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EFFECTIVENESS OF TIME-LAPSE VIDEOS AS A METHOD TO TEACH RATES OF SURFACE GEOLOGICAL PROCESSES

By

Zachary P. Schierl

Accepted in Partial Completion
Of the Requirements for the Degree
Master of Science

Kathleen L. Kitto, Dean of the Graduate School

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Zachary Schierl
November 13, 2014
EFFECTIVENESS OF TIME-LAPSE VIDEOS AS A METHOD TO TEACH RATES OF SURFACE GEOLOGICAL PROCESSES

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

by
Zachary Schierl
November 2014
ABSTRACT

Understanding the wide range of rates at which geological processes operate can be challenging for introductory geology students, and yet is crucial to understanding how the Earth’s landscapes evolve over time. Research has shown that student misconceptions in this area are common. Time-lapse videos can capture processes that cannot be observed by students in the field and offer promise as a way to improve student understanding of rates of landscape evolution on certain timescales. This thesis explores the effectiveness of using time-lapse videos to teach intro geology students about the rates of surficial geological processes compared to before/after photo pairs depicting the same processes. The effect of interactivity on the effectiveness of time-lapse is also explored.

One hundred and thirty students enrolled in introductory geology classes at Western Washington University during Winter and Spring quarter 2014 participated in the study. Subjects took a pre-test where they made qualitative and quantitative predictions about how various landscapes would change over time before completing a series of computer based activities containing before/after photos or time-lapse videos and then a post-test allowing them to revisit their predictions. The performance of three treatment groups, one using before/after photo pairs, one using pre-made time-lapse videos, and one where students made their own custom time-lapse videos using an interactive online program, was compared.

All three groups exhibited large and statistically significant gains in understanding of geologic rates as measured by score gain from pre-test to post-test although differences in gains between groups were small and not significant. A number of steps were taken during study design and data analysis to ensure construct and internal validity. Lack of significant differences in the performance of the three treatment groups on the assessments suggests that there may be cognitive barriers to processing the complex and rapid landscape changes presented in a time-lapse video. This may limit how much students, in particular novice geology students, can learn from time-lapse videos, even though they inherently present more information and a more complete picture of a given geological process as compared to before/after photo pairs.

The results of the study suggest various ways to improve the implementation and effectiveness of time-lapse videos in the geology classroom, including decreasing frame
rates, more guidance on what to focus on when viewing time-lapse videos, inclusion of annotation and/or narration in the videos themselves, more time to look at the videos, and better integration of the videos and assessment questions. Extra care is also needed to ensure that videos explicitly address pre-existing misconceptions held by viewers in order for them to be effective with a wide range of students.
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Thanks to Patrick Griffin who, with his knowledge of the inner workings of the Swift Creek Landslide Observatory site, was able to modify the interactive time-lapse generator to meet the needs of this project. Thanks also to my fellow geology graduate students who assisted me in testing out assessment items and to all who have taught GEOL 101 and 211 in the past two years for letting me impinge upon your class time to recruit students for my research.

Thanks to Bernie Housen for agreeing to join my thesis committee at the last minute and providing helpful feedback. Another member of my thesis committee, Dan Hanley, provided invaluable mentoring throughout my thesis project, especially with regards to designing a valid research methodology and helping me understand the statistical techniques I needed to make sense of my data. And finally, extra special thanks goes to my thesis advisor Scott Linneman for all of his support and thoughtful comments and feedback on my project over the past several years.
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INTRODUCTION

Perhaps more so than any other science, Earth systems science involves timescales that are often outside the realm of human experience. Only in astronomy and cosmology are such immense timescales as regularly encountered. The rate at which processes shape our planet varies considerably (Manduca and Kastens, 2012) and an understanding of the spectrum of rates over which geologic processes occur is crucial to any student’s understanding of geology and the evolution of planet Earth. However, the complexity of this concept, and the fact that it is inherently related to an understanding of “deep time”, itself a concept deeply engrained in earth science, makes it one of the more difficult concepts for earth science educators to teach, and for novice earth science students to understand.

