Supporting Student Learning and Understanding of Geoscience Using Virtual Reality and Video Demonstrations

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Abstract

We examined the impact of geoscience demonstration and virtual reality field trip videos on student assessment confidence, performance, and their overall attitudes towards learning geology using a mixed methods sequential explanatory design. Participants were 111 undergraduate students enrolled in an introductory geology course in one of four consecutive semester offerings. Repeated for 13 videos, students would watch a video of a demonstration or virtual field trip and answer select-response questions. Then during a later exam students answered questions specifically associated with the video content while also rating their answer confidence using a ten-point scale. Open-ended student comments were collected from a four-question survey at the end of each semester. Findings of student responses to four of the videos suggest that the use of the demonstration videos and virtual reality field trips had a positive impact on student learning of geological concepts. Qualitative findings affirmed the voice and personalization principles of the Cognitive Theory of Multimedia Learning.

Keywords: demonstration, virtual reality, geoscience, Cognitive Theory of Multimedia Learning, learning, confidence, visualization

1. Introduction

1.1 Background

Video-based educational resources are well suited to explain the dynamic nature of geosciences. Whether flying over the crystal blue water of Crater Lake in Oregon, the majestic cliffs and waterfalls of Yosemite Valley or tracing the 700-mile gash in the ground that we call the San Andreas Fault, visualizations of specific processes and places can challenge students to think both temporally and spatially. They also can eliminate time, place and situational barriers to learning and thinking scientifically, and promote interaction between the students and the instructor (Kanuka et al. 2009).

Visualizations can increase student control of learning, and serve as a means for self-assessment, that can lead to improved student achievement (Robertson & Flowers, 2020; Gross et al., 2015; Alpay & Gulati, 2010; Traphagan et al., 2010). While there are online resources available through textbook publishers, the existing technology may be a series of static animations. These resources may be linked directly to textbook information, presented at an impersonal level, and offer little motivation to view in their entirety.

1.2 Relevant Scholarship

Why videos of geoscience demonstrations and virtual reality (VR) field trips? Why for introductory geology? Consider climate change, energy, natural resources, mineral exploration, and natural disasters. These are challenges our society must face and meet, and they are all within the domain of geoscience. Geology is the meta-science that can investigate, understand, and pose solutions to these challenges. For students with limited science backgrounds and experiences, the use of video as an instructional tool may raise the students' level and depth of understanding, awareness, and appreciation of geology that a textbook simply cannot do (Hegarty, 2011; Tantrarungoroj, 2008). This is also an avenue for recruitment into a geoscience major, where undergraduate levels are relatively low and stagnant compared to other sciences, and why attrition rates in STEM fields are too high across all demographics (Chen, 2013).

Concurrently, the development of a rich supply of video resources will provide another pedagogical tool for instructors engaged in digital teaching. With in-person instruction, they can support a flipped classroom model and allow instructors to devote class time to explain challenging concepts, check for understanding, and promote active learning environments, all of which can improve student performance (Jeffrey et al., 2014). Use of visualizations and demonstrations as a learning tool, and access to them as a resource for students in an introductory geology class was critical for student understanding and positively impacting student learning outcomes and performance (Roemmele, 2017). The videos may also improve student attitudes and appreciation toward geology and learning geology, and student self-efficacy and motivation to learn (Roemmele, 2017).

This combination of improving conceptual understanding of geology and improving student affect toward geology and learning geology underlies our scholarship of teaching and learning. Although many young students are fascinated with dinosaurs and may have rock or shell collections as a child, the American university student may struggle to find geology interesting or relevant. Learning geology is frequently met with ambivalence, apathy, or scorn (Almberg, 2011). But geology is very much a part of our students' lives and geology is right in front of them. Combined with lack of exposure and instruction (especially at the K-12 level), common misconceptions about geology lead students to adopt a utilitarian view of the subject and its lack of application to their world and society.

The usage and delivery of videos into the curriculum of an introductory geology course as an instructional tool may help to positively impact student learning outcomes and performance, as well as self-efficacy and attitudes toward learning geology (Wang & Stern, 2018). Experience with VR to visit significant geologic locations can also provide an increased level of interest, enthusiasm, and appreciation of geology (McNamee & Bogart, 2018; Sellers, 2020; Eick & King, 2012), as well as gains in geological content knowledge (Mead, Buxner, Bruce, Taylor, Semken, & Anbar, 2019; Chenrai & Jitmahantakul, 2019).

