used VR to practice climate change mitigation behavior by reducing the fossils fuels needed to travel for field trips by visiting locations virtually (Schott, 2017). Challenges with using immersive VR in educational settings are costly, not owning the technology, and lack of experience utilizing it for teaching content (Markowitz et al., 2018). As VR is increasing in popularity and accessibility, there is a dearth of educator training and research based on VR experiences (Peterson & Stone, 2019). Previous studies examined VR and its development, yet few applied learning theories to examine VR impacts (Randianti et al., 2020). The following research examined how the deployment of VR on climate change impacted public audiences and the next generation of science communication students. Two questions guided the qualitative methods and included:

> RQ 1: What were science communication graduate students' experiences implementing self-created 360º VR tours with public audiences in informal community settings?
>
> RQ 2: How did physical and virtual places influence discourse between science communication students and public participants during a guided VR tour focused on climate change and forest conservation?

Additionally, one research objective guided the quantitative methods:

> RO 1: Determine how a VR tour of a local forest impacted public participants' attitudes about VR, climate change, and forest conservation.

Conceptual Framework

The social constructivist research paradigm, Social Cognitive Theory (SCT; Bandura, 1977; 1986) and Place-based Education (PbEd; Smith & Sobel, 2010) guided the study.

Social Constructivism

For researchers, the application of constructivism to examine climate change education prompts the need to consider the context of communication as well as individuals' previous knowledge and perceptions of climate change (Dillon, 2003; Wibeck, 2014). VR is founded on constructivist learning theories, as it allows an individual to have direct experiences and construct knowledge, not mere descriptions of experiences (Winn, 1993). The practice of social constructivism in research includes discussion and interaction with others to form meaning (Creswell & Poth, 2018; Pfadenhauer & Knoblauch, 2019).

Social Cognitive Theory (SCT)

SCT describes the triadic reciprocal relationship between an individual's behavior, personal factors, and environment and how each factor bi-directionally impacts one another for human functioning (Bandura, 1986). An individual's personal factors can include beliefs, self-perceptions, goals, and intentions (Bandura, 1986). Bandura (1986) described the environment as socially and physically constructed and that "people are both products and producers of their environment" (p. 4). Humans are said to have agency over their behavior through motivational processes, including goal-setting and self-regulated learning (Schunk, 2012). Individuals are often motivated, affected, and act based on their self-efficacy, beliefs that they can complete a task and reach a goal (Bandura, 1989). One way to increase self-efficacy could be through observational learning, such as a VR environment, where the observer learns modeled behavior, attitude, and values (Bandura, 1986).

Place-based Education

Place-based education (PbEd) originated from teaching children outside of a classroom and offered a way for teachers and communities to help youth problem solve in local environments (Smith & Sobel, 2010). Smith and Sobel (2010) contended PbEd is a way to prepare youth to help solve the issues they will face in the changing world when they are adults, such as climate change and natural resource depletion. PbEd attempts to bridge and balance the human and natural world, creating a human-ecological sustainable model to better society (Smith & Sobel, 2010). Communicators should utilize the idea of place in the natural landscape to tell the story of climate change and to help learners apply local, social, and emotional meaning to an environment (Schweizer et al., 2013).

Methods

The purpose of the study was to examine graduate students' experiences creating and implementing VR tours focused on forest conservation and climate change and the impacts of the tours on public audiences. We followed a convergent mixed-methods single case study design (Creswell & Creswell, 2018; Yin, 2012) to investigate graduate students' experiences creating 360º VR *Conservation Conversation* tours for *Streaming Science*, a student-driven science communication platform and programming in the University of Florida (UF) Department of Agricultural Education and Communication (AEC). The VR tours included images and content about a local research forest, environmental conservation, and the effects of climate change. Additionally, the students implemented the tours in three public locations and administered a survey to participants for their climate change attitudes.

The research design focused on a single case study because the phenomenon examined occurred within a real-life context. The boundaries of the case existed between both a context and phenomenon (Yin, 2003). The case was bound by time (deploying VR tours in a graduate semester-long course) and context (three community-based informal learning environments), and individuals (graduate students and public audiences) (Creswell & Poth, 2018). Additionally, there were multiple data points that were distinctive to the case study that led to the results (Yin, 2003).