The goal of this thesis is to explore the effect of using time-lapse videos on student understanding of rates of geological processes. Time-lapse videos are useful in that they allow us to visualize geologic processes that occur too slowly to observe in the field. Time-lapse videos are being increasingly utilized in the classroom to teach students about rates of geological processes, yet their effectiveness compared to other more traditional methods that convey similar information, such as viewing “before” and “after” photographs, has not been quantitatively evaluated. This thesis project will therefore test whether viewing a series of time-lapse videos increases student understanding of rates of geological processes compared to viewing time-series photographs and whether actively involving students in the process of generating time-lapse videos using an interactive web-page increases knowledge gains over students who passively view pre-made time-lapse videos.
Time-Lapse Photography

For applications in the geosciences, time-lapse photography is an image capture method in which a series of photos are taken of the same feature or landscape over a period of time, ideally from the exact same location (Fahnestock, 1966). The photos obtained can be used as individual frames to produce a time-lapse video, which is defined as a video in which the individual frames are captured at a slower rate than they are viewed (Fahnestock, 1966). A typical frame rate for conventional video or film playback is 30 frames per second (fps). In a normal video, the frames would be captured at an equivalent rate, whereas in a time-lapse video, the frames will be separated temporally. The result is a video that compresses a long period of time (minutes, days, weeks, or years) into a short video clip. Time-lapse video is the opposite of high-speed video, in which the playback rate is slower than the capture rate.

Many geological processes occur on time-scales that do not allow them to be directly observed in the field and/or occur in locations that are difficult to physically access (Manduca and Kastens, 2012). Time-lapse has long been used by geologists to study these phenomena. Examples include glacial processes (Miller and Crandell, 1959), lava dome growth (Schilling et al., 2007), landslide monitoring (Belknap and Gilmore, 1987), ripple migration in sand dunes (Lorenz and Valdez, 2011), volcanic eruptions (Orr and Hoblitt, 2008), and many others. Recent advances in technology have also allowed time-lapse cameras to be widely utilized among geologists in monitoring processes which occur in areas that are unsafe for humans (Orr and Hoblitt, 2008).

As time-lapse photography becomes more common, time-lapse data-sets are increasingly making their way into the geology classroom in order to communicate concepts related to geologic time and rates of geologic processes. In order to estimate the number of geoscience
faculty currently using time-lapse videos in their courses, and gain insight into how they are being used, I conducted an online survey of college-level geology educators (n=43) in April 2013. The survey was distributed to geoscience faculty nationwide via National Association of Geoscience Teachers (NAGT) and American Geophysical Union (AGU) Education Special Interest Group list serves. Among faculty that responded to the survey, 38% stated that they used time-lapse videos in their classes at least once or twice per semester/quarter while 71% had utilized them at some point in their teaching career (Figure 1).

While time-lapse videos have been used by geoscience educators for decades (Fahnestock, 1966; Reams, 1981), their effectiveness as a teaching tool has not been quantitatively evaluated. Because time-lapse videos allow students to witness slow geologic processes in accelerated time, they may have promise as a method by which to improve students’ conceptual understanding of the rate at which surficial geologic processes occur and the role that these processes play in the long-term evolution of Earth’s landscapes. While abundant anecdotal evidence suggests that students enjoy viewing time-lapse videos, it would be naïve to assume that this enjoyment automatically translates to a deep or thorough understanding of the processes they depict. Oftentimes, student excitement is simply the result of the novelty factor associated with such technology. In addition, while much research has focused on best practices for integrating videos and animations into educational experiences (Mayer, 2001), the best methods for incorporating time-lapse videos into student learning have not been investigated in detail.

