Not Just a Tool: How Pre-Service Teachers Leverage Digital Tools Create Culturally Meaningful Classroom Talk

by

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Abstract

Smartphone hosted virtual reality has the potential to support teachers' modern approaches to science teaching. Teachers pedagogical content knowledge (PCK) not only effects lesson design but can impact how students experience science lessons. This qualitative study of student-created virtual reality field trips (VFTs) explores how the teacher's pedagogical decision impacted students' use of the virtual learning tools. Through a content analysis of n=45 student VR videos, we identified how the teacher's decision to use *small group*, *whole group*, or *individual* designed VR videos changed their approach to science content, VR design, and media use. The results of the study highlight how science teachers' PCK and lesson design impact how EdTech can be used for effective science teaching.

Keywords: Virtual Reality, Pedagogy, Techology, Biology

The challenge of distance education during the pandemic propelled the demand for educational technology in science teaching. Teachers swiftly transitioned to distance learning and utilized existing technology to offer students simulated hands-on experiences (Rochman & Ramdhini Pertiwi, 2020; Stevens & Haines, 2020; Torchia, 2022 C.E.). Digital tools emerged to demonstrate phenomena, simulate labs, and share data (Torchia, 2021). While these tools supported Physics and Chemistry instruction, they did not fully align with the New Generation Science Standards (NGSS) approach (Antonietti et al., 2022; Code et al., 2020).

Years preceding the pandemic, NGSS redefined science education goals, emphasizing understanding dynamic concepts, disciplinary principles, scientific practices, and key scientists' methods (Harris et al., 2017). This shift mandated science teachers to impart skills such as asking questions, constructing explanations, and evaluating evidence (Kang et al., 2018; Moore et al., 2015). However, the available educational technology did not adequately support these NGSS principles.

To bridge this gap, a critical examination of how science educational technology aligns with NGSS teaching is essential. Smartphones equipped with augmented and virtual reality capabilities offer powerful tools for science education (Ercan et al., 2016; Zufall et al., 2020). Leveraging such technology requires ensuring it aligns with NGSS principles, or else we risk developing niche tools incongruent with contemporary science teaching goals.

Virtual field trips utilizing VR technology are an intriguing tool worth exploring further. These trips enable immersive experiences, allowing students to visit distant sites, access data, and interact with experts, aligning with NGSS teaching methods. However, integrating these trips effectively into the curriculum is paramount. The 'Backward Design' approach emphasizes

effectiveness over mere engagement, a crucial consideration in utilizing VR effectively for science education (Wiggins & Mictigthe, 1998).

Empirical research on VR's role in science classrooms has recently flourished, highlighting its positive impact on student engagement and learning outcomes (Bogusevschi et al., 2020; Rojas-Sánchez et al., 2022). VR's strengths lie in providing interactive 3D environments and diverse educational experiences, fostering students' engagement and modeling abilities relevant to NGSS instruction (Liu et al., 2020).

Studies on learning outcomes from VR experiences yield mixed results. While VR enhances engagement, its effectiveness in improving learning varies, influenced by factors like embodiment, task alignment, and assessment tools (Madden et al., 2020; Makransky & Lilleholt, 2018; Parong & Mayer, 2018). The need for alignment between VR tasks and science learning assessments is crucial for understanding its true impact on learning outcomes. While evidence suggests VR positively impacts student engagement and interest in science (Chang et al., 2020; Kersting, 2021), integrating VR effectively into teaching practices remains a challenge (Abulrub et al., 2011; Alalwan et al., 2020). Teachers' understanding and utilization of VR tools, alongside their alignment with existing curricula, are critical factors for successful integration into science teaching methods (Liu et al., 2020).

In conclusion, aligning educational technology, particularly VR, with NGSS principles is a critical next step for modern science teaching. Despite VR's potential to enhance engagement and modeling skills, its effective integration into science pedagogy requires closer examination, ensuring it supports the learning goals of contemporary science education.

Theoretical Framework

Research on STEM teachers' use of educational technology (Ed Tech) has identified a number of key factors that impact EdTech integration (DeCoito & Richardson, 2018; Flick & Bell, 2000; Lazar et al., 2020). Emerging scholarship highlights how teachers are using technology to support learning, but limit their EdTech integration due to pedagogical discontinuities (Boda & Brown 2020; Brown, et al., 2019; DeCoito & Richardson, 2018). Said differently, while the technological tools are engaging, they do not always align with teachers' pedagogical goals. Teachers are challenged to weigh two goals; should they use Edtech to be engaging at the risk of being effective. As a result scholars like DeCoito & Richardson, (2018) and Antonietti et al., (2022) offered the field vivid theoretical models to help explain why some educational technologies are integrated into science teaching and learning, while others are not.

To improve our collective understanding of the impact of EdTech, we must center how teachers play a vital role in the effective design and implementation of STEM EdTech adoption in schools. This project examined how science teachers' pedagogical decision making and instruction deisgn impacted how virtual reality learning tools were used in science teaching.

Research on teachers' integration of STEM Ed Tech center on two domains. First, a series of studies focused on teachers' expertise and perceptions of the values of the software. Lazar et al., (2020) studied 296 teachers' application of digital tools. They found that the teacher's adoption of these tools was linked to the teacher's perception of how useful the tool was. Others, like Tondeur et al. (2019), suggested that STEM Edtech was ineffective because teacher educators were the limiting factors. Through a survey of 284 teachers in Belgium, their research revealed that the implementation of technology was limited by teachers' expertise. They centered their argument on the limited influence of teacher educators by suggesting that while technology can be useful, it is only as useful as the teacher's comfort level in applying those

technologies. One domain of research suggested that educational technology was only as useful as the teacher's expertise and comfort with the tool.