The Cognitive Theory of Multimedia Learning (CTML) provides a theoretical support for ways in which digital video promotes student learning of geoscience concepts. The theory states that multimedia or the use of words and pictures together is a more effective way of learning than words alone or pictures alone (Clark & Mayer, 2016). Developed over the last thirty years, the theory identifies three types of cognitive load to consider when creating digital video and situates within the cognitive loads a series of design principles (Mayer, 2019). According to quantitative research conducted in primarily laboratory settings, when those design principles are applied to digital video, they maximize an individual's opportunity to learn (Rudolph, 2017).

There is concern about students' discomfort with learning and doing science and ultimately performing well, especially in introductory courses. Introductory courses, including geology, may have but cannot present material as a list of topics and vocabulary, disjointed and unconnected, rather than as an engaging topic, relevant to students or society. This was an issue and the challenges that Feinstein et al. (2013) identified in science education. In summary, there has been acknowledgement of the importance of teaching and implementation of more visual components to introductory geology courses. There have been several efforts to include these media such as videos and VR into the course instruction. However, none of these previous studies indicate that they were using self-made demonstration and virtual reality videos. Wang and Stern (2018) did create their own battery of videos although studied less formally. Our study is original in that our video selection were professionally-produced live action instructional demonstrations and VR field trips. We also embraced an extensive creative process to develop these videos with specific storyline and lesson objectives and assessment items (they were treated as a teacher-written lesson plan). Our videos were made with a distinct inclusion of using and referring to common items as analogs in the videos. They were made to break down the fourth wall and treat the viewer as a member of the course or class. And they were designed with principle elements of CTML, an element no other previous study appears to have included.

1.3 Research Questions

In this study, the instructor of an introductory geology course used these instructional demonstration videos and virtual reality (VR) field trips as a regular part of the course (required viewing and completing of questions). The questions driving this research were:

1) What impact do the instructional video demonstrations and virtual field trips in an undergraduate introductory geology class have on student learning and performance, and

2) Does the use of videos as a learning tool improve student confidence and attitudes toward learning geology, and why?

2. Method

This research design follows a mixed methods sequential explanatory design, with quantitative data collected first followed by qualitative data collection. The quantitative statistical data can present an overall picture of the students who took the course and participated in the study. The qualitative component which included open-ended responses to a questionnaire and casual conversations with participants, can further explain, elaborate, and clarify the quantitative results. The integration and merging of quantitative and qualitative data is the characteristic of mixed methods research (Cresswell, 2012).

2.1 Course Background and Population

For this study, the sample population of students were enrolled in an introductory geology course taught by the co-author at a four-year state university for both the fall and spring semesters of the 2019-2020 and 2020-2021 academic years. A majority of the students in this course are non-geoscience majors, as well as being non-science majors, although the students are typically diverse in their respective majors. The introductory geology course meets for "lecture" twice a week for 50 minutes, and a lab that students attend once a week for two hours. The course fulfills a university general education requirement for science. Class size typically is about 64 students, although the cohort in spring 2020 was smaller, as they were the initial class of a hybrid version of the introductory course (asynchronous lecture, in-person lab) for a single class size of 32.

Over the course of a semester, students watched 13 different videos ranging in length from 7 to 12 minutes via the quiz tool in the learning management system. The first segment of the quiz was the video and the second segment contained between 5 and 10 questions assessing student comprehension of the video content. Each demonstration video started with the learning objectives listed on screen and read in voice-over. These objectives were restated at the conclusion of the videos. Students could not go back to the video when answering the questions. Each quiz contained at least three different types of questions drawn from multiple choice, written, short answer, fill in the blank, matching, multiple select and multiple short answer types. The final question of each quiz asked students to rate their confidence at completing listed objectives related to the video content on a scale of 0 – no confidence to 10 – extremely confident.

Students watched 11 of the 13 videos prior to the first exam. On the first exam, students answered 14 questions specifically associated with the video content (in nearly all cases, the same question from the quiz taken after watching the video was used on the exam) and then self-reported their confidence at how accurately they answered that question. Two additional VR videos were seen after Exam 1 with a similar assessment format of associated questions and self-reported confidence questions on the second exam.