Graduate students (n = 8) in an agricultural communication course guided by our research team created VR tours of the university-owned 2,040-acre teaching and research forest, *Austin Cary Forest* (Table 1).

Table 1

Description of Graduate Student Participants

Pseudonym	Graduate Level	Degree/Specialization
Allison	Doctoral Student	Ag Education & Communication/Ag Communication
Randall	Doctoral Student	Ag Education & Communication/Ag Communication
Ben	Master's Student	Ag Education & Communication/Ag Communication
Hunter	Master's Student	Ag Education & Communication/ Ag Communication
Gregory	Master's Student	Arts/Museum Studies
Jackie	Master's Student	Non-Degree Seeking
Mariah	Master's Student	Ag Education & Communication/Ag Communication
Skyler	Master's Student	Ag Education & Communication/ Ag Communication

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The students used Ricoh Theta and Go Pro Fusion 360º cameras to take photos, Google Tour Creator to stitch together the images and typed content, and a portable Google Expeditions kit of ten VR headsets for public viewing. The researchers selected three locations to study how physical places influenced the graduate student participants' and community members' discourse surrounding forest conservation and climate change. We used convenience sampling to recruit voluntary participants (n = 40). We gave student participants pseudonyms for anonymity. We did not give public participants pseudonyms, and they are referenced in this study by location (e.g., museum, university, and brewery). The locations included a natural history museum (n = 21), a tabling location on the university's campus (n = 9), and a local brewery (n = 10). The researchers selected the three different locations for data collection to provide multiple participants' perspectives on VR, climate change, and forest conservation. The deployment of the tours in three different locations served to meet individuals where they already were located (Figure 1).

Figure 1

The Three Locations of the VR Tours

Note. Three public physical spaces where graduate students hosted VR tours and collected data: natural history museum (left), university campus tabling (middle), and local brewery (right).

Description of Locations

The three locations for the study were the Florida Museum of Natural History, a UF campus outdoor tabling site, and a local brewery. The target population of the study was Gainesville community members. The target sample population who participated in the study were museum visitors, brewery patrons, and university students. We intended that the three locations would allow a greater range of participants' perspectives related to VR, climate change, and forest conservation. We selected the natural history museum to include participants interested in learning about science. We selected the university tabling location to include students who were possibly science majors or taking science-related classes. The brewery represented a location where participants might not have anticipated learning about scientific content, although individuals may have a propensity for science. The researchers did not publicly advertise the VR tours prior to the study to recruit participants. Alongside the graduate student science communicators who developed the VR, we spent an average of two hours giving tours to the public audiences, totaling six hours.

Validation Strategies

The strategies for validity in this study included the use of peer review and intercoder reliability for dependability for the qualitative data (Miles et al., 2020). Two authors coded the qualitative data, and agreement checks were made with adequate results of consistent coding. A data audit trail consisted of students' written reflection responses and verbatim transcripts of student-participant VR tour dialogue (Lincoln & Guba, 1985). We triangulated the data sources to confirm the public dialogue transcripts supported students' reflections and vice versa. The emergent themes were reviewed by a different author to peer review and confirm the results. We used thick descriptions and rich supporting quotes from the data to support the results (Geertz, 1973). Although case studies are problematic in creating theory and generalizability (Clarke et al., 2018), we believe that conducting similar studies could build comparative case studies of local contexts. We cannot generalize the findings due to the specific context of the case. Still, we believe conducting more studies about local environmental topics in other communities could lead to more robust studies.

Subjectivity Statements

The first author was a graduate student in the UF AEC department studying agricultural communication at the time of the research. She served as the teaching assistant (TA) during the course where the VR tours were created. Additionally, she was present at all three informal learning locations when students deployed the VR tours and surveys to public audiences. She did not have prior experience with VR before serving as a TA for the course. The second author is an assistant professor of agricultural and natural resources communication also at UF in the AEC department. She developed and taught the course in which the VR tours were implemented, assisted with data collection and peer debriefing, as well as founded the *Streaming Science* where the *Labs and Landscapes* VR tours were featured. The third and fourth authors were also graduate students at UF in AEC studying agricultural communication. These authors were not involved in the study's data collection process, but they did assist in data analysis. Before working on this study, they had no experience with VR.