A second, a series of studies focused on how teachers were challenged to integrate new STEM Ed Tech into their pedagogical practices(Antonetti et al., 2022; Code et al., 2020; Lazar et al., 2020). This group of studies extended beyond teacher knowledge and instead focused on how the technology did not fit with teacher's instructional goals (DeCoito & Richardson, 2018). In exploring this tension (Antonetti et al., 2022) offered an amended *The Technology Acceptance Model.* First framed by Davis et al., (1989). *The User Acceptance* model explored how people's willingness to use new technology or hesitance to use the technology is linked to their vision of ability to solve meaningful problems. Antonetti explained:

> According to the Technology Acceptance model (Davis, 1989). Teachers' beliefs regarding the ease of use and usefulness of technology, and their own attitudes toward technology are the most critical factors influencing their acceptance of technology and their consequent intention to use it (Antonetti et al, 2022, p.132).

Antonetti's (2022) focus on teachers' assessing their ease of use and the capacity to integrate the technology in their pedagogical goals offers a central theoretical relationship between *teacher goals* and *well-designed EdTech*. A series of students by Antonetti et a. (2000, 2022) explored how the teacher's belief in the values of the software impacted on the usefulness of the technology. This included both how teachers perceived the effectiveness of the tool, but also their perception of how the tool supported pedagogy. Continuing this line of scholarship Fahrman et al.,(2020) studied how technology teachers worked to match their pedagogical needs with the technological tools. DeCoito & Richardson (2018) offered the field a theory to explain the challenges of this integration. They used the technology, pedagogy, and content knowledge (TPACK) theory to examine how the curriculum needs to pair both the goals of the teacher with the affordances of the technology (DeCoito & Richardson, 2018). When science teachers want to

use technology to improve their teaching, who do they turn to? What in-person or online resources help them pair the best pedagogical practices with the best learning tools. This project adopts DeCoito & Richardson's (2018) *Technological Content Knowledge Theory* to examine how teacher pedagogical decisions impacted how virtual reality learning tools were used to frame learning opportunities for science students.

While the technological tools that shape school experiences matter, we must consider how teachers skillfully use EDtech to create engaging learning experiences. This integration between understanding technology and using Edtech to craft learning opportunities stands as the heart of Technological Content Knowledge Theory. (Chai et al., 2013)Chai adds depth the additional knowledge back characteristics of TPACK by explaining:

> TPACK refers to the synthesized form of knowledge for the purpose of integrating ICT/educational technology into classroom teaching and learning. The core constituents of TPACK are content knowledge (CK), pedagogical knowledge (PK), and the technological knowledge (TK). The interaction of these three basic forms of knowledge gives rise to pedagogical content knowledge (PCK), technological content knowledge (TCK), technological content knowledge (TPK) and the TPACK (Chai et al, 2013, p. 32)

As Chai et al (2013) explained, teachers are integrating technological learning tools into their broader pedagogical practices. As such, their wisdom, and insights about how to best use technology should be carefully considered in assessing the impact of the technological tool itself. This project adopts the DeCoito & Richardson (2018) on TPACK to explore how teacher's decisions about how to use virtual reality as a learning tool shaped the outcomes for the students.

Research Questions

To explore how teachers used virtual reality in their introductory high school Biology courses, this project examined two research questions:

(1) How do students in each teacher's classroom use virtual field trips (VFTs) as summative assessment tasks?

(2) How does the teacher's pedagogical approach to using VFTs shape students' use of the learning tools?

Methods

This project was a qualitative analysis of students' self-created virtual field trips. The project used content analysis as its primary means of data exploration (Hsieh & Shannon, 2005; Weber, 1990). Content analysis is a method used by sociologists and linguists that examines the patterns of word usage or images used to infer patterns of meaning. As a technique, the process of content analysis assumes the intentionality of the writer or designer of the text and assesses what patterns of interpretive meaning emerges from the products they created (Silverman, 2015; Weber, 1990). As this practice is applied to video analysis, it enables the research team to explore how the videos were created, what images and sounds were used for the video, and what patterns of creation can be identified through a detailed analysis of the types of content being made (Silverman, 2015; Weber, 1990). Working with a group of three 9th grade Biology teachers across the US, this project analyzed the culminating video projects for the students in their class. The result was a collection of 45 student-created virtual reality field trips.

Virtual Field Trips

What is a virtual field trip? A virtual field trip is an application of VR 360 software that takes students on guided tours of environments that allow them to examine local science phenomena. As a typical field trip might allow students to travel to a creek to collect samples, and measurements of the acidity level of that creek, a virtual field trip offers a near approximation. Instead of traveling to a site, students can use their smartphone and cardboard VR goggles to see the site and click through different locations. A newer feature in virtual field trips allows them to use a stop-focus click button. If students stop moving in the VR environment, they can control a white button on their screen which works as a mouse. When they stop on an icon, they can open a new window and see data that they can use to analyze what is happening at the site. For example, table 1 shows screenshots of a virtual field trip to Puerto Rico. In this field trip, students can visit sites that were damaged during Hurricane Maria. In this way, this virtual approximation allows students to visit a site and see different science phenomena. In table 1, students can see how the hurricane damaged the roadways due to both wind damage and floodings. Additionally, they can see how the flooding impacted local homes by using the stop focus feature to open an icon link *(see table 1).* The buttons located in those images enabled students to see data screens that will help students make sense of the local phenomenon. Table 1 shows how the pop-up screens allowed students to analyze data regarding both rainfall levels and mudslides. In this way, these virtual field trips offer students low-cost options to view the environment and explore the scientific data that is associated with those environments.

Table 1 Here

Lesson design

To promote greater uniformity of instruction, the research team worked in collaboration with a set of 10 teachers throughout the United States on a larger study of virtual field trips. All 10 of those teachers participated in a set of qualitative interviews and feedback about the lesson design. This project is a reflection of a subset of teachers who participated in the student created virtual reality field trips project *(N=3 Teachers;*

45 VR Videos). The students participated in a lesson on climate change where they experienced two virtual field trips. First, to support the teaching of biodiversity, the students used their smart phones and VR 360 cardboard boxes, to view a virtual visit to Tanzania. This visit to Tanzania's Ngorongoro crater examined how the nation of Tanzania used local policy to promote a healthy biodiversity in their crater region. During the lesson, students use the goggles to take a Safari throughout the Ngorongoro crater. While there, students were prompted to analyze the animal behavior, and to reflect on the biodiversity of the environment. Second, during the same lesson students were taken on a virtual field trip to Puerto Rico. During this visit, students were able to view Puerto Rico prior to hurricane Maria and afterward. This virtual tour allowed them to see the damage from the hurricane, analyze associated data and then consider how to engage in sustainable environmental restoration. During this virtual field trip, students analyzed the local damage and were asked to view data, make claims, and assess best practices for restoration. They were later asked to evaluate how they might help rebuild Puerto Rico in a way that supported sustainability. Thus, virtual field trips offered students a lens on science phenomena *(Biodiversity & Environmental Restoration)* that was rooted in seeing the effects of the science on different contexts and assessing relevant data.