2.2 Video Design

The demonstration and VR field trip videos investigated in this study applied numerous CTML design principles. The demonstration videos were hosted and performed by the course instructor along with multiple student assistants in order to break down the "fourth wall" to talk directly to the intended audience. The VR videos were created using an HTC Vive virtual reality headset and Google Earth VR. The instructor used the tools to narrate a customized tour of geologic features that students would not otherwise be able to visit. In both video styles, the use of human narrators incorporated the embodiment, personalization and voice principles of CTML. The demonstration videos used common everyday items including foods that students are likely to be familiar with as analogies to more complex geologic concepts and processes. Because the narrators in both video styles were discussing the concepts as they were displayed, the CTML principles of modality, temporal contiguity, and to a lesser extent signaling were incorporated in the videos. Both video styles made use of text pop ups to share key vocabulary and definitions as those terms were introduced but did so in a way that still met the CTML design principles of spatial contiguity and redundancy. Finally, the users had the ability to pause or rewind the videos which were also only 7 to 12 minutes in length, which addressed the segmenting principle.

2.3 Data Collection

Data collection occurred over four separate semesters all from the same introductory geology course taught by the same instructor. In Fall 2019, 43 students agreed to participate, 22 students agreed to participate in Spring 2020 semester, 27 students agreed to participate in the Fall 2020 semester, and 19 students agreed to participate in the Spring 2021 semester for a total of 111 participants. The last two semesters worth of data collection occurred during the COVID-19 pandemic and remote synchronous instruction. The results presented here are focused on four of the videos – two instructional demonstrations, "Relative Time Sandwich" and "Milky Way Tectonics" and two VR field trips "Crater Lake" and "Yosemite."

Qualitative data was collected using the data management system by offering participants a four-question survey at the end of each semester. These questions were:

1. How does learning from the videos and VR trips compare to reading from a text or viewing a PowerPoint slideshow? Explain.

2. What were some specific aspects in any one of the videos that appealed to you to assist your learning? Or was there some aspect that was general to the whole slate of videos that appealed to you and assisted your learning?
3. Apart from the videos created for this class, did you seek out other video resources (from YouTube for example) to assist you in studying a specific concept or process? If so, please identify what/where.
4. In moving forward with making more videos and VR field trips, is there any topic/process or geologically significant location you feel future classes would benefit from by having a video to watch?

2.4 Data Analysis

The first step in data analysis was a preliminary exploration of the response transcripts to get a general sense of the participants' perceptions and understanding of geology and the nature and use of the videos. Significant statements and quotes from the participants who completed responses (N=52) were highlighted and identified as emergent themes. Coding was done by both authors separately, who then met to discuss the categories and coding and establish reliability in the coding system. This was done by identifying the code where it occurred within the portion of the student response. Then the researchers reached agreement by assigning the code to a category. Differences over category or codes were discussed to achieve consensus.

3. Results

3.1 Quantitative Results

The following data were collected to examine the trends and shifts in learning and understanding. For this study, we focused on two question pairs from the Relative Time Sandwich video, the Milky Way video, the Crater Lake VR video, and the Yosemite VR video.

The following measures were analyzed and reported below for each of the four videos in two tables. The first table for each video includes:

1. Percentage of students who answered the item correctly after taking the video and the exam.
2. The confidence mean that students reported after responding to the exam item, on a scale of 0 (no confidence at all) to 10 (fully confident).
3. The statistical significance from the paired t-test in comparing the quiz item response to exam item response (measuring retention with no treatment).
4. The Confidence to Result measure: (Response (right (assigned as 1) or wrong (assigned 0)) - Confidence level)/10. Confidence to Result Measure scores range between –1 and 1. The ideal score is 0. Positive scores indicate students underestimating confidence relative to actual performance. Negative scores indicate students over-estimating confidence relative to performance.

