

At The Scene of The Science: Virtual reality, culture, and its impact on students attitudes towards science

Abstract

Given substantial calls to imbue culturally relevant designs within novel educational technology, we report how virtual reality 360 videos can be designed to embody broader socio-political science education goals. Leveraging VR 360 to contextualize science content, we argue VR can afford students the opportunity to make sense of their community contexts as sites where science can take on a socio-political meaning. The data suggest that our treatment condition students were afforded this type of socio-cultural application of the content to a greater extent than their control counterparts, which we attribute to culturally relevant design elements within the treatment trials. Implications for these findings are discussed in relation to equity in STEM education, socio-political science education, and the affordances virtual reality.

Keywords: Equity in STEM; Cultural Relevancy, Educational Technology

Introduction

As our world experiences rapid technological advancement, science classrooms are emerging as prime spaces to adopt educational technology to improve student learning (Baran, 2014; Fowler, 2015; Gropper, 2017). However, creating powerful educational technology can be challenging for a number of reasons. Oftentimes technology developers create software that does not reflect best pedagogical practices, particularly for underserved students in urban contexts that may differ from the developer's intended audience. Teachers can also be resistant to adopting technology due to divergent pedagogical goals (cf. Ertmer, 2005; Porter & Graham, 2016; Scherer, Siddiq, & Tondeur, 2019). Thus, the divide between the equitable applications of educational technology and the affordances of culturally-aligned classroom practices can provide a central hurdle to the adoption of these innovative technologies for STEM education.

In this paper we argue that to develop equitable applications of novel educational technology, such as virtual reality (VR), we must first think about how to design these platforms in ways that leverage the cultural students bring into the science classroom. In turn, there must be equity-based design schemes informing how these technologies can be utilized. Educational technology must meet the needs of students that have been shown to lack representation in STEM, namely, diverse youth. In agreement with our proposition, scholars over the past 20 years working in culturally responsive educational technology have pursued similar types of studies to argue that cultural relevancy should be incorporated into the designs of educational technology (cf. Duran, 1998; Lee, 2003; McLoughlin, 1999; Scott, Sheridan, & Clark, 2015; Sun 2012).

Given this previous call, and the lacking *cultural* design elements leveraged within current VR literature (as we shall illuminate below), we conducted a quasi-experimental, mixed-methods study using tenets of Ladson-Billings's notion of Culturally Relevant Pedagogy (Ladson-Billings, 1995a). Using CRP as a conceptual framework to guide the design of three

elementary science lessons, we leveraged the affordances of a novel education technology (VR) as a pedagogical platform. We argue that VR can aid in equity-focused learning of science content through a socio-political lens, which, as our design elements and data support, emerge from the technology's capability to situate science content within sites where socio-political issues related to STEM become prevalent through the teaching of science lessons. In turn, we asked the following research question:

In what ways may culturally relevant design elements influence students' attitudes and applications of science content?

Background Literature

Before we provide a comprehensive review of the literature involving VR, we summarize the broad strokes of this field in terms of its affordances and limitations, while also elaborating on where our VR designs fit within this research base. We then provide a thematically based background literature of all the different types of VR and their aligned affordances for learning.

VR 360 Videos: A Novel Design Platform with Affordances and Limitations

There is a wealth of research exploring the potential benefits of virtual reality (VR) across Psychology, Medicine, Computer-based learning, and Education. However, despite the enormous potential VR holds for teaching science as a context-specific discipline, research has just scratched the surface on how this platform can transform urban elementary science education. We urge developers and science teachers to consider design educational technology platforms *for* diverse youth as a way to teach science content and foster a socio-political lens. Current approaches to how this technology can enhance schools, unsurprisingly, lives mostly in the world of psychology (Adams, Finn, Moes, Flannery, & Rizzo, 2009; Mantovani, Castelnovo, Gaggioli, & Riva, 2003) and technology education research (Antonietti, Rasi, Imperio, & Sacco, 2000; Barbour & Reeves, 2009; Domingo & Bradley, 2018). However, although these studies indicate the potential benefits of learning science concepts through VR,

their focus remains on a traditional learning paradigm of science content aligned with the goal to succeed academically on measures such as standardized test items that decontextualize the content from students' sense-making.

Indeed, these type of VR studies also rarely venture into science learning designed *for* diverse students who may benefit from design principles related to cultural relevancy (see Lee, 2003 for an in-depth explanation). To what end, and goal, do these studies emphasize in terms of science learning for diverse population, then? We argue that current VR research goals remain stagnant in their intentions to educate for content acquisition or learning of scientific practices that take students away from their communities to learn, a design feature we contend can be shifted to showcase the importance of contextualization for adopting a socio-political lens in relation to being able to view science as something that is applicable in students' real lives outside of school within their communities, to better their schools and communities.

To their credit, there are a growing number of experimental research reports that suggest that VR can improve students' learning and give them a deeper appreciation of the content (Bailenson, Yee, Blascovich, Beall, Lundblad, & Jin, 2008; Makransky & Lilleholt, 2018). For example, Markowitz, Laha, Perone, Pea, and Bailenson (2018) explored how students and adults who learn about climate change and ocean acidification through their VR lesson developed a deeper understanding of the content due to the immersive nature of the technology. Adding an additional layer to the potential benefits of VR, Makransky, Wismer, and Mayer (2018) implicated the role of the digital identity representations in the platform as a factor in shaping students' connections to the discipline. They explain that VR can enhance the learners' experience by changing who is involved in the teaching and showcased how gender representations in VR had a positive impact on students' attitudes toward learning.

Together, these studies suggest that VR has the potential to impact students' learning and sense of connection to the discipline. Such an affordance has been emphasized by equity-focused STEM education research more broadly (Calabrese-Barton & Tan, 2018; Garibay, 2018; Kayumova, McGuire, & Cardello, 2019; Vakil, 2018; Vossoughi, Hooper, & Escudé, 2016). What remains to be seen is how VR can be used as a *pedagogical tool* to assist contemporary K-12 classrooms in improving how science can be taught towards socio-political ends. VR may help science teachers better represent how phenomenon can impact the sociopolitical realities of modern students. One such charge is summarized by Jones (2017) in her editorial on the impact of VR 360 in urban schools where she describes how teachers are currently in the process of examining the potential benefits of adopting VR into science classrooms. However, this article is one of only a handful that address the potential of VR 360 as an inventive pedagogical tool, rather than a technological novelty. We argue that to date the field offers little practical applicability in ways that could have a classroom of students participating in the learning experience.

The work provided above emphasizes how VR could promote students' making of self-explanations and, therein, induce an enhancement to their learning. However, despite the potential socio-cognitive and sociocultural benefits of adopting VR into science and STEM education, there are an underwhelming number of studies exploring VR as a pedagogical platform *designed specifically* to leverage culturally relevant designs. Our VR design is similar in some ways to these designs and departs in others, with our data supporting these affordances and limitations. Principally, VR designs such as those by Markowitz, Laha, Perone, Pea, and Bailenson (2018) and Makransky, Wismer, and Mayer (2018) are created through the use of expensive and elaborate teams of technology designers, learning scientists, and cognitive scientists. These VR studies emphasize that VR's capability to *immerse* participants in the

learning experience (i.e., they feel like ‘they are there’) and have them feel a sense of *presence* (i.e., when viewing the haptic responses to their actions, they gain a feeling of interactivity) are the greatest affordances for VR’s use in teaching and learning. However, scholars should consider the substantial limitations to such elaborate designs, as well as to what ends do they pursue.

These VR studies must be supported by expensive computer systems with high performance graphics card, as well as can only support a few students at a time. By contrast, our VR 360 designs can support a learning experience for 34 students at one time (see Image 1 below). This is a substantial limitation of higher-quality VR in terms of relevancy to practice (Gutiérrez & Penuel, 2014) given that classrooms do not just contain a few students, and engaging some students in a novel learning experience while others look on, as noted by some of these scholars, becomes an issue in terms of the promise of such a use of VR in terms of designing technology that can be feasibly adapted for classroom instruction. Many of the current VR designs take students away from their locales, emphasizing to students that this type of ‘learning’ only occurs beyond their lived realities. Thus, the external uses of technology alone cue to students that their more local realities and ways of knowing are not worthy of exploring via enhanced technology.