While each teacher was working from different locations (Missouri, Colorado, & Michigan), they all used common instructional materials. Working as consultants for the project, the teachers helped the research team, improve the quality of those materials, and used a sequence of 3–90-minute lessons to teach the overall lesson on climate change.

The research team conducted an initial design of the lesson planning materials. This included drafting a lesson plan, designing handouts, creating virtual field trips, and designing an instructional PowerPoint. The teaching team reviewed the materials and offered feedback on improving the materials. After three rounds of revision the team arrived at an agreed upon set of instructional materials. To ensure the teachers comfort level with the instructional materials, and to ensure there was uniformity in the application of those materials the research team met with the teachers via Zoom, over the course of four months to plan the design and implementation of the lessons. **VR As a Summative Assessment**

One unique feature of this lesson was the summative assessment task. As students learned about climate change, biodiversity, and environmental restoration they were asked to consider how these concepts applied to their local environments. As a result, the summative assessment for the lesson was to have students create their own virtual field trips to tell the story of climate change, biodiversity, restoration, or environmental pollution in their own environment. Although each of our teachers used the same summative task, pedagogically they approached it differently. One teacher asked each individual student to create their own virtual field trip. A second teacher assigned students to small groups and asked students to work collaboratively on the virtual field

trips. A third teacher assigned each student the job of contributing to a class wide analysis of the local biodiversity. This study focuses on the impact of the teachers' technological pedagogical content knowledge on the students use a virtual field trip. **Research sites**

The data presented here comes from three unique learning sites. As indicated in table 2, the teachers had a wealth of experience in teaching in different contexts. One teacher taught in an urban public school with a diversity of students, both in racial and linguistic backgrounds. Another teacher taught in the suburban school with little racial diversity, while the third teacher taught in an urban continuation school with both linguistic and racial diversity. Collectively, they represented a dynamic set of instructional experiences and backgrounds. Originally, we started with 49 virtual field trips, but due to technical issues like loss of sound, and erroneous VR formatting issues it made some videos unviewable and shareable. As a result, we ended with a total of 45 student created VR videos *(see table 2).*

Table 2 Here

Data collection

To collect data from these sites, the research team created shared accounts using the Thinglink™ technology. We provided our participating teachers with accounts to use for uploading and sharing their digital creations. As soon as they created their virtual field trips, they were uploaded to our shared account. A member of our research team, then video recorded screenshots of themselves taking the virtual field trips so we could have a non-streaming MP4 version of the field trips for analysis. We saved and labeled

those video versions of the field trips to use for analysis. To coordinate with our teachers, each teacher had a seven-day window to complete their instruction and uploading of their virtual field trips. The lead author served us technical support for each of these classrooms, supporting their creation and uploading of their virtual field trips. This process resulted in the creation of 45 local virtual field trips, documenting students from the states of Colorado, Michigan, and Missouri.

Data analysis

To code and analyze these VR 360 virtual field trips, we used a hybrid approach that blended deductive and inductive coding processes, derived from Silverman, (2015) and Glaser & Strauss, (2009). To do this, we entered our coding process with two intellectual priorities. First, we were curious about how students used the virtual field trip tools and what science content they were exploring. We used this focus to support our prescriptive approach to analyze the data as we were attuned to how students used the virtual tools and what science concepts they chose to focus on. Second, we also applied a contrary inductive lens. We also identified emerging themes as they became significant. As a result, our initial analysis enabled us to document three macro level codes that were drawn both by theory, and by their emerging presence.

Our coding process involved an iterative analysis of the patterns VFT making that revealed three macro categories: a) students' approach to designing virtual field trips; (b) a focus on science content, and (c) an exploration on the types of media, and VR tools they used. We watched each video looking for emerging patterns of how students created their virtual field trips with the focus on what *science* the students focused on, what

media they used to represent that phenomenon, and what aspects the VR *tools* of virtual reality did they use for their summative assessment project. This process enabled us to complete an initial coding process *(science, media, tools)*. To ensure reliability of our assessment, we engaged in a multi-tiered analysis process. Each virtual field trip was coded by two coders, who viewed and documented coding practices. This led to the initial identification of an emerging pattern of content creation. The findings section below outline the emergent patterns and themes that were recognized throughout our primary and secondary analysis.

Findings

Students created virtual field trips VR videos as part of their summative assessment on a lesson about two aspects of climate change: Reforestation and Biodiversity. The analysis of how they used VFTs to show the science of their community revealed that students used the VFT to represent five aspects of the science they learned: (1) Biodiversity, (2) Deforestation, (3) Environmental Restoration, (4) Air Pollution, and (5) Water Pollution. We discovered that as the students used VFTs to represent the concepts in their local environment, they used 6 media types: (1) Downloaded 2D photos, (2) Text Boxes (3) Videos (4) Links to websites (5) Local Photos (6) VR 360° Videos. Our third category of our initial content analysis explored how students used the ThinkLink™ technology for their VFTs. We identified 4 approaches that included: (1) 2D Photos with pop up links to other media, (2) Links to 2D videos, (3) Text box labels of phenomenon, and (4) Embedded VR 360° Videos. Collectively these tools provided evidence of how virtual field trips served as learning tools to help students leverage technology to make the science that is happening in their communities visible to themselves in others.

The data analysis that follows explores two categories of results. First, we will review the content analysis of how students used VR tools for sense-making. Second, we will explore how the teachers' use of pedagogy, individual vs. small group vs. whole class assignments impacted how students created virtual field trips.