The second table includes:

1. A crosstab showing the average exam item confidence based on the students' results on the paired quiz-exam items. Students fell into four classes:
    1. Right on quiz; Right on Exam
    2. Wrong on quiz; Right on Exam
    3. Right on quiz; Wrong on Exam
    4. Wrong on quiz: Wrong on Exam

3.1.1 Relative Time Sandwich Video

Two pairs of question items that were analyzed after watching the Relative Time Sandwich demonstration video and taking the exam (see Table 1). All four relative time questions were multiple choice with four options. Student scores across all four questions (see Table 2) were above the recognized learning threshold of 85% (Rosenshine, 2012; Wilson, Shenhav, Straccia, & Cohen, 2019). The t-test results for the question pairs were not statistically significant. The confidence to result measure means both approached the ideal situation of zero with students underestimating their expertise. Students who answered correctly on the exam had a generally high confidence level over 8.5 out of 10 compared to those who answered incorrectly on the exam with both instances below 8 out of 10 (see Table 3).

Table 1. Relative Time Sandwich questions and correct responses

Assessment	Question Item	Correct Response
Video Quiz 1	The layer of peanut butter on top of the bread is an example of which principle?	Superposition
Exam 1	Rock layers on top of a series of rock layers are younger than rock layers at the bottom - similar to the peanut butter on top of the bread - is an example of which relative age principle?	Superposition
Video Quiz 2	What actions were taken in the video to demonstrate the Principle of Cross Cutting Relationships?	The sandwich was cut into thirds with a knife
Exam 2	A batholith, sill, or dike intrusion that cuts across layers of rock, or a fault which cuts across several rock layers, like the knife cutting the peanut butter and jelly sandwich, is representative of which relative age principle?	Cross Cutting Relationships

Table 2. Relative Time Sandwich Quiz and Exam Results

	N	Mean	Std. Deviation	T-test 2-tailed significance between quiz and exam	Confidence Mean	Confidence Std. Deviation	Confidence to Result Measure Mean	Std. Deviation
Video Quiz 1	111	.90	.300	-	-	-	-	-
Exam 1	111	.95	.227	0.227	8.698	1.7879	.0761	.2723
Video Quiz 2	111	.91	.288	-	-	-	-	-
Exam 2	111	.96	.187	0.109	8.522	1.8158	.1117	.2405

Table 3. Relative Time Sandwich Quiz and Exam Results Crosstab

	Video Quiz 1 to Exam 1		Video Quiz 2 to Exam 2	
	N	Exam Question Confidence Average	*N*	Exam Question Confidence Average
Right Quiz and Right Exam	94	8.74	97	8.60
Wrong Quiz and Right Exam	11	8.82	10	8.30
Right Quiz and Wrong Exam	6	7.83	4	7.13
Wrong Quiz and Wrong Exam	-	-	-	-

3.1.2 Milky Way Tectonics Video

Two pairs of question items that were analyzed after watching the Milky Way Tectonics demonstration video and taking the exam (see Table 4). Both exam questions and the first quiz question were multiple choice questions with 5 options and the second quiz question was a multiple select question with five options. The first question pair of the Milky Way Tectonics video had scores above the 85% threshold resulting in no statistically significant change (see Table 5). In the second pair, the students quiz question performance was below 85% and the resulting change on the exam performance was a statistically significant difference. The confidence to result measure means both approached the ideal situation of zero. Students had a higher overall average confidence on the second question pair of the Milky Way Tectonics video than the first pair (see Table 6).

Table 4. Milky Way Tectonics questions and correct responses

Assessment	Question Item	Correct Response
Video Quiz 1	In this demonstration, the chocolate layer is an analog for (which of the following)?	Lithosphere
Exam 1	The hard, rigid, rocky material of which the plates are made and which the chocolate of the Milky Way represented is the?	Lithosphere
Video Quiz 2	Which of the following describes characteristics of the asthenosphere? (select all that apply)	All responses should be checked (1) below the lithosphere, 2) hotter than the lithosphere, 3) contains partially melted rock, 4) moves slowly carrying the plates, 5) its analog in the video is the caramel)
Exam 2	Which of the following is characteristic of the asthenosphere?	All of the Above (included options: 1) hotter than the lithosphere, 2) located below the lithosphere, 3) behaves plastically and moves slowly carrying plates, 4) its analog was the caramel)

Table 5. Milky Way Tectonics Quiz and Exam Results

	N	Mean	Std. Deviation	T-test 2-tailed significance between quiz and exam	Confidence Mean	Confidence Std. Deviation	Confidence to Result Measure Mean	Std. Deviation
Video Quiz 1	111	.87	.333	-	-	-	-	-
Exam 1	111	.94	.244	0.109	8.095	2.1779	.1275	.3022
Video Quiz 2	111	.83	.318	-	-	-	-	-
Exam 2	111	.97	.163	0.000*	8.635	1.9152	.1095	.2388