**Understanding Rates of Geological Processes**

Comprehending the concept of “deep time” is central to any students understanding of geology and geological processes (Dodick and Orion, 2003; McPhee, 1981), and yet the
short nature of human lifetimes make this inherently one of the most difficult concepts for any student of geology to understand. Understanding deep time is undoubtedly important, because it is the only way for us to properly frame rates and realize, for example, that erosion rates or the rate of a glacier are extremely fast compared to the rate of say, renewing of fossil fuel resources (Zen, 2001). A number of studies have attempted to quantify preconceptions and misconceptions about geologic time held by elementary school students (Ault, 1982), high school students (Dodick and Orion, 2003; Cheek, 2012), undergraduate introductory geology students (DeLaughter et al., 1998; Libarkin et al., 2005; Libarkin, Kurdziel, et al., 2007; Cheek, 2012), and teachers (Trend, 2001). Some of these studies even suggest that deep time is so integral to students comprehension of geology as a science that it should be the first topic covered in introductory geology courses (Libarkin et al. 2007).

While much of the literature on student learning on this topic has been focused on ways to help students understand the magnitude of geologic time, a related concept has been more neglected, namely student understanding of the range of rates on which geologic processes shape the surface of the Earth. The concept of “landscape evolution”, the idea the surface of the Earth is shaped by a variety of processes that occur on wildly varying timescales was first laid out by James Hutton in the 18th century (Hutton, 1788). The Earth’s surface as we see it today is the product of a multitude of complex and interacting processes, each occurring at different rates in both time and space (Sharp, 1982; Manduca and Kastens, 2012). Rapid events, such as the 1980 eruption of Mt. St. Helens, can drastically alter the landscape in seconds, while slower events, such as regional-scale mountain building events, occur slowly over millions of years and yet produce the topography of large swaths of our planet. To make things even more confusing for the novice geology student, the rate of a single process, such
as a landslide, can vary widely (from $5 \times 10^{-7}$ to $5 \times 10^3$ mm/sec) depending on factors such as material properties, precipitation, and climate (Cruden and Varnes, 1996). Yet, geologists frequently refer to all significant slope failure events, at least casually or when simplifying to meet the needs of an introductory geology class, by the same name: “landslide”.

Geoscience educators have long recognized the importance of ensuring that students understand the wide spectrum of geologic rates that are responsible for shaping Earth’s surface (Bailey, 2000; Earth Science Literacy Initiative, 2010). The Earth Science Literacy Initiative, a consortium of geologists and geoscience educators, has identified a set of crucial concepts and ideas about earth science that “all citizens should know” called the Earth Science Literacy Principles. Many of these principles are directly connected with the idea of rates of geological processes (emphasis added):

“2.7-Over’s Earth’s vast history, both gradual and catastrophic processes have produced enormous changes.”

“3.4-Earth’s systems interact over a wide range of temporal and spatial scales. These scales range from microscopic to global in size and operate over fractions of a second to billions of years. These interactions among Earth’s systems have shaped Earth’s history and will shape Earth’s future.”

“3.6-Earth’s systems are dynamic; they continually react to changing influences. Components of Earth’s systems may appear stable, change slowly over long periods of time, or change abruptly with significant consequences for living organisms.”

“4.1-Earth’s geosphere changes through geological, hydrological, physical, chemical, and biological processes that are explained by universal laws. These changes can be small or large, continuous or sporadic, and gradual or catastrophic.”

“8.4-Hazardous events can be sudden or gradual. They range from sudden events such as Earthquakes and explosive volcanic eruptions, to more
gradual phenomena such as droughts, which may last decades or longer. Changes caused by continuous processes such as erosion and land subsidence can also result in risks to human populations, as with the increased risk of flooding in New Orleans.”

“9.1-Human activities significantly change the rates of many of Earth’s surface processes. Humankind has become a geological agent that must be taken into account equally with natural processes in any attempt to understand the workings of Earth’s systems. As human populations and per capita consumption of natural resources increase, so do our impacts on Earth’s systems.”