We argue these limitations can be mediated when thinking about how to use VR 360 to *immerse* students in their local communities in order to showcase how and in what ways these contexts may have socio-political connections to science learning. As shown in Image 1 below, while students do not become embodied in the VR 360 experience, nor do they interact with avatars or the contexts through haptic responses, these VR 360 experiences afford them the opportunity to be *explicitly and individually guided* with linguistic, visual, and auditory cueing, which enhances the “rudimentary” type of VR that a VR 360 platform provides to learners (see

Online Supplemental Material for a more in-depth explanation of our design template). Finally, VR 360 also allows for embedded visualizations that, as we present later, have their own affordances in terms of science and STEM learning.

Indeed, as scholars think critically about the potential value of learning science through VR, we contend that its potential is deeply rooted in its capacity to impact students across five

Image 1. Students in this study experiencing our VR 360 lesson



specific dimensions discussed broadly in the VR literature. These five dimensions are *Experiential, Cognitive, Cultural, Technological, and Pedagogical* – the cultural and pedagogical dimensions representing an underdeveloped focus in the literature that we address in this study. Table 1 below provides an overview of the dimensions of this VR research with descriptions of how we parse out these dimensions and examples of their possible use.

The Experiential Dimension

From an experiential perspective, the benefits of VR are well-studied (see Kirkwood & Price, (2014) for a critical review of what constitutes ‘enhanced learning’ in relation to technology). *Experiential* perspectives on the benefits of VR share an assumption that the most profound benefit of virtual environments lies in their capacity to help students feel like they are actually experiencing the phenomenon. For example, Huang, Liaw, and Lai (2016) explored how

the numerous dimensions of VR impacted students' experiences and found a number of factors ranging from interaction, immersion, and imagination that shaped students' learning through VR. They also found that the extent to which students felt a sense of immersion positively impacted the students' experiences while learning through the platform. These perspectives highlight how enabling students to gain a sense of immersion in the content can lead to a positive learning experience for the student (Ausburn & Ausburn, 2004; Minocha, Tudor, & Tilling, 2017).

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The Cognitive Dimension

A second potential benefit to using VR in classrooms is found in its cognitive potential for learning. The *Cognitive* potential of VR is found in the capacity of virtual experiences to help students embody a scientific phenomenon, therein gaining a more intimate sense of the structure and function of concepts. Whether students are able to enter into a capillary and experience how blood travels of the body, or how students are able to experience what the earth looks like from space, the inherent benefit of virtual reality-based science education lies in its capacity to allow students to get a personalized experience of the phenomenon. While similar to the experiential perspective above, these studies depart from a narrow focus on cognitive perspectives and point to the potential of VR as a way to engage in constructivist teaching by suggesting that the digital resources embedded in VR can be used to extend the benefits of VR learning.

From a constructivist perspective, scholars like Burkle & Magee (2018) suggest that having students engaged in learning through video games offers students a rich learning environment, while Merchant et al. (2014) challenge scholars to think about the cognitive potential of gaming as a constructivist VR learning tool. Additionally from a cognitive

perspective, scholars have begun to reconsider how we might use VR technology to enhance contemporary learning across a variety of disciplines in medicine and beyond (Loftin, Chen, & Rosenblum, 2005; Ota, Loftin, Saito, Lea, & Keller, 1995). This was complimented by Dalgarno & Lee (2010) who conducted research that supports that students will develop an improved spatial understanding and enhanced understanding of the contextual value of the science concepts from being embedded in a virtual world. This scholarship points to a shared assumption that VR can be used to develop a deeper understanding of why the content matters, but does not explicitly address culture or socio-political applications of the content in ways that have been articulated by critical scholars and multicultural theorists, such as CRP.

The Cultural Dimension

Another aspect of VR involves the *Cultural* domain of learning through which developers understand the value of allowing learners to see themselves embodied within VR. We argue that scholars should begin to explore how VR can serve as a pathway to help students see themselves as practitioners within communities that they may traditionally not become exposed to as being related to their lived realities outside of school, such as science and STEM. As VR begins to be designed to serve the needs of a diverse student populations, teachers and developers must leverage the dynamic resources of applying cultural relevancy within VR software.

In turn, embedded cultural cues have been shown in content learning studies outside of science education to help students enhance their cultural awareness and that this type of cueing can enhance students' sense of connection to the content they are learning (Shih, Jheng, & Tseng, 2015). Indeed, in a recent study on the gender influences embodied among avatars when teaching through VR, Makransky, Wismer, and Mayer (2018) explored what would happen if girls were taught by women. They discovered that girls reported a preference for being engaged with similarly gendered virtual representations. This aligns with previous research that describes

the ways in which gender identity of participants in VR environments can determine comfort and accessibility for participants based on learning style (Ausburn, Martens, Washington, Steele, & Washburn, 2009). Despite the potential narrowness of that framework, there is enormous promise in examining how the cultural representations in VR platforms may impact students learning, specifically if we think about the affordances of VR technology to bring students into their local contexts to learn about the science content in ways that they may never think to connect to the content, such as their own communities, as showcased in this study.

The Technology Dimension

The *Technology Domain* is a well research aspect of VR scholarship, however, this body of research about the capabilities of VR related to the technology itself is primarily found in computer science (Barbour & Reeves, 2009; Gallopoulos, Houstis, & Rice, 1994; Ota et al., 1995) but has branches of research that have explored its psychological value (Mantovani et al., 2003; Markowitz et al., 2018). When examined closely, the technology domain of VR research can be parsed into two schools of thought; *sensory* and *cyberworlds*, each providing a nuanced attentiveness to the value of VR for students' experiences and learning when leveraging VR as a way for students to be educated around specific topics.

The sensory scholarship examines how VR influences human behavior across the context of biological and emotional grounds (Adams et al., 2009; Thisgaard & Makransky, 2017). This research highlights how VR can change how users see the world racially and politically. In addition, cyberworld studies from the early 2000's explored how virtual reality worlds changed the nature of human interaction in relation to content. For example, Prasolova-Førland, E., Sourin, and Sourina (2006) challenged scholars to think about the potential benefits of VR cyberworlds and cyber campuses for learning and charged VR developers to incorporate metaphors of place and think about the learning goals of these designs. Together, these

perspectives share a central tenant that the design features of VR can alter students' learning experience in various ways when leveraged for specific goals; to wit, we argue, these goals have continued to neglected the socio-political nature of science content and its application emphasized by scholars in science education (cf. Dimick, 2012; Hodson, 1999; Roth & Désautels, 2002; Santos, 2009; Tolbert & Bazzul, 2017).

The Pedagogical Dimension

The final dimension to consider in VR literature is the *Pedagogical Domain*. To date the pedagogical research on virtual reality is limited. As Freina and Ott explain:

... it is difficult, and some would say impossible (see Clark, 1994) to separate the technology from the pedagogy. However, some light can be shed on the individual contributions by comparing studies that retain the existing pedagogy but deliver it using new technology. (2015, p. 421)

Freina & Ott's (2015) suggestion that technology and pedagogy are inseparable centralizes the role of pedagogy in enhancing the impact of VR instruction, but leaves out a description of how culture plays a role in these designs. Additionally, without a lens on pedagogy scholars must consider what goals can be aligned to these designs in ways that help students make connections between the content and their lived realities. Many of these connections should, instead, be related to proximal social issues that disproportionately affect poor communities of color such as food deserts, preponderance of lead in urban schools, and 'grit' ideologies that lack interrogation for the ways that they deny students' lived realities as positionalities that are not easily overcome by merely changing one's mindset.

Our perspective aligns with the views shared by Freina and Ott (2015) that though VR is an intriguing learning tool, it can also be re-conceived as a pedagogical instrument. VR can afford students the opportunity to make new meaning of the content presented – if designed appropriately and in ways that respond to the culture context of the students. An impactful integration of VR into modern schools, therefore, must consider how VR can serve experiential,

cognitive, cultural, technological, and pedagogical purposes in science and STEM education.