Data Collection and Analysis

Students delivered the tours by reading a script, a compellation of the students' writing while the participants simultaneously explored a 360º forest photo tour through VR headsets. We collected three forms of data: a) graduate students' pre-reflections before giving the VR tours and post-reflections after the experience (qualitative), b) transcripts of audio recordings of the think-aloud discussions between the graduate student VR tour developers and public participants (qualitative), and c) a post-VR survey about community participants' climate change attitudes and VR tour perceptions (quantitative).

We analyzed the data in three sequential steps: a) a qualitative analysis of the participant think-aloud discussions, b) qualitative analysis of the student reflections, and c) analysis of descriptive statistics for the survey results. The data were integrated by comparing results from the quantitative and qualitative data to have a more holistic understanding of the phenomena than if quantitative and qualitative data were reported alone. We analyzed the qualitative data using process coding and in vivo coding (Saldaña, 2009). The researchers compiled these codes into categories to help create the themes (Yin, 2016). Researchers made constant comparisons while dissembling the data and reassembling for codes (Yin, 2016). Additionally, two coders from our team reviewed the students' pre- and post-reflections about giving their virtual tours to various audiences. We used a statistical analysis computer software for the quantitative portion of the research design (i.e., SPSS, Version 26) to analyze the survey results. The mean and standard deviation were reported for both sections of the survey results.

Results

RQ1: Graduate Students' Experiences Implementing Tours with Public Audiences

After coding graduate students' pre- and post-reflections, two themes emerged: *students' increasing self-efficacy* and *showcasing learned content*. Graduate students' reflections indicated students increased their self-efficacy by engaging in science communication with public audiences. The students' reflections noted varying levels of comfortability approaching public audiences, yet they overcame their reservations to engage adults and youth. For instance, Mariah wrote in her pre-reflection:

> I do feel a little intimidated about being in such a non-formal setting and asking people to participate in the study; however, I think that the results will be interesting. I am nervous and apprehensive about this because I know that if I were personally out at a brewery trying to hang out and some college students asked me to take part in their study, I would definitely say no.

However, Mariah's post-reflection showed she overcame her nerves and held conversations with public participants. She wrote, "I was excited that people were engaging with the tour, so I encouraged participants and asked them questions that pushed them to really think about what they were seeing, hearing and learning." Student post-reflections revealed how their tours were a bridge to educating audiences about the local forest and conservation efforts:

> It was nice getting people's reactions about the forest. I noticed that people didn't even know what Austin Cary was (neither did I before this class), let alone forest conservation...Getting the community aware of forests in the local area is a great start to teaching about forest conservation. [Skyler]

One challenge multiple students outlined was lacking self-efficacy in their knowledge and abilities as science communicators to answer public participants' specific questions about forest management practices and climate change impacts. Skyler reflected, "Not necessarily knowing enough to be able to answer all the people's questions was a little scary, I usually just tried to answer as best I could and then, told them how to learn more." Hunter similarly wrote:

> I tried to answer to the best of my abilities…I felt that was appropriate, as I'm not trying to be an expert in that field, but a communicator to help further interest in various fields.

While students initially described a low self-efficacy in their science communication abilities, the coded transcripts of the student-public dialogue showed students did indeed demonstrate and explain their content knowledge about the Austin Cary Forest, conservation, and climate change during the VR tours. For instance, a tour dialogue excerpt from the museum setting indicated knowledge of prescribed burning:

> Public Participant: So, do you prescribe burn the entire forests, in different stages?

> Allison: So that's right. But they do it [prescribed burning] at different stages depending on what the objective that the landlord or whoever is trying to achieve.

Similarly, in the campus setting, a graduate student was able to articulate specific information about prescribed burning and Saw Palmettos (tree species).