The Next Generation Science Standards also incorporate ideas about geologic rate into their performance expectations and associated “crosscutting concepts” (NGSS Lead States, 2013):

“HS-ESS2-1: Develop a model to illustrate how Earth’s internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.”

“Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS1-6)”

“Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS2-1)”

Why Do We Care?

Ultimately, understanding geologic time and rates is a crucial skill for not just geologists but for the general public as well, hence the focus of this study on introductory geology students, most of whom will not go on to become geologists, rather than more advanced geology students. The rate of geological processes in relation to human activities has implications far beyond the geoscience community and therefore the ability to communicate concepts related to the rate of geological processes to people of all ages and
social backgrounds is of the utmost importance (Cervato and Frodeman, 2012). A large number of contemporary social and political issues involve an element of rates of geological processes, such as global climate change, recurrence intervals of natural catastrophes such as earthquakes, hurricanes, landslides, and floods, and the depletion of fossil fuel resources. Fully comprehension of such issues can only be accomplished by viewing them through the lens of geologic time and rates (Cervato and Frodeman, 2012).

**Documented Misconceptions about Rates of Geological Processes**

If understanding rates of geological processes is so important, then an important question to ask is how well current instructional methods in geology classrooms, in particular introductory geology classrooms, are addressing these concepts. How well do students understand rates of geological processes, both prior to enrolling in an introductory geology class, and after? Furthermore, what aspects of geologic rate are most misunderstood, and what is it about commonly misunderstood topics that make them so difficult to understand?

All students new to a subject, and even many “experts”, hold preconceptions that may be naïve or misguided (Reif, 2010), even if they have had previous exposure to the subject at a lower level, such as high school or middle school Earth Science classes (Libarkin et al., 2005). Effective teaching involves not only presenting new information, but doing so in a way that addresses students pre-existing misconceptions so that these ideas do not persist and inhibit a student’s ability to absorb new material (Halloun, 1985; National Research Council, 2000; Reif, 2010). A large body of literature exists in the geoscience education community regarding these “misconceptions” (also referred to as “alternative conceptions” or “preconceptions”) that are held by novice geology students. These misconceptions range
from completely inaccurate or unscientific beliefs to partially correct frameworks (Roth, 1990).

Many studies have established that novice geology students at a variety of levels struggle with comprehending geologic time and rates of change (e.g. (Trend, 2001; Dodick and Orion, 2003, 2004; Libarkin et al., 2007). A study of undergraduate geology students at the University of British Columbia discovered that both novice and advanced geology students (geology majors) have difficulty identifying how long geological features take to form, even if they can correctly identify what a feature is and how it formed (Jolley, 2010). Previous work has also found that beginning geology students are most comfortable with rates that fall at either extreme of the geologic spectrum (e.g., extremely fast or extremely slow), but are less confident when it comes to processes that occur at more intermediate rates (Jolley, 2010). A comprehensive review of the existing geoscience misconception literature compiled by Francek (2013) includes dozens of misconceptions related to the rate of geological processes that are held by significant percentages of high school and college age students. Among them are:

- Glacial ice moves backwards during glacial “retreats” (Kirkby, 2011)
- Glacier ice is stationary during times when front is neither advancing or retreating (Kirkby, 2011)
- Uniformitarianism holds that the rates of processes have been constant (Shea, 1982)
- Uniformitarianism holds that only gradual processes have acted and that catastrophes have not occurred during Earth’s past (Shea, 1982)
- Flooding occurs only in the spring, after the winter snow melts (Schoon, 1995)
- Although rivers can cut down over time, they do not cut to the sides (Kirkby, 2011)
- Idea that human activities cannot affect geological processes like river flow, flood cycles, etc…(Kirkby, 2011)
- Flood are rate, atypical, almost unnatural events rather than normal river behavior (Kirkby, 2011)
- Moving water can only change the surface of the earth over long time-periods. Changes are not happening over short time periods (i.e. a day or a year) (AAAS., n.d.)
- Erosion takes place only over millions of years (King 2008)
- Wind and water only change the surface of the earth during rare events, such as huge storms (AAAS., n.d.)
- It only takes hundreds of years for wind and water to wear away the solid rock of a mountain (bedrock) so that the mountain is almost flat (AAAS., n.d.)
- Landforms look similar today as they did many millions of years ago. For example, a river on earth has not changed over time (Dove, 1998; Trend, 2001)
- Landforms can change in size, but not by the motions of wind and water (AAAS., n.d.)
- Water can wear away only a small amount of a mountains height (feet or inches) over millions of years (AAAS., n.d.)
- Wind and water changed the surface of the Earth in the past but are no longer changing the surface of the Earth (AAAS., n.d.)
- It only takes a short time (tens of years) for wind and water to wear down the solid rock of a mountain so that the mountain is almost flat (AAAS., n.d.)

The preponderance of misconceptions related to rates of geological processes has been proposed to stem from a variety of factors. As mentioned previously, it has been shown that novice geology students struggle with the large scale of geologic time (Libarkin et al., 2007) which could simply inhibit student ability to understand rates. Others suggest that these difficulties may stem from the common perception among those unfamiliar with the geosciences that rocks and landforms are unchanging on human timescales (Dove, 1998). Dove (1998) states that novice geology students’ “inability to visualize that rocks, soil and
landforms change over time” makes it difficult for these students to fully comprehend how landscapes evolve over time and that videos and suggests that computer animations could help address this difficulty.

To further probe student ideas about rates of geological processes, a preliminary survey of introductory geology students (n=381) at Western Washington University was administered Winter quarter 2013 during the first week of classes. Three versions of the survey were distributed to three different sections of GEOL 101 on the first day of the quarter. Students were asked to list the fastest and slowest geologic processes they could think of, respond to statements about landscape evolution on a 5-point Likert-scale, and use before and after pictures of a rapidly moving glacier to compare the relative rate of change of a tidewater glacier and a mountain range (Appendix A). In order to express their knowledge about geologic rate, students were asked to use a logarithmic number line representing the future of the Earth to predict how long they thought it would take for the landscape shown to them to change “significantly”. While the method of using timelines to have students express their thoughts about geologic time has been used with success by previous researchers (Libarkin, Kurdziel, et al., 2007; Clary et al., 2009), many students did not interpret the instructions as intended and thus data from this question were extremely difficult to interpret.

While this survey was imperfect, the survey nevertheless revealed a number of common and nearly ubiquitous misconceptions about the relative temporal scale of various geological processes. For example, many students indicated that they thought the glacier would change at a slower rate than the mountain range. Students who were shown before and after images of a glacier taken three years apart were much more likely to think that the landscape would change significantly in a short period of time than students who were shown a single image
of the same glacier. Many students also predicted that “significant changes” in the mountains in as little as 10 years. Aside from illuminating misconceptions, this survey also served as an exercise in designing valid assessment questions, which proved to be useful later on during design of the assessment that would be used for this thesis project.

Various methods have been utilized by geoscience educators in an attempt to help students gain a better appreciation of the range in rates at which geological processes operate. Some of these methods include solving mathematical problems (Bailey, 2000), and library research (Conrad, 2005). Other authors have lamented about the lack of teaching techniques specifically designed to address inadequacies in how students are taught about geologic time and rate (Cervato and Frodeman, 2012). While research on misconceptions about rate and why students hold such conceptions is abundant, little to no quantitative research has been done on the effectiveness of teaching methods designed to correct these misconceptions and improve student understanding of the rates of surficial geologic processes.