With that premise in mind, this study adopts a theoretical framework that centralizes the cultural and pedagogical domains of VR in an effort to understand how VR can help students learn science while developing a nuanced perspective on why the science they are learning matters to their lives – namely, Culturally Relevant Pedagogy.

Theoretical Framework

Culturally relevant pedagogy (CRP), originally articulated by Gloria Ladson-Billings (1995b) calls for educators to rethink the possibilities of teaching by reframing education as an opportunity to promote students' cultural competency, academic success, and socio-political awareness. In principle, CRP instruction should both teach content while helping students see themselves as change agents in relation to the the science concepts they are learning. This approach to science teaching has been echoed across urban education more broadly (Emdin, 2016; Paris & Alim, 2017). Through CRP, Ladson-Billings argued that schooling need not be a site where oppression and suppression of voice and culture take place; instead, she argued for a shift in the sense of purpose for the goal of schooling to devote time and energy to (1) appreciation and integration of students identities as indispensable for them to embrace a sense of value for themselves and their heritages when learning; (2) change the biased perceptions teachers and students hold about what high expectations and a sense of critical care means for teaching and learning; (3) explore and integrate the nuanced positional identities students take up outside of school to improve learning; and (4) to develop skills that can be applied to cultural contexts.

Prior to the introduction of CRP, Gay (1975) proposed *Culturally Responsive Teaching* in a subtly different way. Gay (1975; 1988) challenged educators to use altered pedagogy to teach content, while explicitly validating students home cultures. In sum, Gay argued that teachers

need to (1) think about students as agents rather than objects of learning; (2) disrupt the epistemological status quo wherein teachers and 'someone else' are the only people that can produce knowledge about students' self (identity/positionality) and their connection to the content; (3) encourage students to see the value in their home cultures and self-identify as learners for life as a goal of education; and (4) understand how to empower students to maintain their commitments to this learning process as one of strengths and limitations that describe not a sense of self as deficit but, instead, as integral to understanding learning as a process rather than a product. In turn, Aronson & Laughter's (2016) recently offered the field a comprehensive review that integrates both the Gay (1975) and Ladson-Billings (1995b) positions.

Aronson and Laughter (2016) argue that the method through which students should learn that aligns most with the pedagogical requests made by Ladson-Billings and Gay is one of constructivist learning. Meaning that students should not just be recipients of content but active participants in the learning process wherein they become a participant among the communities of practice that become emphasized in the classroom as valuable ways to know the world and engage with the citizens therein. Additionally, Aronson and Laughter (2016) argue that students should be afforded the opportunity to critically reflect on both the learning process as well as the structures through which discourse is produced within the classroom (and beyond) to challenge the oppressive hegemony embodied by our modern schooling and mass media systems of representation. Said differently, science should offer students an understanding of their world and the tools to critique the society they are a part of. Finally, akin to Ladson-Billings's cultural competency and Gay's pursuit of valuing a sense of Self, Aronson and Laughter (2016) argued that to produce such a revolutionary and critical consciousness within the curriculum and pedagogy of the classroom, students need to understand themselves as being positioned in specific ways in the larger society. This move from content alone to learning how to value the

diversity of their identities is one intended to help students move beyond neo-colonial rhetoric, to become capable knowledge bearers who can influence the wider cultural contexts.

For the current study we posit that the VR platform must leverage the deep connections between science content and the culture of the students. More specifically, we contend that the contexts in which these communities are situated should be honored and integrated within the ways students are asked to engage, explore, and extend their learning in meaningful ways that encourage individual and collective sense-making. The insights gleaned from understanding the intersection of science and the cultural nuances of students' lives, we argue, should inform how technology developers alter the design elements, and research foci, within curricular decisions to improve students' learning and understanding of the value of science in their lives. We also contend that these designs should specifically strive to afford the opportunity to adopt a socio-political consciousness toward the content, which we argue is a novel application of VR in equity-based STEM instruction.

This adoption of CRP in VR is not without critique. We argue that while some scholars may, instead, suggest taking students *physically* into their communities to conduct such a learning experience, we contend that these suggestions do not fully take into consideration the affordances of a VR learning experience (elaborated above), nor do they account for the number of adult chaperones and resources needed to bring a class of 34 elementary students to walk around their neighborhood. Any former teacher can attest to these limitations. Additionally, while we can take students on an actual car ride around their neighborhood to have them notice particular features such as the preponderance of fast food restaurants in their locale through VR, such an experience would be almost impossible to create for hundreds of students at a school. Thus, we stake the claim that using VR 360 videos to contextualize elementary science content

within diverse students' local communities affords a fundamentally different and novel learning experience that both leverages VR research findings and the importance of cultural relevancy.

Research Questions

To reiterate, the research question that guided the study design for this project was:

In what ways may culturally relevant design elements influence urban students' attitudes and applications of the science content? To address the quasi-experimental, mixed-methods research design we added two sub-questions based on our data measures:

- Are there statistically significant differences between treatment and control condition means in relation to students' perceptions about the relevancy of science?
- How may students' applications of the science content within this VR intervention differ across the treatment and control conditions?

Research Design

We tested the extent to which culturally relevant science instruction within a VR platform influenced urban elementary students' perceptions, conceptions, and applications of science through a quasi-experimental, mixed methods design (Johnson & Onwuegbuzie, 2004). Working with nine 4th and 5th grade teachers across four partner schools in the Bay Area of California, we implemented 3 trials designed using the tenets of CRP on a VR platform. Each trial taught the following topics in order of implementation: (1) food chains, (2) adaptations, and (3) the water cycle. Students were randomly assigned to either the treatment or control condition before implementation, with each condition representing similar demographics across race and gender. First, we describe the hardware and software used to design these lessons, then we describe the differences in the conditions, design elements, and research methods.

Equipment: Structure and Function

For consistency sake each lesson included four VR 360 videos for each of the 3 trials. The lessons were administered on Samsung Galaxy S6 phones and stereoscopically displayed through Google Cardboard boxes. All students had their own phone, VR cardboard box, and

earphones. In total, we created 24 VR videos that students would engage with during their learning experiences – 12 for each condition; 3 trials x 4 VR videos per trial. This VR 360 apparatus leveraged rotational movement (i.e., students were able to rotate in 360 degrees around a fixed point where the VR camera was stationed during recording), but none of the VR 360 videos included positional movement (i.e., students could not walk forward and, therein, ‘walk into’ the VR video). In other words, our students moved their head to change their field of view and explore the VR 360 content.

Furthermore, our VR 360 videos were designed specifically to not have a ‘Feedback,’ or haptic, response; in turn, our VR video experiences are more aligned with designs in technology research concerned with ‘dynamic visualization’ (i.e., animations) than they are with ‘interactive dynamic visualizations’ (i.e., simulations) (see Plass, Homer, and Hayward (2009) for a more in-depth description of the differences between these two types of visualizations). In sum, the VR 360 videos, and the experience therein, sought to leverage design principles related to change over time (i.e., transformations, such as fruit decomposing, and in-real-time discussions about the content’s purpose happening in-context) in order to encourage students to develop their own ideas about the content being taught while being guided by reflective question prompts within the visual cues (such as overlaid text and audio scaffolds) and the NearPod structure to control pacing – design decisions shown to positively impact students’ making inferences about science content compared to non-dynamic visualizations (McElhaney, Chang, Chiu, & Linn, 2015).

Culturally Relevant and Lacking Cultural Relevant Design Elements

The control condition was designed to lack cultural relevancy; i.e., this condition was decontextualized from the students’ geography and community cultures in ways that denoted the normative center of schools (cf. Hatt, 2012; Leonardo & Broderick, 2011). By contrast the

treatment condition exhibited people, places, and things that were familiar to the students, their communities and families. Figure 1 below represents the design schema for these VR lessons.