Students Creation of Virtual Tools

An intriguing outcome of our content analysis was the various ways in which students portrayed the science of biodiversity and climate change within their respective communities. Table 3 offers an overview of how students identified these concepts in their local context. Cell 1-A in Table 3 reveals that several students applied their knowledge of climate change to explore local biodiversity. For instance, in the visual representation from Table 3 (cell 1A), students investigated how a particular local tree provided a healthy habitat for the "Northern Flicker," a bird species. This approach was adopted by multiple students, examining how different local species thrived together in their habitats. Some focused on the impact of deforestation (Row 2), highlighting the transformation of once-forested areas in their communities due to construction projects. Others utilized virtual field trips to showcase environmental pollution, such as a group exploring their school's recycling deficiencies in a dumpster via a VR camera (see cell 3-C). Additionally, students documented instances of air and water pollution in their local settings (cells 4-C and 5-C, respectively, referring to air pollution in the local skyline and inequitable access to clean water in Michigan). By demonstrating how their learning about reforestation and biodiversity in case studies from Tanzania and Puerto Rico connected with their local communities, students showcased diverse applications of scientific principles.

In exploring how they used the different media used for their virtual field trips, a secondary analysis focused on the varied tools employed by students. These included smartphones, laptops, GoPro cameras, and VR 360° cameras. Table 4 illustrates six media sources utilized by students. Many opted for 2D photos, known as Photospheres, easily captured using smartphones, allowing them to encapsulate the local environment in a single VR 360 photo. Textboxes were another popular medium, with students using standalone or overlaid text boxes (depicted in cell 2-C of Table 4) to explain local phenomena. Some students utilized 2D videos to elucidate scientific concepts, while others incorporated websites (cell 4-C) or embedded local photos into their virtual field trips (cell 5-C). Furthermore, some students recorded 360° VR videos showcasing their local environment, emphasizing the versatility of media usage to construct engaging virtual field trips.

The integration of technology posed challenges for students in creating their virtual field trips, particularly in using the ThinkLink™ platform. Our analysis of this technological domain, presented in Table 5, identified four common approaches employed by students. These included the use of pop-up boxes linking to additional information (cell 1-C), videos as authoritative scientific sources (cell 2-C), text boxes for documenting environmental occurrences (cell 3-C), and the creation of VR 360° videos (cell 4-C). Students leveraged these approaches to highlight reforestation and biodiversity within their local contexts, marking significant locations and phenomena.

In considering the pedagogical impact of teachers on VFT creation, our investigation, outlined in Table 6, delineates how different teachers integrated VFTs into their instructional plans. One teacher tasked individual students with creating their VFTs, fostering diverse representations of local scientific phenomena. For example, Mrs. Donovan's students showcased various topics including Biodiversity, Deforestation, and Environmental Pollution through a mix of self-captured and downloaded local photos (as indicated in Figure 2). On the other hand, Mrs.

Bradley organized her class into small groups, focusing on specific aspects of climate change, and provided a structured heuristic to guide their VFT creation. This approach led to more uniform analyses across groups, as evidenced by Table 7, which displays how different groups addressed microplastics in distinct local environments.

In summary, the diverse applications of scientific concepts by students in their local contexts, the utilization of various media sources for VFT creation, and the impact of different pedagogical approaches highlight the multifaceted nature of integrating technology for learning purposes. Each method of VFT creation offered unique advantages, shaping students' depth of knowledge and technological use within their learning experiences.

Instert Table 7 Here

Where we noticed the biggest difference in the outcomes of the VFT was in how the small groups used the technology comparted to the individuals. In some ways, the small groups were more ambitious with their use of technology as they used more complex technological tools. 6 of the 8 groups successfully recorded and designed VR 360 field trips that documented their local environment. Students applied their creativity to their heuristic responses. For example, one group interviewed a local leader in waste management to ask questions about what was being done locally to address pollution and climate change (see table 4, 1-c). As outlined in Table 6, despite the approach most students used pop-up text boxes to explain what was occurring locally. This is a subtle, but important feature as students relied on their own expertise to explain what was happening locally as opposed to liking to external authority. Ultimately, the small group design promoted uniformity of approach and allowed students to work together to define key ideas by leveraging their newly gained expertise.

Greenberg: Whole Group with Individual Contribution

The final pedagogical approach involved a whole group design. Mr. Greenberg asked all his students to contribute to single virtual field trip on biodiversity. The students created a VR360 photosphere of the outside of their school and analyzed the biodiversity of the school. The result of this approach was a voluminous exploration of the environmental health of their local environment. To ensure students did not create duplicate pop-ups, Mr. Greenberg required each student to make a unique contribution to the classes virtual field trip. As a result, the students produced a virtual field trip with 72 embedded pop-up boxes, videos, and interviews. This approach both constrained the topics that students were able to explore and promoted creativity and exploration. One of the obvious benefits of this approach was that designing a whole-class virtual field trip produced a singular narrative. The powerful question of what is impacting our local biodiversity helped channel students' focus towards examining what was happening locally. Students narrowly discussed biodiversity. However, because everyone needed to contribute in their unique ways students analyzed several aspects of their local biodiversity.

This pedagogical structure produced layered explanations as students identified the local phenomena and explained why and how those species impacted the community at large. For example, in figure 3 below, students initiated their virtual field trip by capturing the external biodiversity of the school site using a searchable photosphere. Each of the pop-up buttons in the photosphere offered an analysis of a specific contributor to the biodiversity. While the pop-up images in figure 3 are icons of hamburgers, they take the viewer to images and analysis of the local food sources for the birds that reside at the school site. The task of identifying the local

biodiversity phenomenon and assigning students to offer their unique analysis produced a diverse and dynamic set of subsequent analyses.