*$p < .05$

Table 6. Milky Way Tectonics Quiz and Exam Results Crosstab

	Video Quiz 1 to Exam 1		Video Quiz 2 to Exam 2	
	N	Exam Question Confidence Average	*N*	Exam Question Confidence Average
Right Quiz and Right Exam	91	8.28	88	8.60
Wrong Quiz and Right Exam	13	7.46	20	8.95
Right Quiz and Wrong Exam	6	6.67	3	7.50
Wrong Quiz and Wrong Exam	1	8.00	-	-

3.1.3 Crater Lake Virtual Reality (VR) Field Trip

The two quiz questions for the Crater Lake Virtual Reality (VR) field trip video were written responses while the exam questions were multiple choice with 4 answer options (See Table 7). Student mean scores remained above 80 percent in all four questions for the Crater Lake Virtual Reality video (See Table 8). The demonstrated gains from quiz question to exam question were both statistically significant. The confidence to result measure mean again remains close to the ideal situation of zero. Student confidence for those that scored correctly on both the quiz and exam question for the Crater Lake VR video was high with averages of 8.75 and 8.77 (See Table 9).

Table 7. Crater Lake VR questions and correct responses

Assessment	Question Item	Correct Response
Video Quiz 1	Although it is called Crater Lake, the geologic feature (which Crater Lake is a part of) is actually called which of the following?	Caldera
Exam 1	While it may be called Crater Lake, the actual feature we find at this national park is geologically speaking actually which of the following?	Caldera
Video Quiz 2	What can be inferred about the intensity or size of the eruptive event?	Very high magnitude / intensity / cataclysmic event
Exam 2	What interpretation can you make about the eruption that created such a feature?	Very high magnitude / intensity / cataclysmic event

Table 8. Crater Lake VR Quiz and Exam Results

	N	Mean	Std. Deviation	T-test 2-tailed significance between quiz and exam	Confidence Mean	Confidence Std. Deviation	Confidence to Result Measure Mean	Std. Deviation
Video Quiz 1	111	.82	.386	-	-	-	-	-
Exam 1	111	.99	.095	0.000*	8.689	1.790	.1221	.1804
Video Quiz 2	111	.86	.321	-	-	-	-	-
Exam 2	111	.95	.117	0.011*	8.486	1.917	.0973	.2511

*$p < .05$

Table 9. Crater Lake VR Quiz and Exam Results Crosstab

	Video Quiz 1 to Exam 1		Video Quiz 2 to Exam 2	
	N	Exam Question Confidence Average	*N*	Exam Question Confidence Average
Right Quiz and Right Exam	90	8.75	93	8.77
Wrong Quiz and Right Exam	20	8.65	12	7.42
Right Quiz and Wrong Exam	1	4.00	2	5.00
Wrong Quiz and Wrong Exam	-	-	4	6.75

3.1.4 Yosemite Virtual Reality (VR) Field Trip

All four questions that relate to the Yosemite Virtual Reality (VR) field trip video were multiple choice with 5 answer options (See Table 10). The second paired question set for the Yosemite Virtual Reality (VR) filed trip video was the only one where results decreased between the initial quiz and the exam and it also has the highest confidence to result measure mean of the analyzed data (See Table 11). The Yosemite VR field trip video second exam question confidence average for those that scored correctly on both quiz and exam was the lowest among the analyzed data at 8.20. For the 10 students who were wrong on the quiz, but right on the exam they reported the highest exam question confidence average among the analyzed data at 9.1 (See Table 12).

Table 10. Yosemite VR field trip video questions and correct responses

Assessment	Question Item	Correct Response
Video Quiz 1	The primary form of mechanical weathering occurring in the rocks at Yosemite?	Exfoliation
Exam 1	What you see here is how the granite at Yosemite National Park is weathering - what is this weathering process called?	Exfoliation
Video Quiz 2	The size and shape of Yosemite indicates that it was carved out and eroded by glaciers - what is this feature called where the park sits?	U-shaped valley
Exam 2	Similar to what makes Yosemite National Park what it is, what is the similar feature shown here that was eroded by a glacier?	U-shaped valley