> Public Participant: Just curious, do you know if the saw palmetto can withstand fire?
> Jackie: So, they [saw palmettos] will burn with the burn regimes then come back up...This is why the burning regime established 50 years ago is really important because we've seen with climate change, this span of being really dry has gotten bigger and bigger.

As demonstrated via the transcript excerpts, while students initially described feeling a sense of low self-efficacy prior to working with a public audience, their post reflections and the VR tour transcripts showed students were able to become more comfortable with their science communication abilities and to share the knowledge they learned about the forest and forest management in their discussions with the public. Self-efficacy is a tenet of social cognitive theory where individuals believe in their abilities to complete a task (Bandura, 1989). Thus, increasing students' confidence in public science communication is vital to prepare students to engage with various audiences on scientific issues.

RQ 2: The Influence of Physical Place and Virtual Place on Discourse

Through VR, public participants virtually explored a local research forest not typically open to visitors. The themes that emerged from the student-public discourses from participating in the VR tours included: *exploring a new place* and *being cognitively overwhelmed*. Participants at all three locations had various questions and recounted holistic and detailed observations of the virtual space, stating how they felt when seeing a virtual space: "Looks like someone is trying to make you cross that tree," and "I see a jungle" compared to others who noticed minute details like, "I see someone's hand." Participants noted looking at details and noticing items unnatural to the space, like a camera glare and the foresters' vehicles. In their post-reflections, the student tour guides also noted how participants were searching for items in the virtual space:

> I think people like to use VR as almost a 'where's Waldo' like they go into it looking for something. I think that this inclination could be tapped in to and the learning could become more participatory as a scavenger hunt for specific points of interest. [Skyler]

Many participants described visiting an environment similar to the one they were virtually exploring. Still, several people discussed that the VR experience was their first time being exposed to this specific forest ecosystem. Many participants reacted with expressions of amazement when hearing facts about the depletion of the ecosystem over time, including the specifics about human-caused overlogging and the increase in lightening-ignited fire season due to the rise in global temperatures. The participants' experiences exploring the local forest through VR promoted PbEd, where teaching occurs outside of a formal classroom setting. Accessing the local forest via VR through the lens of PbEd, allowed participants to visit a place to begin to make meaning of an environment that some were not familiar with prior to the tour.

In all three informal settings, participants showed signs of being cognitively overwhelmed with the combination of visual and audible content, especially when looking at a new scene and when student guides presented statistics. Researchers observed that the student guides had to repeat information, especially the script that contained numbers/statistics about the content. In addition, students described the same findings:

> I think a lot of comments were about the images being popped out. Also, the trucks in the background were commented on. In general, I feel the participants were paying attention and often asked the guide to repeat certain things about the changing [eco]system. [Jackie]

Participants also reacted in amazement when they were shown an image of a local endangered wildlife and an image of a prescribed fire (Figure 2).

Figure 2

Example Image from the VR Tour

Note. Example of a prescribed fire within the Google tour (Flattened two-dimensional format for print).

RO 1: Public Attitudes about VR, Climate Change, and Forest Conservation

After engaging in the VR forest tour, public participants voluntarily consented and answered a short touchscreen survey via iPads. Survey results showed public participants' perceived learning about climate change and forest conservation as important. They also perceived their knowledge increased about VR after taking the virtual tour and would likely recommend VR to their friends. The participants' post-VR tour surveys explored their perceptions of the virtual forest tour, climate change and conservation, (Table 2) and perceived knowledge before and after the virtual tour (Table 3).