One of the more intriguing analyses involved students use of contrasting local and distant examples. As a part of analyzing the biodiversity of the school students conducted an analysis of the local Goldfinch birds that lived in front of the school. The students used two pop-ups for the analysis. The first pop-up showed where the gold finch lived at the school site. The students did something intriguing. They made the claim that the Gold Finch was a non-native species and would not thrive at the school site due to several environmental features. They offered a third pop-up in their VFT. They took the viewer to another more distant site where they would expect the Goldfinch to thrive. They recorded a VR 360 video and showed where those Goldfinches were thriving and where the bird outside of their classroom was likely coming from. Figure 4 offers a snapshot of this embedded 360 VFT. This visit to this local environment included a virtual fieldtrip to the site, where the 3 pop-up showed VR 360° video of trees filled with Goldfinches and YouTube videos explaining the ideal environment for the bird species. In this way, students offered an intriguing contrast. They mapped out how the Goldfinch was operating in the local environment and showed a secondary idealized habitat for the bird that was just minutes from the school site.

This contrastive approach showed up in other times in the whole group virtual fieldtrip. In a similar example, one student used a pop-up link to identify a Cherry Blossom tree in front of the school. Using a similar approach to the students above, they elected to offer two analyses. First, they identified how the Cherry Blossom trees were non-native species. They used a link to an external website to explain the native document the environment of the Cherry Blossom tree and questioned what impact the tree might have in altering the biodiversity of their school.

Second, they created a link to an embedded virtual field trip (VR 360) to a local neighborhood that was lined with Cherry Blossom trees. This intriguing secondary analysis was used to make a claim that the Cherry Blossom trees were not ideal in supporting local bird life and thus had a negative impact on the overall biodiversity of the school environment. Ultimately, students were both skillful and creative in using the digital tools to show how the content (biodiversity) was prevalent in their local environment and used the virtual tools to design contrastive analysis of how particular plant and animal species coexisted.

Although the teachers taught from the same original lesson plan and used identical technological resources, the results of this study highlight the power of teacher's technological pedagogical content knowledge (Chai et al., 2013; Koehler & Mishra, 2009). While the technology offers learning opportunities, how the technology is used can also have a profound impact on students' learning experience. The exploration of how students created their own VFTs revealed that virtual reality has benefits as an effective summative assessment tool. Creating a digital space for student to show how science impacts their local environment can become an important learning tool. What emerged as intriguing in our analysis is the extent to which the teacher's pedagogical decisions shape outcomes. Whether the teacher used individual, small group, or whole group tasks each of these approaches offered students powerful opportunities to explain key ideas and to analyze the local implications of reforestation and biodiversity.

Discussion

What can science educators learn from the relationship between science teaching, technology, and transfer? Geng & Law (2019) documented how blended learning shows positive impact on students learning. Arici et al. (2019) reviewed several studies on digital learning tools

and noted the mostly positive results on attitudes and mixed results on learning. These studies share a common focus on students' benefitting from educational technology as ***users*** of the technology. This project inverted that process. Students used technology to create their VR 360 videos of science phenomena. The outcomes of student created VR videos implicate the power in student creation in three ways: (1) First,VR served a site for cognitive transfer, (2) second, it served as a means to use technology to support NGSS teaching (argumentation) , and (3) it revealed how teachers pedagogical decision making and instructional wisdom shaped how students used digital tools in their science classroom.

Tech as a mechanism for local transfer…. I can "see it"

Pea, (1987) challenged science educators to support student learning by focusing on Transfer. As students applied what they learned to similar *(near transfer)* or less similar *(far transfer)* contexts research noted how students' improved their learning (Barnett & Ceci, 2002; Bransford et al., 1999; Sala & Gobet, 2017). These powerful insights were directives about learning, not necessarily about teaching. How were teachers to create transfer tasks that promote students' application of their scientific understanding to new areas? This question continues to be a difficult query to explore, however the student created virtual reality offered an intriguing new step forward. Allowing students to use digital learning tools to transfer what they learned to their local context emerged as a powerful, yet diverse tool to support meaningful transfer tasks. **NGSS**

instruction and digital tools

One of the insights that emerged from the NGSS standards is a movement from setting an expectation that challenges students to explains science concepts towards a benchmark that challenges students to argue from evidence. In following the wisdom of our participating teachers, we asked students to use the virtual reality to apply what they learned (or transfer) to

their home environments and include data on local biodiversity. The power embedded in the digital tool allowed the students to document local biodiversity, analyze effective versus ineffective sustainability practices, and to argue how the principles learned in their biology course occurred outside of their classroom doors.

A simple shift from allowing students to be *users* of virtual tools to allowing them to be *creators* of their own virtual environments was enlightening. While many high school educators might fear the learning curve needed to learn to design and created virtual reality, learning to use new technology is among students' greatest strengths. The technology allowed students to "see" the science happening in their community, but the teachers' instructional decisions shaped how students would use those tools in powerful ways.

Ethics Statement

Ethics Statement. This project went through a detailed review process to attain human subjects' approval via Stanford University's Human Subjects board (Approval #IRB-65525). After the review, the project received approval. This ethical approval required us to document how we kept all identifiable information of the students and the schools private. This project included video analysis of classroom products. To achieve access to participation we administered and received consent forms from all students and consent forms from all parents. All files are kept on a password protected external drive maintained by the PI. The project maintains the safety of all participants and was conducted in a way to create minimal disruption to the students and schools while maintaining their anonymity.

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Figure 1. Sample of students VR 360 local image with