**How Time-Lapse May Help Students**

Time-lapse photography is well-suited to capture a variety of surficial geologic processes, in particular, those processes which occur fast enough to result in noticeable landscape changes during a human lifetime (and thus the ones most likely to have an impact on our society), but occur too slowly for a student to be able to observe in person in the field. Examples that were specifically listed by educators who participated in the April 2013 online survey as processes they have demonstrated in their courses using time-lapse videos include lava dome growth, lava flows, flooding, coastal erosion, glacier flow, slow-moving landslides and other mass wasting processes, tidal processes, and stream-channel migration.
Using video-editing software, a series of time-lapse photographs can be assembled into a video clip (a time-lapse video) which can depict several years of photographs in a matter of seconds or minutes, allowing the viewer to easily view and perceive changes that occurred in the landscape during this time. The visually arresting nature of time-lapse videos can and has been used as a means by which to draw the general public’s attention to geological and environmental issues, such as the time-lapses of rapidly melting glaciers shown in the 2012 documentary *Chasing Ice* (Orlowski, 2012).

The widespread use of time-lapse video is a relatively recent development and traditionally, landscape changes that occur on time-scales that would be suitable for time-lapse photography and video have been presented via the use of time-series photographs (also known as “before/after photographs”). To illustrate the rate of glacial movement, many introductory geology textbooks include side-by-side photographs of glaciers taken years or decades apart (Tarbuck and Lutgens, 2005, p. 539). Interactive “before and after” images with drag-able sliders are increasingly used in popular media to depict changes in landscapes, often those associated with natural disasters such as Hurricane Sandy and the Oso landslide (Esri, 2012; San Jose Mercury News, 2012; Seattle Times, 2014), but also for longer term landscape changes such as glacial retreat (New Zealand Herald, 2012). NASA has developed an iPad app and website titled “Images of Change” that uses animated repeat photography (both satellite imagery and ground-based photography) and side-by-side images to showcase landscape changes in hundreds of different locations around the globe (NASA, 2014). The National Park Service has explored the use of animating repeat photography in order to educate the public about the rate of glacial retreat in Alaskan national parks (Karpilo Jr. et al., 2006).
In theory, an observant student should be able to ascertain the approximate rate of a given geological process by viewing such before and after images. For example, if the terminus of a glacier is observed to retreat 100 m in two images taken 10 years apart, then it is straightforward to assume that the average rate of retreat is 10m/yr. However, a time-lapse video of the same process offers the opportunity to see the entire process itself in action, rather than simply a start and end point. The time-lapse video may reveal that the rate of retreat is not constant over the 10-year timespan or not constant over the course of a year and may reveal other important information about the process. One of the primary questions this study seeks to answer then becomes, does a student who views a time-lapse video of a process gain a better comprehension of the rate at which the process occurs than a student who views before/after images of the same process?

**Research on Computer and Multimedia-Aided Learning**

While the effect of time-lapse videos on student understanding of rates of geological processes has not been quantitatively studied, the use of time-lapse videos to communicate concepts in other scientific disciplines has been explored with inconclusive results (Schultz, 2007).

A much larger body of literature exists with regard to determining the effectiveness of computer-based animations and videos (although not specifically time-lapse videos) on student learning in the sciences. Computers have the advantage of being able to display a wide variety of information, and can help students visualize abstract processes that can be difficult to see for themselves (Reif, 2010). Like other forms of computer-based visualizations, research has shown that students who learn using multimedia devices, generally defined as a combination of text along with visual aids such as pictures or
animation, retain knowledge better, and are more successful in applying their knowledge to new problems and situations (Mayer, 2001). Other studies have demonstrated that computer based visualizations and activities are more effective at communicating scientific concepts than traditional text and static image based instruction (Malone, 2005; Thatcher, 2006; Klenk, 2012).