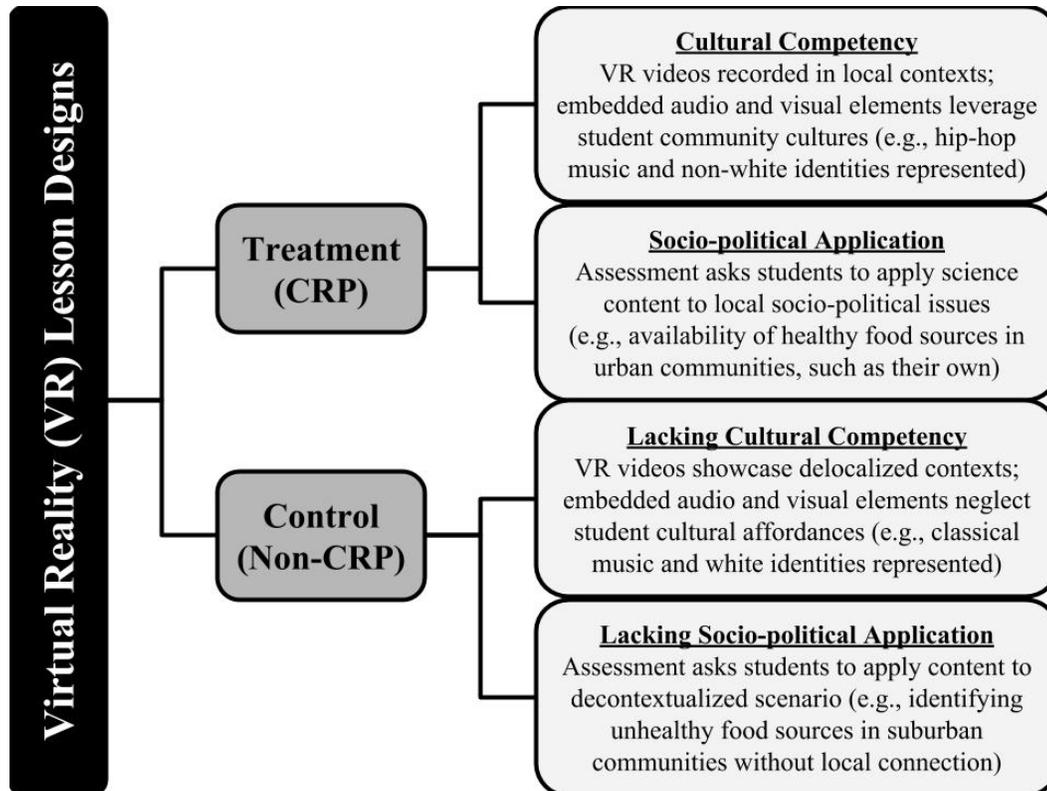


Figure 1. CRP-VR and Non-CRP-VR lesson design elements for treatment and control

Our treatment condition VR lessons contained VR videos that our research team recorded in students' local communities using a 360-degree camera and then manipulated through the use of computer software to embed auditory inputs that were related to the communities in which these students lived (e.g., music, such a hip-hop, and children's voices reading text). We also used this software to embed visual imagery of children and adults that looked like the student population (e.g., Black and Brown youth and adults). These auditory and visual cues were spatially situated within the VR 360 videos that were recorded in and around the schools that the students attended. For example, most of the backgrounds of the VR videos were recorded in the contexts in and around the schools with the audio and images designed to sound and look like the communities in which they resided, as well as the people they interacted with the most. These

design elements draw from the research presented above around VR and culturally relevant learning.

The control condition contained VR 360 videos wherein some were pre-made by other software developers while others we recorded as a team and took students to places outside of their community to consider how the content was relevant in terms of application to decontextualized sites. The auditory inputs for the control condition, thus, were also designed to lack cultural relevancy. For example, to cue cultural distance the videos included loud classical music, voiceovers using a British male adult reading text with a thick British accent, and images of adults who are not typically a part of the students' local community. The visual imagery similarly mirrored this lacking cultural relevancy in that the images of children and adults were designed to not look like the student population, their communities or families. We argue that this differentiation in design elements represents a culturally relevant (treatment) and lacking cultural relevancy (control) set of conditions from which students learned about the content and its application.

We also contend, indeed, that there is no such thing as 'acultural' designs so, instead, we argue that for our control to be lacking cultural relevancy for our students that it should not represent the people, places, and discourses that they interact with on a daily basis. We also want to note that these design elements emerged from a multiple-year research-practice partnership that had developed between the research team, the teachers who volunteered to participate, and the students. Herein, we implore the reader to recognize that when we design such elements that they were not from assumption or from superficial generalizations about the population, quite the opposite, both students and teachers contributed to these designs.

In turn, rather than assuming what our students' cultural contexts contained and valued, we piloted the first lesson (Trial 1) within multiple iterations wherein both teachers and students

participated in its critique and revision. It is from this iteratively revised Trial that we derived our template for what would be considered cultural relevancy and contextually familiar design elements for our population. We, therein, argue that while the reader may view these design elements through their own positionality as not having 'cultural relevance,' to the participants in our study - the primary population we wished to serve through our design - these elements embodied the ways of knowing and being they experienced the world.

For brevity, a slide-by-slide description of the VR lesson from Trial 1 that was used as the template through which the other 2 trials were created, with corresponding screenshots from within the NearPod platform and of the VR videos, are provided in the Online Supplemental Materials. To summarize these elaborated design elements, and to justify the decision to design these lessons through VR within the NearPod platform, we draw from McElhaney, Chang, Chiu, and Linn, (2015) in their rationale for why dynamic visualizations aid in learning:

- Learners benefit from opportunities to process and reflect on the complexity of dynamic visualisations relative to static visuals;
- Dynamic visualisations are particularly effective for promoting conceptual inferences about science;
- Classroom learning settings can foster robust, collaborative engagement with dynamic visualisations to promote deep and generalisable understanding of science. (p. 73-74)

Methods

We assessed the impact of these trials in two ways: (1) A pre-/post-intervention attitudinal survey and (2) two post-intervention open-ended questions to elicit student's perceptions of the applicability of science within the trials, and more broadly, to their personal lives and communities. Henceforth, we use 'intervention' to denote the set of three trials as a whole and 'trial' to denote a single, content specific implementation of a CRP-VR designed instructional environment that ran about 90 minutes on average, per trial. These instruments explored students' attitudes towards science and their perceived applications of science.

Sample. In all four Northern California schools, we conducted our research primarily with 5th grade students approximately 50% identifying as male and 50% identifying as female. The schools share similar demographic and academic profiles, as well, with the students' racial backgrounds roughly representing the following percentages, both within each class and overall as a sample, as well as each condition: ~60% Hispanic/Latino, ~20% African-American, ~10 % Filipino-Asian-Pacific Islander, and ~10% White. All four schools served low-income students, represented by a majority of students (>50%) qualifying for free or reduced lunch and low (i.e., at-risk of falling behind) scores on standardized state assessments for English and Math.

Priming students for VR use. We used a training lesson to prepare students to use the virtual reality software. In this training lesson, we visited each classroom and offered students a 75-minute training about how to use VR software. Doing this in each classroom limited the potential impact of students' different levels of prior experience using VR.

Data Collection

To assess the changes in students' appreciation for the role of science in their lives, we implemented a modified version of the Changes in Attitudes about the Relevance of Science (CARS) survey developed by Siegel & Ranney (2003). The same version of this survey was used pre-/post-intervention. The instrument uses a 5-point Likert scale to explore two constructs. First, it measures change in students' science related attitudes over time. Second, it is used to assess the effect of curriculum in changing students' attitudes post instruction (Siegel & Rainney, 2003). We altered the instruments to ensure a 4th grade reading level, which, after data collection, still held similar reliability as the previous instruments' reported estimates (Cronbach's Alpha > .80). In total, 244 students completed the pre-/post-intervention CARS instrument: 129 students populated the treatment condition while 115 students populated the control condition.

We previously piloted Trial 1 and conducted semi-structured interviews with over 40 students across our research sites, to which their responses about their experiences illuminated the sense of *immersion* they felt within our VR lesson. Additionally, students showcased a preponderance to make connections between the content being presented and ways that this content could be applied to their communities through a socio-political lens, which led to the development of two open-ended questions that 220 students completed post-intervention. The questions used for this data collection were the following: (1): “Some people think science is important. Some people don't. What do you think and why? Be sure to use AT LEAST 3 reasons for your explanation;” (2): “Do you think these three lessons are related to where you live (your community) - the people, places, and things? If so, how?”