Table 2

Participant Perceptions of the Virtual Forest Tour

	M(SD)
It is important to learn about conservation.	4.85(.36)
It is important to learn about climate change.	4.85(.36)
It is important we learn about forests.	4.78(.48)
The tour guide communicated at a level that I understood.	4.68(.76)
I like to spend time outside.	4.63(.63)
The tour guide was knowledgeable about the topic.	4.63(.67)

The tour guide did a good job answering questions.	4.45(.90)
I would recommend this virtual tour to my friends.	4.38(.87)
This topic was interesting.	4.38(.75)
The images were interesting.	4.22(.86)
The tour guide talked about something I did not already know.	4.18(1.06)
The images were engaging.	4.18(.84)
I am very aware of environmental issues.	4.00(.88)
Humans cannot prevent climate change.	2.56(1.21)

Note. Real limits of the scale: 1.00 - 1.49 = *strongly disagree*, 1.50 - 2.49 = *disagree*, 2.50 - 3.49 = *neutral*, 3.50 - 4.49 = *agree*, 4.50 - 5.00 = *strongly agree.*

Table 3

Participants' Perceived Knowledge Before and After the Virtual Forest Tour

My knowledge before/after the 'Virtual Forest Tour'…	Before *M(SD)*	After *M(SD)*
Climate change	2.83(.81)	3.33(.62)
Florida forests	2.42(.81)	3.36(.63)
Forest conservation	2.40(.87)	3.46(.60)
VR	2.30(.91)	3.26(.64)
Austin Cary Forest	1.63(.87)	3.23(.71)

Note. Real limits of the scale: 1.00 – 1.49 = *none*, 1.50 – 2.49 = *low*, 2.50 – 3.49 = *medium*, 3.50 – 4.00 = *high*

The first portion of the 14-question survey measured individuals' perceptions about the VR tour and the content presented on a 5-point, Likert-type scale (Table 2). The Likert-scale for the first section of questions regarding *participants perceptions of the virtual forest tour* included the range: 1.00 – 1.49 = *strongly disagree*, 1.50 - 2.49 = *disagree*, 2.50 - 3.49 = *neutral*, 3.50 - 4.49 = *agree*, 4.50 - 5.00 = *strongly agree.* The results exploring participant perceptions of the virtual forest tour demonstrated the highest mean statements: *It is important to learn about conservation*, and *It is important to learn about climate change*. Both statements had the same means and standard deviations (*M= 4.63, SD= .63*). The lowest mean reported by participants was the statement, *Humans cannot prevent climate change (M=2.56, SD 1.21).* Results also indicated respondents would recommend the VR tour to their friends, and their knowledge of VR increased.

The second portion of the survey asked the participants to rate their knowledge before and after the virtual forest tour on a 4-point Likert-type scale (Table 3). The Likert-scale used to answer *participants perceived knowledge before and after the virtual forest tour* includes: 1.00 – 1.49 = *none*, 1.50 – 2.49 = *low*, 2.50 – 3.49 = *medium*, 3.50 – 4.00 = *high.* When examining the participants' previous knowledge and perceptions before and after the VR tour, the result indicated that participants felt their knowledge about *forest conservation* as the highest after the tour (*M = 3.46, SD = .60*). The participants indicated perceived knowledge before the virtual forest tour, *Austin Cary Forest*, as the lowest (*M = 1.63, SD = .87*), and after the tour was the lowest (*M = 3.23, SD = .71*). The results indicated participants perceived their knowledge about the research forest to be the lowest, and the researchers believe this could be because the research forest is not regularly open to the public. The tour provided the information about the research forest throughout, which is attributed to the greatest difference in means, ultimately demonstrating the most increase in perceived knowledge. The participants' perceived knowledge was the least pre- and post-virtual tour pertaining to climate change. The authors attribute this to the lack of visuals showing climate change – a gradual phenomenon – difficult to represent visually in the VR tours.

We analyzed the qualitative transcripts from participants' think-aloud discussions to complement the survey data,. Two themes emerged: *reacting to content* and *blending previous environmental knowledge*. Participants reacted to content by asking questions and responding to questions posed by the student researchers. All participants said they believed in climate change when asked by the students. Several participants suggested forests would not exist in the future due to the effects of climate change. Participants used the term *hope* in their responses to the future of forests. For instance, when a student asked, "What do you think forests will look like in the future?" a participant responded, "If there are still any [forests] there because of development? I hope we can take care of what we have, not like California" [brewery]. At the university tabling setting, one participant said, "I hope with good management, we can maintain them [forests] to be productive ecosystems, but if we don't get the fire thing under control, they could just be charred grasslands." The excerpts demonstrate varying reactions climate change and forest conservation content. The idea of hope relates to self-efficacy in SCT, where participants may have varying levels of confidence that they can mitigate climate change impacts.