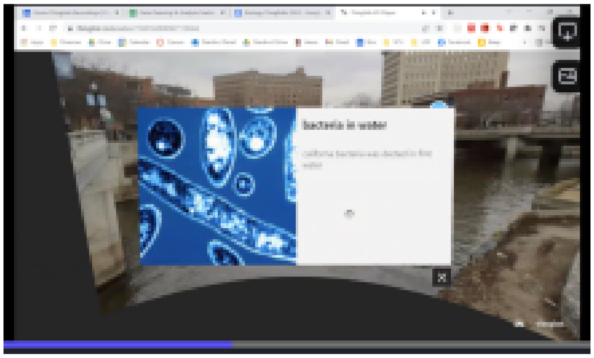
media 

Figure 2. Students use of 3 party images with local content

Figure 3. *Example of whole group VR 360 VFT*

Figure 4. Sample of students linking to the idealized habitat

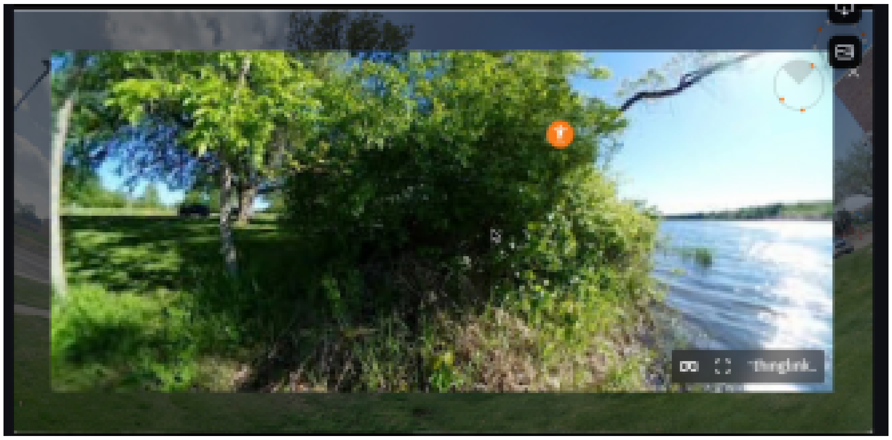


Figure 5. Sample of the invasive species analysis cherry blossom trees

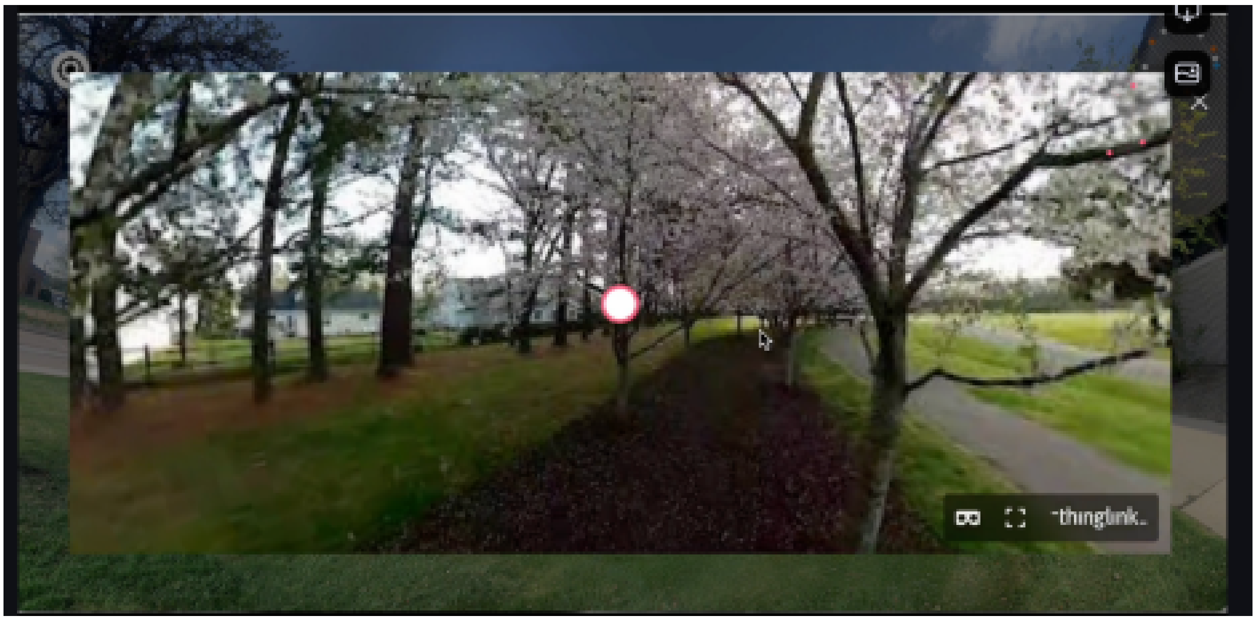
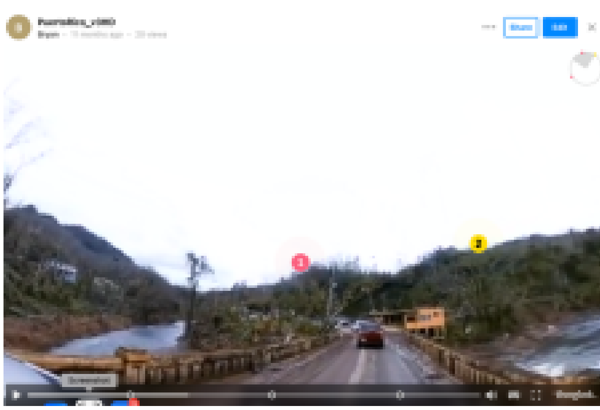
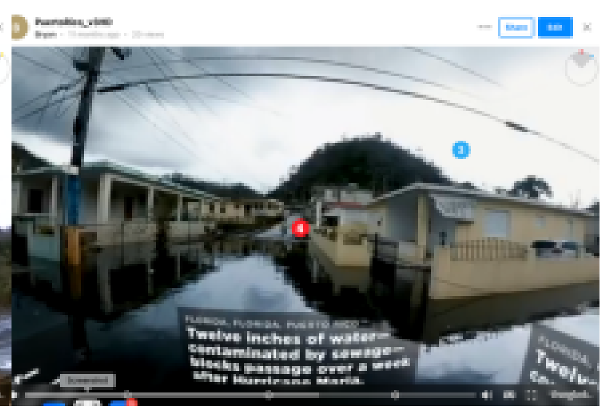


Table 1. *Sample of VR 360 screens*

	Virtual visit to Puerto Rico	
Site Ima		

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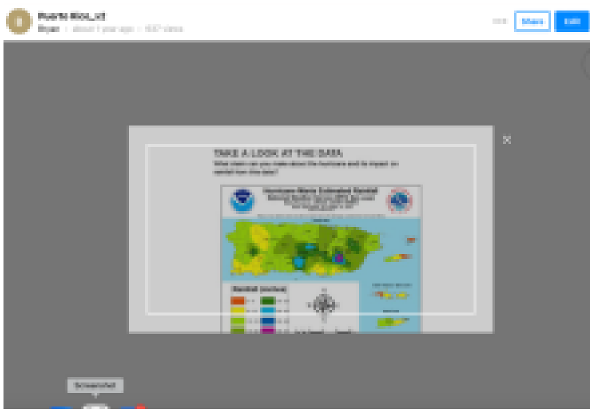