Data Analysis

Given the mixed-methods research design, we conducted two concurrent analyses. We adopted a constant comparative method (Fram, 2013) using culturally relevant pedagogy as a theoretical frame for our qualitative analysis procedure and various statistical tests for our quantitative analysis procedure.

Quantitative analysis. All statistical tests were conducted on SPSS, version 24, and, for brevity, all assumptions of the statistics used were met before the calculation of each estimate. We conducted Wilcoxon signed-rank tests to compare the pre-and post-intervention results on the overall CARS instrument score between conditions. We then conducted Wilcoxon signed-rank tests comparing pre-and post-test results of each individual item for each condition. Students from both conditions showcased no significant differences between pre-/post-intervention on the overall CARS scores and the individual item analysis showcased a similar pattern. After this initial investigation we also conducted a Kruskal-Wallis test on the total post-intervention means between condition and found no significant difference between the

participants' attitudes towards the relevancy of science after the intervention of our three VR trials (Chi-square value (1) = .116, $p = .733$). We did, however, observe significant differences among individual item correlations when further investigating the correlation matrix.

Spearman's rho correlation coefficients were then compared between treatment and control conditions among the pre and post-CARS reported scores to illuminate if and to what extent any relationship between CARS items differed significantly between these two conditions. In other words, given that the treatment and control condition were independently sampled, we were able to test if there were significant differences between the strength of the relationships among the post-CARS items across conditions. Fisher Z-scores of these independent sample correlation coefficient comparisons using an online calculator determined the significance of these estimates (<https://www.psychometrica.de/correlation.html>; estimates were subsequently corroborated by another online calculator for confirmation: <http://vassarstats.net/>). Five Spearman's rho estimates were significantly different between conditions post-intervention that corroborated similar patterns of responses within the qualitative responses. Eta-squared effect sizes of those Z-scores were then calculated using an online calculator, as well (www.psychometrica.de/effect_size.html#transform).

Qualitative analysis. We engaged in an iterative coding process based on the principles of grounded theory and the constant comparative method adopting a theoretical lens (cf. Fram, 2013; Morse et al., 2016). During our constant comparative qualitative data analysis process, two researchers were assigned to review the responses to the post-intervention questionnaire items. Each researcher was asked to identify emergent themes that appeared throughout the responses within one of the questions, with the other researcher analyzing the other question concurrently. The research team - these two researchers combined with 1 other researcher - met to discuss

patterns of similar responses within the data sets and outlined any open codes that emerged. Subsequent axial connections were also made at this point.

This process was replicated until we were able to identify a set of themes within which the majority of the responses populated in terms of characteristics of the responses and attributes related to our theoretical frame, CRP. Once we created our thematic codes, each transcript was coded by the original primary coder for each of the questions separately to determine the nuanced variations between the purpose of the questions - Question 1 eliciting students' perceptions of science more broadly and Question 2 eliciting the application of the content taught in the CRP-VR trials to the students' local communities and personal experiences.

A third researcher then reviewed these codes and the research team met to identify and resolve any discrepancies in their coding and focus on responses that would be indicative of the intervention's impact as related to culturally relevant pedagogy. The team discussed the codes until the 3 researchers reached 100% agreement on the codes, their axial connections, and their respective theme. To triangulate the data, we used a simultaneous analysis (qualitative and quantitative) procedure to identify patterns that emerged concurrently (Creswell & Creswell, 2017; Creswell & Plano Clark, 2011) among these qualitative findings and the quantitative patterns that emerged from the analysis of the CARS item rho correlation coefficients. We also compared this study's data to the previous pilot to confirm reliability in our coding.

Findings

The results of the exploration of the benefits of culturally relevant VR offer competing results regarding students' learning and attitudes towards science. We examine the results of our qualitative questions about the relevancy of science content and the students quantitatively assessed attitudes towards science. Using a mixed-methods analytic procedure, we explored students' attitudes and applications of science and encountered statistically significant

differences in how students reported the perceived relevance of science content and its meaning in their lives. Additionally, students came to value the information differently in both the types of qualitative responses found between conditions and the quantitative strength of the relationships students' reported perceptions on items within the CARS instrument.

In sum, students in the treatment condition (n=129) demonstrated a tendency to engage more frequently in the sense-making process of perceiving the content being taught within the lessons to have socio-political value and community need through their application of the learned material in comparison to their control condition counterparts (n=115). In turn, the treatment condition participants adopted a more focused culturally relevant application of scientific practices advocated more broadly in science education as a path toward equitable and socially-just methods of teaching and learning in science (Brown, J., 2017), as well as connected the content to their lived realities, while the control condition focused more on abstract notions of scientific literacy as the important relevancy of science content learning.

Differential Value - Students' Attitudes and Applications of Science

Where we found our most compelling results was in uncovering a differential perception of the meaning of the science content in relation to its application. We found that students in the treatment condition viewed the usefulness of science differently than their control counterparts. This was consistent on both our qualitative and quantitative measures. Treatment condition students focused on the culturally relevant application of the science content to their local contexts (i.e., on how the application of scientific practices such as investigation and analysis were relevant to the local cultures that these students occupy), while control condition students focused on the utility of the science content in relation to abstract applications related to scientific literacy more broadly. The labeling of this control condition's focus as scientific

literacy was identified due to the similarity it held to how PISA articulates scientific literacy (PISA, 2015; www.pisa.tum.de/en/domains/scientific-literacy/).

While there was no statistically significant difference between post-intervention CARS instrument means between the treatment and control conditions, the qualitative findings reported by the students in response to our open-ended questionnaire items elicited difference in the types of qualitative answers students gave in relation to their perceived applications of science. Table 2 below summarizes these thematic qualitative findings.

--- Place Table 2 about here ---

Two themes with an additional two sub-codes per theme emerged from our constant comparative analysis that relate to theoretical frames of the purpose and application of science adopted more broadly: (1) Scientific Literacy (PISA, 2015; sub-codes: personal utility and problem-solving) and (2) Culturally Relevant Applications of Scientific Practices (Brown, J., 2017; sub-codes: community connections and environmental connections). Moreover, identifying the independent frequency counts of each theme and sub-codes showcased a preponderance of the treatment condition to respond within these themes and sub-codes at a greater frequency than their control condition counterparts. Below we parse out each theme in relation to their sub-codes and corroborate these qualitative findings with the statistically significant differences among the Spearman's rho correlation coefficients reported in the post-intervention CARS instrument that differ between treatment and condition.

Scientific Literacy

Within both conditions, students reported that science's importance, broadly speaking, could be categorized into two uses: (1) Personal Utility and (2) Problem-solving. For

the personal utility sub-code, students framed science as important because it will be useful for them personally, either now or in the future (e.g., *“I think science is important because it will help you in the future”*), with many responses specifically referencing science’s influence on their academic performance and their personal welfare in terms of their individual health. As shown in the following quotes, students perceived science content as pertinent to how they could be successful in their school studies, and career prospects, as well:

“I think it is important because it will help you and you could learn more in high school. It is very important;”

“I think science is important: 1. it helps you get a scholarship. 2 it helps you get a good job. 3 it helps you be aware;”

“science is important because if you want to become a scientist you need to know science;”

“I also think it is important because if i want to be a geologist I will have to know science;”

“I think that science is good because when you grow up you could do a lot of things.”

Students also saw science being relevant to their personal welfare and individual health concerns, which is showcased by the following quote by a participating young woman:

“I think it is important because when I am sick the knowledge of science will help me from spreading it. The last reason I think it is important is because all woman going through a thing called puberty and puberty is science, so to know what's happening to your body, you will have to know science.”

Indeed, the purpose of educating students to become more scientifically literate about the applications and implications of learning science in relation to academic success and personal welfare is a paramount goal for science education. To which, for our population, the treatment condition in our trials exhibited a more frequent response pattern, alluding to students adopting, integrating, and applying what they learned within the trials to broad applications of science in terms of importance with greater ease than their control condition counterparts. These goals are also seen in the second sub-code exhibited by participants in this theme: Problem-solving.