Table 11. Yosemite VR field trip quiz and exam results

	N	Mean	Std. Deviation	T-test 2-tailed significance between quiz and exam	Confidence Mean	Confidence Std. Deviation	Confidence to Result Measure Mean	Std. Deviation
Video Quiz 1	111	.87	.333	-	-	-	-	-
Exam 1	111	.93	.260	0.109	8.077	2.209	.1203	.2657
Video Quiz 2	100	.95	.219	-	-	-	-	-
Exam 2	110	.92	.275	0.566	7.809	2.369	.1373	.2940

Table 12. Yosemite VR Quiz and Exam Results Crosstab

	Video Quiz 1 to Exam 1		Video Quiz 2 to Exam 2	
	N	Exam Question Confidence Average	*N*	Exam Question Confidence Average
Right Quiz and Right Exam	93	8.51	88	8.20
Wrong Quiz and Right Exam	10	6.55	5	9.10
Right Quiz and Wrong Exam	4	4.88	7	5.36
Wrong Quiz and Wrong Exam	4	5.00	-	-

3.2 Qualitative Results

When asked how learning from the demonstration videos and VR trips compare to reading a textbook or viewing a slideshow, a number of participants (n=28) cited that they did like or appreciate the videos over the text or slideshows. Some representative comments from the students included:

- "I like being able to see what is happening rather just hearing about. Visuals are a key for this class"
- "I enjoyed the videos, made the lesson go by fast and left a more memorable impression"
- "I actually absolutely loved learning from the videos compared to reading from text"
- "The videos are more interesting and engaging but with texts and PowerPoints it is easy to zone out or have to keep rereading the same sentence."
- "learning from the videos and VR trips is better than just looking at pictures in a textbook or slideshow"

Responses also included a significant number of students who stated that learning from the videos was easier to understand, sometimes noting that they better understood the information from the videos because they could stay focused.

- "They are much more easier to understand"
- "they make it easier to comprehend the material."
- "really helped me sink in the information and remember each other topics"
- "I've found that it's easier to pay attention to the virtual field trips and videos compared to the readings"
- "The videos helped me visualize the ideas/theories/facts of the content that was being presented"
- "helps with my ability to remember them"
- "it helped me learn the concepts much easier"
- "It is actually much more helpful and allows me to understand the content much easier than from a textbook or PowerPoint"

One student noted that while the demonstration videos made it easier to learn, the VR field trip videos were not helpful.

An equal number of comments made reference to themselves being visual learners, a common student misconception or neuormyth with regard to learning (Kirschner, 2017).

- "I like being able to see what is happening rather just hearing about. Visuals are a key for this class"
- "I am a visual learner and it is harder for me to read and take notes than it is to watch a video on the information."
- "I feel like I gained more as I am a visual learner,"
- "The videos helped me visualize the ideas/theories/facts of the content that was being presented"
- "Learning from the videos and VR allows students who are visual learners to understand the material."
- "when I can see it for myself I take in the information better than when it's just being spoken to me"
- "It's nice to have a visual that associates with what we're learning."

Some responses highlighted the students' appreciation of the fact that these field trips were to real places, and highlighted a number of aspects at these locations. As one student points out, "VR also gives us an experience that you would only be able to get if you were in that location" the virtual reality videos provided a slightly more realistic experience.

- "Learning from the videos helps to see a real-life example of the material"
- "the videos show a real-life example more clearly"
- "piece concepts together from actually seeing and experiencing different topics of actual places"
- "we get to see real world evidence for what we are learning"
- "taking a field trip without actually having to"
- "It goes into depth by relating personal/ real life experiences with the course material"

An additional component of the "real world" comments was the acknowledgement to the everyday items that were used in the instructional demonstrations that students knew and could meaningfully relate to.

Another theme that emerged was the explanations and key concepts, and that this emphasis of being both visual (in the form of pop-ups with key terms and definitions) and spoken as well.