When students asked what participants could do to help with forest conservation, many answered with retained content from the tours. However, in many instances, they blended their knowledge with previous environmental and climate change assumptions not mentioned by the student tour guides. The blending of knowledge was evident in all three learning environments. Examples of the blending of knowledge included the brewery location where a participant said, "Probably [climate change affecting forest] because the fires are getting hotter and plants to adapt relatively quickly to risk going extinct." Students discussed how the ecosystem would change in the tours, but they did not discuss plants extinction. A participant at the university setting noted, "Like not littering, don't set forest fires," when asked how they could preserve the forests, although students did not discuss littering during the tour. Additionally, the students distinguished wild forest fires from prescribed burns during tours to clarify terms. At the natural science museum, a participant stated, "I was saying we are probably going to keep losing trees if there's not more active action to keep them and not take them down. Deforestation." Students did not discuss deforestation during the tours, which contradicted the content in the tour. Students reviewed how the research forest practiced forestry and logging to support research in the tours. Other responses included past campaigns with forests and forest fires, "The Smoky the Bear campaign. That's what popped into my head," when asked how they would protect the forests. Another participant felt less development would help protect forests, "I certainly think less development would be beneficial. Take out Disney World." Others engaged in discussions about the recent development in the city and how zoning could protect ecosystems:

> Well, zoning, commercial zoning. There is where it begins and ends. Who owns it? So, if it [land] has a commercial zone, they can develop whatever they want to. It starts with

> city planning, county, and state planning. It's the best way to protect it [the forests]. [brewery transcript]

The participants' answers to how they could protect the forests mostly arrived from previous knowledge, not from the content within the tours. Observational learning, a tenant of SCT, may have also informed their responses since they recalled content from prior conservation campaigns.

Discussion and Conclusions

Students increased their self-efficacy when communicating science to public audiences and displayed their own observational learning while working with various audiences and environmental education. As noted in SCT, students can observe from each other how a behavior (talking with the community about the environment) is rewarding (seeing participants learn through students' work). Therefore, observational learning can motivate students to repeat their behavior of communicating with the public about local environments (tenets of PbEd) and conservation efforts. Increasing students' self-efficacy in communicating science is vital since the next generation of science communicators should learn how to explore contentious scientific topics with various public audiences (Bray et al., 2012).

The public audiences felt climate change and forest conservation were important but did not agree or disagree that humans could prevent climate change. They also indicated their knowledge increased about VR, and they would likely recommend it to their friends. The quantitative and qualitative data converged to suggest that many participants retained content from tours. However, they blended previous knowledge of environmental conservation behaviors into their VR tour learning, such as not littering. Additionally, the participants discussed their perceived ability, or self-efficacy, to conserve forests as a communal activity, not from their individual behaviors. SCT assumes one's self-efficacy directly influences coping skills of environments (Bandura, 1977), and these findings demonstrate efficacy as a community's ability, not necessarily an individual's ability to mitigate climate change or conserve forests. The findings are similar to other research where hopelessness is present in discourse about environmental concerns and climate change (Chadwick, 2015) and how people lack optimism in how humans can reduce global warming (Leiserowitz et al., 2017).

VR in informal learning settings can allow individuals to explore a space not readily accessible to the public and foster discussion on local environmental practices and issues. The discourse surrounding the virtual forest tours indicated the audiences were curious about VR and the content presented in the tours. The topic of climate change, a gradual phenomenon, was challenging to represent in the 360º images. The visual and auditory content at times was cognitively overloading some participants. Researchers conclude that place contributes to learning about climate change and familiarizing audiences with it in their own community. Moreover, *place*, both content and context of VR, influences how people engage in learning. Communication and extension professionals can use VR technology to help familiarize their communities with environmental issues, create environments for people to engage in learning, and provide access to places not readily accessible. The use of VR in various informal learning environments can assist in communicating local issues and promote dialogue with community members.