Within the problem-solving code, students reported that science was important because they could apply their knowledge of science to improve the world by using its inquisitive and deductive logic; for example, because “*science can help you make medicine for sick people.*” The following quotes exemplify this epistemological application of science:

“Science can be used for lots of different things, you can use science for making cures for sick people;”

“Science is important because it can help diseases, it get make artificial arms and legs, and finally it can be healthy for the whole wide world;”

“I think science can help because it can show us how to cure a disease, it shows us what we need to do more efficient tech.”

This application of science as a process of solving problems that plague the world illuminates that relevancy of science focused on investigation and analysis, which is further corroborated by the following quote from a poignant student exemplifying this point:

“I think that science is important. Reason 1: Science could help us solved problems in the world like finding ways to not have to use gas to power our cars. Reason 2: Science could help us solve help people in hospitals feel better from the sickness or a sort of cancer that that person has. Reason 3: If we didn't have science, we wouldn't be able to figure out everything about the world that we know today.”

This application again, for our population, favored the treatment condition exhibiting a more frequent response pattern, alluding to students adopting, integrating, and applying what they learned within the trials to broad applications of science in terms of importance with greater ease than their control condition counterparts. In turn, these results offer the opportunity to define VR as a tool to engage students with this type of application of science content in relation to scientific literacy - as a product that is earned by the person utilizing it for personal betterment and as a process to improve existing human struggles. These findings align with PISA’s articulation of scientific literacy, defined below:

“...scientific literacy is defined as the ability to understand the characteristics of science and the significance of science in our modern world, to apply scientific knowledge, identify issues, describe scientific phenomena, draw conclusions based on

evidence, and the willingness to reflect on and engage with scientific ideas and subjects.” (PISA, 2015; <https://www.pisa.tum.de/en/domains/scientific-literacy/>)

Finally, while students in the treatment condition reported these codes more frequently than condition participants, two Spearman’s rho correlation coefficient comparisons between post-intervention CARS items were statistically significant in favoring the control condition, specifically as it relates to this theme. Tables 3 and 4, below, showcase all of these CARS items’ descriptive statements, their correlational strengths via condition, and their effect sizes, while illuminating that this perceived application of science was stronger among control participants.

As Tables 3 and 4 below exhibit, control condition students post-intervention exhibited statistically greater strength in their perceived connection of the relevancy of science in relation to academic success. Upon reviewing the scatter plots for these rho values, the best-fit trend lines for all plots were linear and, therefore, we treated these rho values as indications of the strength of agreement between two discrete statements among the condition participants. This, in turn, we used as justification to claim that the strength of these relationships indicated the participants’ perceived connections of the statements representing where their focus on the relevancy of science was placed by the end of the intervention.

--- Place Tables 3 & 4 about here ---

Highlighting the importance of these rho values in terms of the control condition, Items 6 and 7, the largest rho difference among all rho comparisons, connects science content to actual school classwork and the judgment of ideas therein, the latter often being emphasized in science classrooms as an epistemological practice to construct scientific knowledge. In turn, students in the control condition exhibited a stronger tendency to see science as relevant to them because of its application in terms of ‘judging people’s’ ideas’ and this practice’s connection to

other disciplines, as well as science, in terms of academic success. In coordination with the qualitative findings provided above, this relationship compliments these self-reported findings in that it showcases a statistically significant difference between the conditions in terms of the purpose of science as being part of the schooling process wherein the evaluation of claims made by others is foregrounded as an important goal for understanding science as practice and product.

Similarly, items 10 and 16 exhibit a complimentary logic of evaluating evidence as being important to the prospect of wanting to take science in their future academic trajectories. Item 16, attending to 'reliable evidence' as important to 'making decisions' was more strongly related to students' urges to take science in high school. Through this connection, the students in the control condition exhibit a similar pattern found within the previous rho comparison in that they connect the epistemological practice of evaluating data collection practices - 'getting reliable evidence' - to their prospects of wanting to pursue science in their latter school years. This corroborates the qualitative findings presented in the previous pages in that students saw science as being relevant through the lens of its direct connection to their personal lives in terms of its utility for them to be successful in their academic trajectories. Moreover, while the treatment condition does not exhibit such a significant relationship between the items, this does not mean students in the treatment condition did not see relevancy for these epistemological bases of scientific knowledge construction.

Our qualitative findings support that students in the treatment group recognized the relevancy of science more frequently in their responses than their control counterparts. Rather than interpreting these quantitative findings as showcasing a lack of relevancy for scientific literacy, we argue that it merely exhibits a *shifting of focus* in terms of relevance in students' perceived attitudes toward the application of science. This difference in rho strength, then, exposed that within the treatment group students focused more on the culturally relevant

applications of scientific practices rather than on abstract scientific literacy. We elaborate on this in the next section, where the qualitative and quantitative findings exhibit this differential value of science among the students within the CRP-VR design.

Culturally Relevant Applications of Scientific Practices

Within both conditions, students reported that our trials were connected to their community into two distinct ways: (1) Environmental Connections and (2) Community Connections. For the environmental connections sub-code, students revealed their concern about how their community was a part of the environment and that this human-environmental connectivity emerged from experiencing CRP-based VR. For example, one student noted that “I think these lessons are connected to my community because it's connected to nature” but did not elaborate further; however, others noted more specific relevancy of the trials when talking about how they were directly connected to their local ecology: “we learned about water and animals in [our city].” Again, the preponderance of self-reports favored treatments participants overall.

Students also suggested that the trials related to their community because “the community that I live in is trying to keep it clean” and “there is a lot of pollution in [our city] like the rivers are all polluted,” designating the importance of the trials’ science content as being nested within the environmental issues that they view when they step outside of school. In turn, still other students pursued this line of thinking when applying how science may be able to ‘fix’ how people think about their impact when littering and pollution, and that the CRP-based VR trials made them recognize these connections: “I think that all of the lessons relate to where I live because where I live is right near the ocean and we can see what is happening to the water and if anything is thrown into it” and “there is a lot of people who litter and make nature less beautiful and I think science can fix that.” This example emerges among the many that framed the connections to the content as being important for community improvement.

Finally, this application of the practices of science (i.e., asking questions, making observations, and analyzing relevant evidence) was further illuminated when students connected the trials to issues in their community and solidified that their concerns about the environment were also indicative of their concerns about their own well-being. One student noted this in an exemplary quote about the concern for human illness and its connection to where you live and what is offered in that environment in relation to food sources: “It made me feel worried when I get sick because there is too much bad water and air, there is also too much unhealthy food where I live.” These connections to their community, as reported by our participants, highlight that the relevancy of our trials were such that they provided a ‘jump-off’ point from which the students could ask questions about what is happening in terms of the environmental impact of humans in their own locale. It provided them epistemic agency (Miller, Manz, Russ, Stroupe, & Berland, 2018) to investigate how it may be possible to ameliorate that impact and analyze solutions to these issues as being part of the science taught throughout our trials. These applications of scientific practices applied to the places where they live and the ecologies that sustain them were further illuminated in the second sub-code: Community Connections.

For this sub-code, students showcased a similar concern as the environmental connection sub-code; however, what differed in the students’ connections of their community was a focus on issues of ethics of care for their local community. In this code, students recognized our specific design elements wherein we sampled the local contexts to situate their learning experiences in the communities they live, exemplified by the following list of quotes:

“It’s near my community because I saw a video when it was near a Walmart and it was near my house;”

“when they show one video it showed where I lived when they were driving because I felt happy when I saw they were driving past where I lived;”

“it’s related to my community because they literally showed the video of a driver driving through a place close to our school;”

“it shows places around here;”

“it is close to where some of my family's live there and the what I thought about the lessons it was fun to do I like the vr videos;”

“I saw mostly the same things that I see in my community.”

Our attempts to activate students' prior experiences outside of school and bring local contexts into the purview of where science exists into the classroom were effective based on the self-reported perceptions of our participating students. Additionally, students offered another layer of connections between our trials and their communities.

Students that participated in our three trials also considered the impact of our trials in both abstract and pragmatic ways in relation to their connection to their communities. As an example of more abstract perceptions of this connection, one student noted: “I think that they [the trials] are related to where we live because science is all around the world because we need to learn and I feel so proud of myself because I learn every day.” Others noted more pragmatic connections in relation to how the science in our trials connected to their community. For example, students suggested that the CRP-based VR got them to think about an ethics of care for their community: “I think I felt good about the lesson because I can help people;” “people can help other people;” and “now I'm seeing more people help the community.”