3.2.1 Visual Comments

- “Reading is always annoying, so it's nice to hear someone talk over a video”
- “since I have a neurological disability, my brain can easily receive general knowledge from any subject if it is explained orally, in plain English and in a shorter amount of time than 50 minutes.”
- “It was cool to have the observations explained as we viewed a mountain, valley, or volcano.”
- “because you are talking over it and making it easy to understand”

3.2.2 Written Comments

- “the explanations in the graphic overlay of terms simultaneously tied everything together”
- “with text popping up on the screen”
- “copy each vocabulary word along with its definition every time it was mentioned”
- “A lot of definitions and what we need to know are included within the videos”

Finally, eight students referenced the interactive nature of the videos as a benefit – students ability to stop and go back to watch and make note of a location, a process, or a term. One student said, “I could pause the video whenever I needed extra time to copy down the notes” while another student indicated that “The videos were helpful because you could pause or rewind to help go at your own pace.” This data affirms previous findings that indicate students value control over video playback (Xiu, et al., 2019).

- “The videos were helpful because you could pause or rewind to help go at your own pace.”
- “I could pause the video whenever i needed extra time to copy down the notes”
- “Definitely much more interactive”

For the second question, students were asked about a specific aspect from any one video or some aspect that was general or common to all of the videos that assisted in their learning and that they found appealing. A number of participants stated the use of analogies or familiar items used as analogs was beneficial.

- “I liked the videos that are related to food because it was really easy to understand because I know what most foods look like. It also helped me remember the material.”
- “Using things like food or objects we’re familiar with helped familiarize the concepts. It,’s a lot easier to remember how ketchup moves and how milkshakes bubble rather than trying to just remember how volcanoes work, I do a lot better with analogies”
- “I loved the food or objects as visual aids to help further explain the information that was being given.”
- “Also for some reason the examples of mafic and felsic lava using molasses/ketchup/peanut butter are something i think about often”
- “I also liked relating complex concepts to everyday things like food. It makes the concepts so much easier to understand and is a way that I've always understood things”
- “One specific part of the videos that helped me were the analogies, because then I could think of PB&J and know how it relates to different aspects of geology. This definitely helped me remember and learn certain parts of the curriculum that would have been more challenging to me if the analogies weren't a thing”

A smaller sample of participants mentioned the explanations, the popup and audio-visual nature indicating their importance.

Another theme strictly related to the VR field trips. These responses mentioned the maneuverability of the VR to show different locations and view from different angles, and the very fact that these were indeed actual geologically important places in the real world.

- “The google maps virtual field trips helped put the concepts from class into their broader context”
- “I really liked using google earth and moving it around myself but in the videos I just felt like it was easier to understand”
- “I have never been to any of the places that were discussed so it was a much better way to see the exact locations and details that we were discussing in class. It was much better than just a picture could have been”

- “The maps and animated view of these areas really helped me get a picture in my head of what these places and geologic features looked like.”
- “I like how you can move around and see all of Yosemite park not just a small part of it”

Finally, a handful of participants mentioned the professor specifically and his presence in the demonstrations and field trips.

- “I also liked how they were students conducting the experiments, not just teachers”
- “watching what you were doing helped a lot versus”
- “I personally enjoyed the professor being in the video while taking us through the tour. By following his hands and reading his lips as he was talking I felt that my comprehension of the topic increased greatly”

4. Discussion

Results from the quantitative data analysis showed that participants’ overall performance on the two items from the Relative Time Sandwich video changed very little following their viewing of the demonstration video to taking the exam. There were no statistically significant differences between the video and exam, which we attribute to the high number of students who had already performed well in responding to questions after viewing the video. The same is true for the first Milky Way Tectonics item about the lithosphere-chocolate analogy. However, the exam confidence level mean for both Sandwich items were both rather high (8.5-9.0 out of 10), which are notably higher than the first Milky Way item (about 8.0 out of 10). This confidence mean may have been lower due to the perceived binary choice in responses to the exam item (with either lithosphere or asthenosphere as likely correct choices).

The relationship to students’ responses about their preference and ease of learning from the videos, being visual learners by watching their instructor perform the demonstration may have assisted in their strong scores in both the video quiz and exam items. Specifically, the inclusion of a human narrator addressed the CTML design principles of embodiment, personalization and voice which likely also contributed to the high student scores. Additionally, the videos were the primary source of the analogies during the course, which a good portion of participants mentioned in the survey responses. Although the course textbook did contain other analogy examples, we can infer from their responses, that the visual nature of the videos, compared to reading text, may mean that the videos did have a positive impact on learning and understanding, when we examine the strong scores on the corresponding exam items.