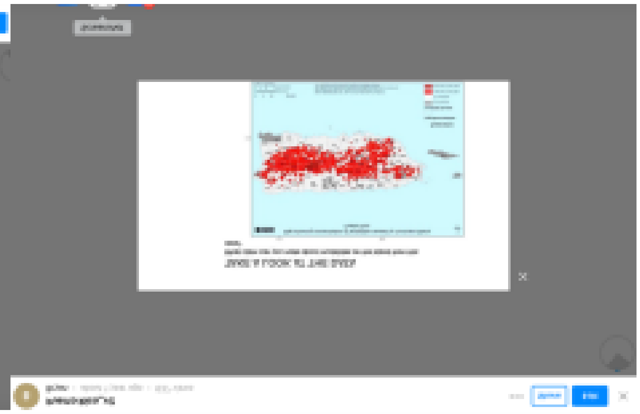

Site visit #1: road damage Site visit #2: flooding **D**
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Data excerpt #1: rainfall data Data Excerpt #2: mudslide data

Table 2. *Data sample and by teacher*

Total # of Uses by Instruc5onal Approach

Teacher Name **Donovan Bradley Greenberg**

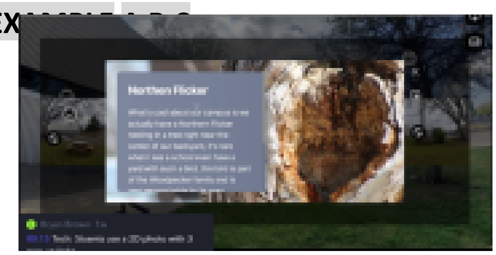
Biology *7 years experience*
Biology
12 years experience
24 years experience Ph.D. Students
Biology

School Context Urban Public School Suburban Public School Urban Con0nua0on School

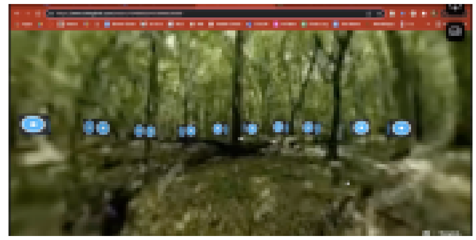
Pedagogical Style Individual Small Group Whole Group **Total VR Videos** 45 32 12 1

Table 3. Overview of students' scien1fic representa1ons

CODE CODE DESCRIPTION EX



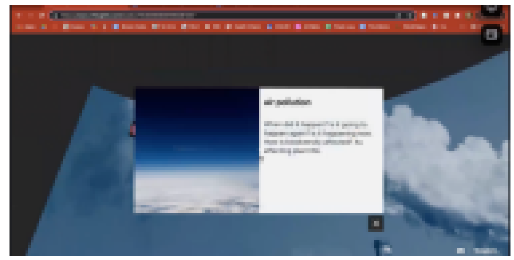
1 **Biodiversity** Students used videos to explain how local issues of Biodiversity are impac8ng their local environment.



2 **Deforesta/on** Students discussed how deforesta8on is happening in their local community and its impact on the community ecosystem.

Students used VR tools to explain

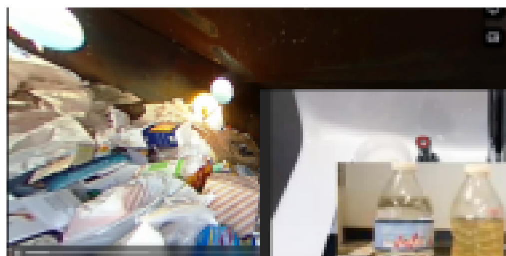
3 **Environmental Pollu/on**

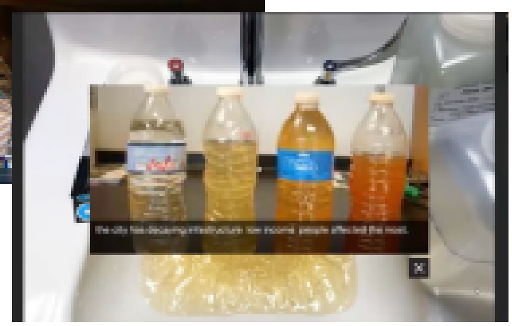


Students created VR videos that explain the causes and impact of air pollu8on

4 **Air Pollu/on**

how environmental pollu8on and waste are impac8ng the local community.

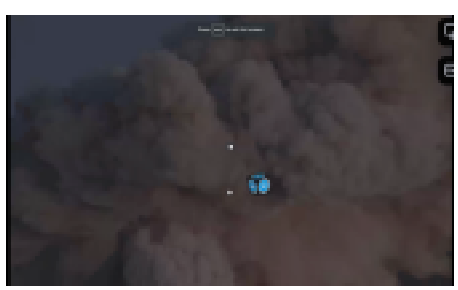




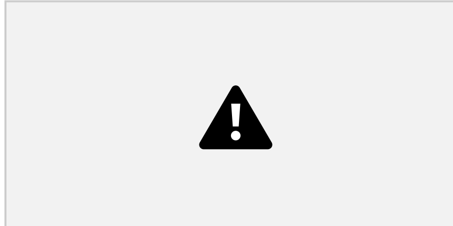
5 **Water Pollu<on** These are instances of talk where students discuss how water pollu1on is impac1ng their local community.

Table 3. Sample of the types of Science students represented in their VFTs

Table 4. *Overview of students' interac2ve media usage*

CODE	CODE DESCRIPTION	EXAMPLE
A	B	C
1 2D Downloaded Photos	Students use photos with text overlays to show science phenomenon with real pictures.	