Students also suggested that it inspired them to seek out more scientific views of their own community in terms of who is helping, what science has to do with this caring process. This took the form of generally articulated interests in the community and its care (e.g., “once it [the trials] told me about my community, [its] places and things I started to learn more about them”) and showcased an appreciation from the students that we took the time to infuse their communities into the process of learning science: “it made me feel great to take this classes it did

made me think of my community and all the things that are in my community so thank you very [much] for giving these lessons.”

Finally, after learning about science in terms of its application in relation to their community, they started to develop a socio-political consciousness about the lacking ethics of care from others and their community. Students expressed their frustration that, “It’s connected with my community because there’s a lot of trust and people pretty much don’t care about our community and that’s why people [in my community] have to take care of our community.” Indeed, two students eloquently pointed out the contextual nature of science and its use as being dependent on the study of science: “if you go to study science it’s going to be in a place and you will meet new people and work with different things so science is related to our community;” and “where I live the people are sick and messed up, so science can help them.” These qualitative findings showcase a similar pattern of higher frequencies from the treatment condition than their control counterparts and are also corroborated by our quantitative data.

When examining the Spearman’s rho strength comparisons that favor the treatment group (Tables 5 and 6, below), three comparisons align with the qualitative findings reported. For example, CARS Item 3 and Item 10, when compared in terms of the strength of their relationships, showcased the largest difference between treatment and control. The connection between these two items - ‘making better choices about what I buy’ and ‘taking more science in high school’ - fit within the structuring of the first trial in relation to the primary question for the science content presented therein: Would it be healthier to eat, snack food or fruit? This stronger rho value in the treatment group, we argue, is an indication of students in that condition finding a stronger relevancy of the argument presented to them because of the culturally relevant design elements purposefully embedded within that trial, and not afforded to the control condition. In other words, students in the treatment group, when considering how to make a good choice about

their purchases (food, in this instance, CARS Item 3), perceived that this was more relevant in that it was connected to their fluency with science content, and their interest to pursue it (i.e., taking more science courses in high school, CARS Item 10).

Items 4 and 20 - concerned with the ‘use of science to prevent illness’ and ways to ‘help my community using science’ - and items 10 and 20 - ‘taking more science in high school’ and ‘scientific choices as care for people’ - corroborate the above qualitative findings, as well. The stronger relationships found among the treatment condition between these items suggest the use of science as being specific to the community it may serve, specifically in relation to illness and diseases (Items 4 and 20). Moreover, the data suggest that when connected to students’ local communities (specifically the people students interact with), scientific choices that emphasize a care for that context are related to their fluency with science content (Items 10 and 20).

Through this perception of science as an applied set of understandings, students’ in the treatment group exhibited a significantly greater chance to respond in ways that perceive science content as a vehicle to help ‘cure’ human issues related to how illness is spread by thinking about the community context in which it is situated. The last two rho comparisons showcase a similar *shifting of focus* reported in the above theme ‘Scientific Literacy’ but, as they favor the treatment group, they expose that students in that condition perceived the relevancy of science as more strongly related to how science is connected to their personal communities, as well as the environments surrounding them.

--- Place Tables 5 & 6 about here ---

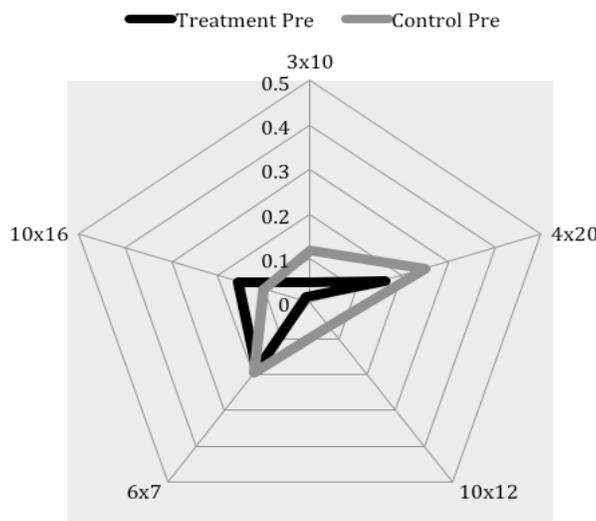
In sum, our mixed methods analysis of how students valued the science taught within our trials showcases a preponderance for treatment condition participants thinking more about

contextual and community-based applications of scientific practices, while the control condition focused on scientific literacy more broadly, specifically in abstract ways of applying the content disconnected from the students' local communities. This differential valuing of the science taught within our trials is further supported by the rho shifts present among the CARS items in relation to pre-intervention and post-intervention, specifically related to the rho correlations found to be statistically significant at the end of our intervention.

To represent this shift, we present two figures below: Figure 2 below shows the pre-intervention CARS item rho values among the CARS items compared in Tables 3, 4, 5, and 6 across the two conditions. Figure 2 below shows the post-intervention CARS items rho values compared in Table 3, 4, 5, and 5 across the two conditions, on the same scale (that scale being rho strength). Each point on these radar diagrams represents either a treatment or control rho value that aligns with the items being compared.

Figure 2. Radar diagram of pre-intervention rho values

For example, in Figure 2, the values labeled within the 3x10 component at 12 o'clock on the diagram represent the rho value for each condition pre-intervention in relation to Items 3



and 10 as a rho value. In Figure 3, we see these same values (3x10) change, as per representing

the shift in rho value provided numerically in Table Y. Finally, the following rho comparisons represent the two different preponderances described in the qualitative findings and further illuminated in the quantitative findings in relation to Culturally Relevant Applications of Scientific Practices and Scientific Literacy, respectively: CR Applications = 3x10, 4x20, 10x12 and Scientific Literacy = 6x7, 10x16.

As these radar diagrams show, before the intervention (Figure 2), both treatment and control exhibit similar strengths within the rho values for these CARS item comparisons; moreover, none of the differences between the pre-intervention rho values were significantly different. After the intervention (Figure 3), though, there is a visible *shifting of content relevancy* as to what CARS item comparisons were stronger - this difference supported statistically, as well, with all CARS items comparison in Figure 3 being significantly different.

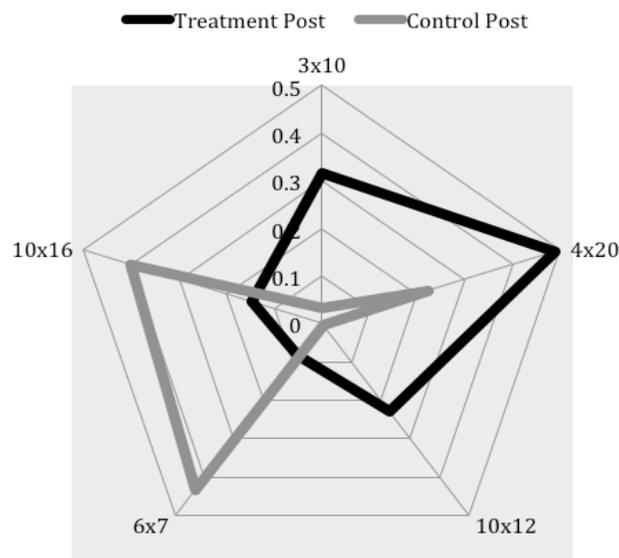


Figure 3. Radar diagram of post-intervention rho values

We argue that, in combination with the qualitative findings, these data sets represent the impact that the culturally relevant design elements had on students' attitudes and applications of the relevancy of science and illuminate the promise of designing for cultural relevancy in VR.

Discussion

To reiterate, the driving research question of this study focused on the ways in which design elements that leverage tenets of culturally relevant pedagogy may influence urban elementary students' learning when embedded within a virtual reality pedagogical platform. We further sought to illuminate, through a quasi-experimental, mixed-methods research design, whether the differential condition design elements significantly influenced these students' attitudes toward the relevancy of science, as well as exploring the myriad of ways that students in each condition perceived the application of the content presented within the lessons.