The theoretical implications suggest a local environment accessed through VR, and in this study the research forest, is the bridge between shared community knowledge about climate

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change and individuals' knowledge about climate change. A local environment does not solely pertain to the location in the content but the context where people engage and learn. SCT (Bandura, 1977; 1986) can be used in concert with PBEd (Smith & Sobel, 2010) when working with VR and environmental education outreach in informal learning settings. A *place* shared virtually via observational learning can assist audiences in learning more about environmental topics and sites, thus helping to make a location less abstract and contribute to community knowledge and self-efficacy about climate change. These findings can make a place more relevant to individuals who do not have access to visit in the community. VR can display local places where people might not realize the continuing climate change effects in their local communities. Moreover, engaging audiences in climate change education can assist in educating other members in the community through transferred knowledge from youth to adults and adults to youth, as found by Vallor et al. (2016). Our study extended previous research on VR as a teaching tool for both youth and adult learners. Our study indicated that locations accessed virtually do not have to be geographically distanced; VR can explore local places where people might not realize the continuing climate change effects in their local communities.

Limitations included a small sample size (n = 40), limiting the amount of data for additional statistical analysis. Additionally, the results cannot be generalized beyond this sample to the larger population. The lack of prolonged engagement in the field with participants was also a limitation in gaining more qualitative data. Another limitation is that VR technology is constantly changing. The Google Tour Creator online VR tour software used in this study became obsolete in June 2021, and the research team shifted to exploring the use of new VR editing and viewing software for future projects.

Recommendations

Communication instructors can utilize VR to teach students cutting-edge photography and technology skills, and how to apply VR for public engagement about environmental science topics in informal learning environments. The researchers recommend that participants find specific details within images in future VR tours for a complete immersion into virtual space and scientific content. Other recommendations include reducing the cognitive load of VR participants, limiting the information in a space, or giving more time for independent exploration. Additional recommendations include having a subject matter expert or scientists present to help answer questions to clarify information and answer participants' more in-depth questions Lastly, based on previous literature and results of this study, audiences need more local and direct solutions to mitigating climate change to provide hope (Chadwick, 2015) and how they can help in their local communities where they are socially connected (Groulx et al., 2014). Additionally, within those solutions, future researchers should develop further questions based on emotions with various audiences, especially among younger audiences and coping strategies on climate change as recommended by Ojala (2012), i.e., how do you feel about climate change? Future studies should examine the relationship between communicating direct solutions and climate change mitigation behaviors.

VR technology is often utilized in a classroom setting, yet this study demonstrated how VR can be deployed in informal learning environments to meet audiences where they are. Science communication educators, extension professionals, and researchers can use VR technologies in the future to further develop community-based instances to engage youth and adults in local environmental and natural resource issues. Although climate change can seem like an abstract concept to individuals, VR technology can visually show its impacts that individuals may be unaware of in their communities. VR used in informal learning environments can promote discourse with public audiences and be a space for individuals to ask questions about scientific content outside of a traditional classroom setting.

All three learning environments were located in a large research university town. Consequentially, the sample of participants and locations may have a predisposition in interests toward environmental education and science education tools like VR. The participants in the brewery location were the most difficult to recruit and participate in the students' tours. Due to this reason, the researchers recommend marketing VR tours to audiences in locations where VR is not readily available and accessed to promote participation in environmental communication, education, and outreach. Additionally, future research should look at conducting tours in other informal locations to foster discourse and promote equitable access to VR and environmental communication and education. VR for science communication and engagement is very much in its infancy. For instance, the Google Tour and Google Expeditions platforms used in this study were shut down in July 2020, and the authors began to adopt newer cameras such as GoPro Fusion and viewing sites such as Theasys and Matterport. It will be imperative for current and emerging science communication and extension professionals to continue to adopt and test VR technology for engagement. Much room for growth exists to further develop VR tours for a variety of agricultural and natural resource sites and phenomena for public exploration to ultimately impact attitudes, knowledge, and behaviors.

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