The second Milky Way item results showed the greatest change in all the questions analyzed for this research, and the change was statistically significant (0.000), with a high confidence level (>8.5/10). Analysis of the qualitative data responses identify the use of analogies (in this instance caramel nougat being the asthenosphere), and using a food students may be familiar with, may have instigated this change.

The two Crater Lake items also showed statistically significant changes from the video quiz to exam, as an increase of 20 students were able to identify Crater Lake as a caldera correctly on the exam, an increase of 12 students were then able to reason that the eruption must have been cataclysmic in nature in order to create such a feature. Their reported confidence levels were reasonably high (~8.5/10) for both Crater Lake exam items. When complemented with students’ survey responses, we can infer that the virtual field trip to an actual well-known caldera that students have not seen or visited before, and the exploration of the Crater Lake caldera by flying over and around it using Google Earth, may have helped in their understanding of the feature and process that created it. However, neither of the Yosemite items showed statistically significant changes. Both items had already been highly successful on the video quizzes so a dramatic shift in the number of students answering correctly would be unlikely.

The confidence level of students is also a revealing variable, with the marked drop in confidence levels of students who got the item wrong on the exam, and who had answered the same question correctly after the video quiz. The confidence level mean of this small cohort (right quiz-wrong exam) is always the lowest, in some cases by several points, as with the second Yosemite item about the type of weathering the rocks are experiencing. This lower confidence, combined with the incorrect response, may indicate they did not recollect the information from the video, and thus were unsure of the correct response couple amongst the distractors.

The two research questions that guided this study were 1) What impact do the instructional video demonstrations and virtual field trips in an undergraduate introductory geology class have on student learning and performance, and 2) Does the use of videos as a learning tool improve student confidence and attitudes toward learning geology, and why? Results from both the quantitative data and quantitative data analysis showed that the use of the demonstration videos and VR field trips had a positive impact on student learning of geological concepts. There was a distinctly overall strong performance and generally high confidence level, especially pronounced after the exam items. Based on the survey results, participants' content knowledge did indicate some significant gains. Thematic analysis and interpretation of student responses showed that participants generally enjoyed their experience using the demonstration videos and VR field trips as a learning instrument, with several reasons as to their positive impact on student confidence levels in understanding geological concepts, and their appreciation of geology by allowing them to see processes and concepts demonstrated and to visit geologically significant locations.

4.1 Limitations

Several limitations were identified during the course of this study. This includes the odds of guessing, and on a 4 or 5 option multiple choice item, this means that the probability of guessing correctly (or incorrectly) twice is between 4 and 6.25%. Additionally, the sampling of students for this research was done for one specific course at one university, so there is a level of generalizability that the sample is representative of the population of students in the same or similar course elsewhere.

There was also the potential for threat to internal validity due to subject effect if students were not inclined to answer the questionnaire items in a particular way, or honestly, if attitudes about the videos or geology did or did not change by the end of the semester. This also impacts the actual testing, if participating students may anticipate the survey and may have developed a stance about the need to complete it, thus potentially impacting the type of response they provided.

Because this study includes qualitative research, data obtained here may also be subject to internal and external validity, primarily in the form of investigator bias, as one of the investigators is the course instructor. However, the other investigator did not teach the course and had no interaction with the student sample. Another possible threat to external validity stems from the fact that the study was limited to two academic years at one specific university. Thus, population generalizability may be considered a factor. Generalizability of any conclusions beyond the university and the course being studied is limited.

4.2 Recommendations

The participants in this study showed a definitive appreciation of the presence of all videos as a learning tool. Providing students with visualizations of geologic concepts and processes during instruction can significantly improve understanding and the ability to transfer this knowledge to a new context (Titus & Horsman, 2009; Mayer et al., 2002). These instructional videos can also serve as motivational pieces, especially when students have time to control or manipulate the visualization (Wang & Reeves, 2007), as students in this study noted that the ability to watch and go back to rewatch parts of the videos was beneficial to their own learning. We strongly recommend that geology instructors, or any science instructor, develop their own instructional demonstration videos as a means for improving conceptual understanding amongst their students. Reaching out to a school's digital media center or video production unit can provide instructors the opportunity and assistance to create more dynamic, engaging, and interactive learning experiences that allow students to learn and think critically about different aspects of our Earth, their place in it and how they may affect it. This may lead to increased levels of science literacy, as well as a greater value students place on our planet.

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