While a preliminary pre-/post-intervention statistical analysis of the CARS data showcased no difference between conditions, as we further pursued relationships that had been fostered through the designed conditions we found that each condition exhibited a specific development of relationships among some items post-intervention. In other words, while the conditions did not significantly differ in terms of the correlation matrix before our intervention, each condition began to develop differential correlation strengths among the items that were statistically different by the end of our study. In coordination with the qualitative data from our open-ended questionnaire, we saw that these differences in correlation strength, as well as their alignment between condition and items, also aligned with the students self-reports in terms of the ways in which students in each condition perceived the importance - or relevancy - of the science content taught within each of the conditions, as well as how these findings align with the previous pilot study's data that showcased similar qualitative self-reports via interviews.

In turn, it is also notable that students in both conditions felt that they had an *immersive* learning experience through our VR designs, echoing previous research in VR that supports this affordance being pertinent to any VR-based learning designs (Makransky, Wismer, & Mayer 2018; Markowitz, Laha, Perone, Pea, & Bailenson, 2018), even as our VR 360 design departs from the high-end nature of these studies' VR designs. Additionally, students reported an overall

positive experience learning through our VR intervention, which also aligns with the extant literature about important features that influence learning in VR (Ausburn & Ausburn, 2004; Minocha, Tudor, & Tilling, 2017). Finally, and in more alignment with the purpose of this research, students in our treatment group also exhibited a higher preponderance to take up applications of science content in relevant ways that could identify and solve issues in their local contexts, an affordance advocated in equity-based STEM research more broadly (Calabrese-Barton & Tan, 2018; Garibay, 2018; Kayumova, McGuire, & Cardello, 2019; Vakil, 2018; Vossoughi, Hooper, & Escudé, 2016), but, as we have shown in our background literature, is very minimally being taken up within VR research over the past couple decades.

We argue, then, as a function of the design elements embedded within our VR 360 intervention, diverse youth can be afforded a learning experience wherein their view of science as a relevant discipline to their lived realities outside of school can be fostered *by design* rather than happenstance. Additionally, we contend that when this type of pedagogical platform (VR 360) is used to contextualize content within students' local contexts, it is plausible that this design feature affords students a greater chance to adopt a socio-political application of that content. Anecdotally, we also wish to impart that teachers have noted students taking up this socio-political positioning of the science content within their day-to-day interactions at school, as noted by one teacher: "Since the lesson (Trial 1), my students, while in the cafeteria line, keep looking at the food in their trays and saying 'OMG, this would've been this temperature or that temperature' – students really connected with the idea, 'I really shouldn't eat this food!'"

Indeed, another participating teacher also noted how the design elements helped them relate to learning science: "Students saw themselves in the VR images within their communities. They saw their communities; It was them!" A third participating teacher also noted the importance of the contextualization that the VR intervention brought with it, specifically how it

provided a space for students to be subjects within the learning process rather than objects of it: “I feel that instead of students being bystanders in the science lesson, they were part of the science and the science surrounded them ... creating a new reality.” This ancillary ‘rippling’ effects, while not studied explicitly in this research, denotes the value and promise of VR 360 to assist in youth of color making sense of the content in their own ways of knowing and being, as well as adopting a socio-political lens toward the content that could lead to social action, which is at the very core of culturally relevant and culturally responsive teaching and learning.

Limitations and Future Work

While the results of this study illustrate the promise of culturally relevant VR design, the lessons explored in this study tested multiple culturally relevant design features simultaneously. Thus, it is still unclear which design features, in particular, may be necessary for the results outlined here - i.e., we can make no claims to causality of which design elements were of most important; be it the visual, auditory, or contextualization cues. This limitation was, indeed, expected, as this is the first study of its kind to study such a novel design within VR. Future studies may explore the impact of culturally relevant auditory features, local contexts, and visual cues separately in order to parse out which design features may have the most impact on student attitudes and applications of science content.

Additionally, this study only explores lessons designed using one community context. Due to this, it is possible that the results of this study may be specific to this particular community context and not generalizable to other contexts. We argue, however, this specific and purposeful decision to embrace a localized contextualization of the content afforded students in the experimental condition a perception of the content taught emphasized by the literature on cultural relevancy and VR literatures presented at the beginning of this manuscript; namely, students in the experimental group began to develop a nuanced application of the discipline-

based content knowledge. We attribute this differential valuing of how the content was applied as a function of the opportunity to embrace their own sense-making processes that were a function of being afforded the chance to apply said content to their local cultural contexts, while concurrently participating in a constructivist-like pedagogical structure that was designed specifically for students to be able to become agents of the learning process rather than objects.

Further studies should explore the impacts of culturally relevant VR design across various cultural contexts in order to determine whether similar effects would be measured in students content knowledge, attitudes about science, and applications of science content. This aligns with another limitation of the study in that while attitudes and applications of the science content in general were measured, there were no items to assess a student's ability to apply content knowledge to their individual context. For example, there were no questions asking students to solve content problems in context, such as those projects that Calabrese-Barton and Tan (2018) pursue. Similarly, while one question did ask students about their perception of the three lessons overall, there were no questions that explored how students' beliefs about individual topics in science were relevant to their lives, even as this emerged as a valuable finding that students impressed was one of the ways the VR intervention influenced their own understandings of the content and its application through a socio-political lens. This, however, adds credence to the importance of embedding dynamic visualizations within our VR 360 intervention, which has been noted elsewhere as a component that can induce a thought process wherein students make their own inferences about the importance of the science being taught in their own ways of making sense (McElhaney, Chang, Chiu, & Linn, 2015). This delves into the other component of learning (assessment) that should be pursued with future studies.

Conclusive Remarks and Implications

The results of this study suggest that designing virtual reality lessons with culturally relevant imagery and auditory cues can have a positive impact on diverse students' capabilities to embrace science as culturally meaningful. This affirms Aronson & Laughter's (2016) argument that when pedagogy and curriculum are designed through the lens of cultural relevancy, students can be afforded the opportunity to take-up a socio-political awareness of the content. Moreover, by leveraging the technological affordances of virtual reality to influence students' experiences and appreciation of learning no matter the content (as elaborated on within the Background Literature section), we argue that this study sheds light on how novel technology such as VR need not be part of the stoic and traditional agendas of learning as an acquisition of knowledge that is decontextualized from students' lived realities.

Aligning curriculum and pedagogy to pursue socially-just and culturally relevant ways of teaching and learning science continues to be a struggle for science teachers (Braaten & Sheth, 2016; Mensah, Brown, Titu, Rozowa, Sivaraj, & Heydari, 2018; Rodriguez, 2001). However, this struggle, in elementary science at least, has been shown to be ameliorated by research-practice partnerships where research design elements that contextualize science content in students' local cultural contexts and leverage students' cultural identities afford students the chance to embrace this type of learning, as well as the capacity to apply what they have learned in socio-political ways (Buxton, 2006; Djonko-Moore, Leonard, Holifield, Bailey, & Almughyirah, 2018; González-Espada, Llerandi-Román, Fortis-Santiago, Guerrero-Medina, Ortiz-Vega, Feliú-Mójer, & Colón-Ramos, 2015; Upadhyay, Maruyama, & Albrecht, 2017).

Thus, we argue, that while the pursuit of educating students to be successful at tradition notions of content acquisition may, in the short-term, lead to greater performance on standardized tests, these types of curricular and pedagogical designs may not fulfill the promise of designing for equity as a process that allows students to see themselves as life-long learners

related to the STEM fields, nor does it embrace the idea that cultural relevancy impacts motivation within such disciplines (Kumar, Zusho, & Bondie, 2018). To this end, we as education researchers must continue to push back against the hegemony of traditional goals for academic success that has denied diverse students equitable access to STEM disciplinary learning that is both for the purpose of developing interest in these fields but, more importantly, for the purpose of educating a critical citizenry that can see the 'word and the world' in ways that can aid in their capabilities to create a more equitable world in which to live, as well as transform their Selves and the communities in which they are situated. Without such a radical goal taken up explicitly in the design and research among educational technologists, we risk neglecting crucial affordances of technology, specifically those that places context as a pivotal element in the learning process and that emphasizes process over product.

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