2 Text Boxes Students use



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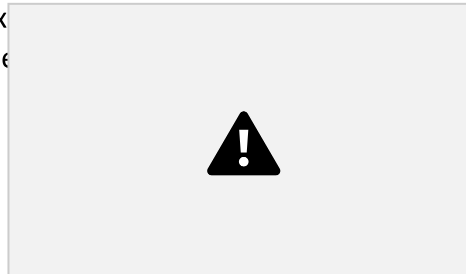
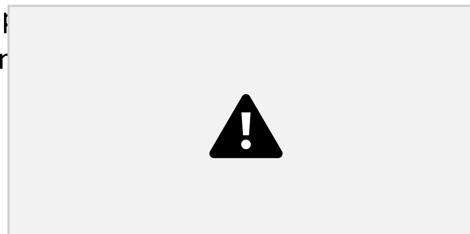


3 Videos Students use videos to explain local

app

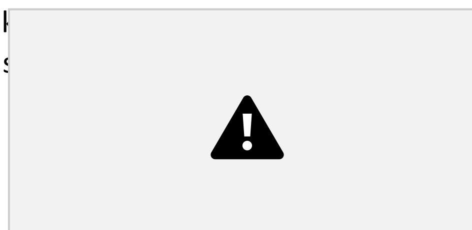
cor



4 Website Links These are instances where students use pop up web

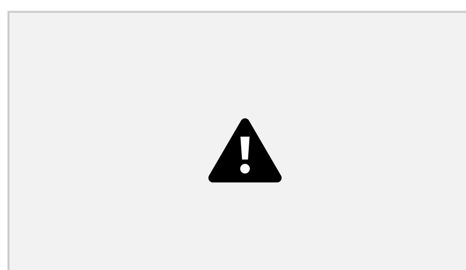
link

to s



5 2 D Local Photos

Students used pictures they snapped of local phenomenon with text overlays



6

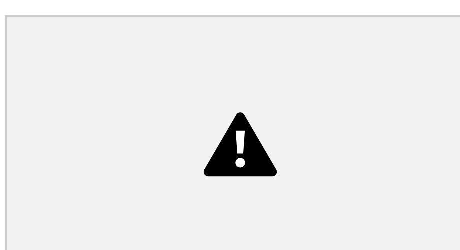
VR 360° Videos Students used VR 360 video of local environments.

Table 5. Overview of students overlayed content

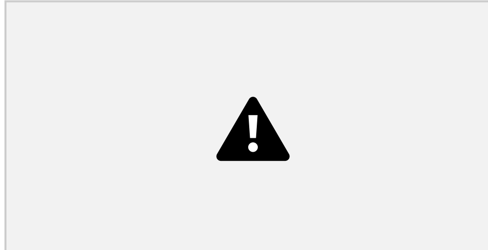
CODE	CODE DESCRIPTION	EXAMPLE	A B C

informa6on.

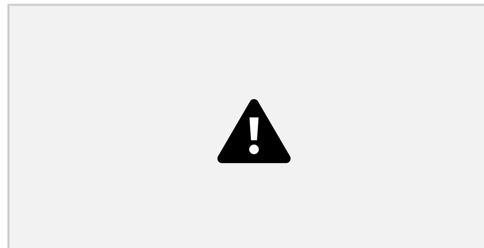
1 Photos with Pop Up Links These are instances where students used 2D photos of phenomenon with pop up details with addi6onal content



2 2D Links to Videos These are instances where students used 2D photos with popup video explaining the content.



3 Text Boxes Students used pop ups that lead to text boxes that explain phenomenon.



4 VR 360° Videos Students used self-recorded VR 360° videos to show the local science happening in their community.

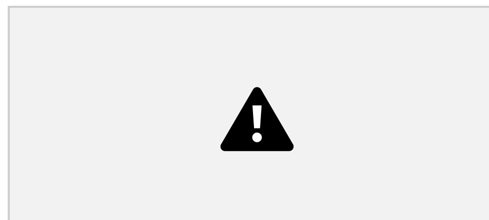


Table 6. *Overview of differences by teacher pedagogy*

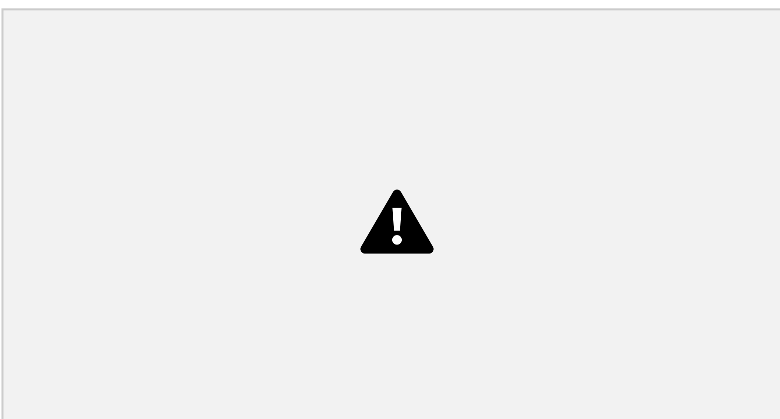
Total # of Uses by Instruc4onal Approach

Teacher Name **Donovan Bradley Greenberg**

Pedagogical Style	Total	*Individual*	*Small Group*	*Whole Group*
Total VR Videos	45	32	12	1
Media				
2D Photos w Labels	76	62	10	4
Text Boxes	53	12	22	19
Videos	4	0	1	3
Weblinks	4	0	0	4
2D Local Photos	21	14	1	6
VR 360	22	0	19	3
Science				
Biodiversity	47	13	6	28

Deforesta4on	12	3	9	0
Environment al Pollu4on	47	22	25	0
Air Pollu4on	37	32	5	0
Water Pollu4on	37	36	1	0
Approach to Using ThinkLink™ Technology				
2D photos w/Pop up links	207	113	22	72
Video Links	7	1	2	4
Text Box	20	8	7	5
VR 360° Video	11	2	6	3

Introduction Science to VFT Informative Pop UP *Group A Group B*



I n t r o S c e n e

PopUp