With the research supporting the use of multimedia education in mind, it is important to remember that time-lapse videos differ from other forms of computer visualizations in several important ways. First of all, a time-lapse video is not a “cartoon”, but rather an actual depiction of some geologic process, seen precisely as a human observer would view it. A time-lapse video, while still a computer visualization in the strictest sense of the term, is based in the real world in a way that few other types of computer animation can match. Time-lapse is a depiction of the process at the same scale as it occurs in the real Earth, not a video of a small-scale model of the process. Simulating landscape changes in a laboratory setting or through theoretical modeling generally suffer from pitfalls related to the scale of the experiment (Sharp, 1982). As a result, few geologists would dispute that the best way to learn about a geologic process is to observe it in person (Sharp, 1982). By this reasoning, a time-lapse video is the next best thing to actually being there in the field to observe the process firsthand. In the cases of slower processes where this is not possible, a time-lapse video may be even better than in person observations.

**Effects of Interactivity**

Computer-based instructional methods also offer the advantage of increased interactivity compared to a textbook or static photographs. Research has shown that students who use computer-based learning exercises with greater levels of interactivity perform better and are
more engaged when compared to students who use computer-based learning exercises with less interactivity (Zhang, 2005).

The Swift Creek Landslide Observatory at Western Washington University operates a website that combines interactivity with viewing time-lapse videos (http://landslide.geol.wwu.edu/). This site allows anyone with an internet connection to access several years of time-lapse photographs of the Swift Creek landslide, a slow moving landslide in Whatcom County, Washington. The website interface allows users to generate their own custom time-lapse videos of the landslide by allowing control over various parameters of the video, such as start and end date, frame rate, and video duration. The impetus behind development of this tool was the idea that students who are actively involved in the creation of the time-lapse videos they view may have a better sense of the time-span that the video represents and thus better be able to comprehend the rates of processes depicted in the video. However, this added complexity could conceivably inhibit the learning of some students. For example, a student who struggles with new or unfamiliar forms of technology may find the process of generating their own videos daunting, which may limit their enjoyment of the activity and limit the amount of useful information they are able to extract from the videos.

Potential Drawbacks of Time-lapse

While time-lapse videos have promise as a way to increase student understanding of rates of geological processes, the medium also has some potential drawbacks. One of the issues is that of availability. The creation of long-duration time-lapse data sets (long enough to show significant changes in the landscape) is inherently time-consuming and often resource-intensive. Many of the time-lapse data sets being used for educational purposes in geology
courses were originally gathered as part of large-scale research projects; long duration time-lapse data sets collected explicitly for use in the classroom are essentially non-existent and obtaining use of others for educational purposes can be difficult, ultimately limiting the availability of time-lapse videos for student use.

Taking time-lapse data sets and converting them into a form that can be easily utilized by educators in the classroom also requires significant time and effort. Raw time-lapse data sets require extensive processing in order to produce a video that clearly depicts the process being monitored. The amount of time required to do this is likely much more than a typical geology instructor will be able to manage. A repository of processed and ready-to-use time-lapse data sets and videos could alleviate this, although none currently exists.

Time-lapse videos are also inherently limited in the types of geologic processes they can depict. Without the development of camera systems that can survive intense pressures and temperatures, time-lapse photography is unfortunately currently limited to surficial geologic processes. Very fast processes whose duration is shorter than the capture interval of a time-lapse camera are not appropriate for depiction using time-lapse. Furthermore, given that the longest duration time-lapse sets currently in existence are on the order of decades, surface processes that occur on the scale of millions of years are unlikely to be effectively illustrated via this method any time in the foreseeable future. Such extremely long duration processes are likely best communicated to students via the use of computer animations and models (Malone, 2005; Thatcher, 2006). However it is still possible to achieve an understanding of the relative rates of these slower processes with a time-lapse video.

For example, time-lapse videos of the Columbia Glacier in Alaska depict a fast-moving tidewater glacier that undergoes significant change in the form of large calving events over as
little as a few days and large-scale changes in the position of the glacier terminus over months to years. However, a several year-long time-lapse video of the glacier and surrounding landscape reveals almost no change in the position of rocks in the foreground outcrops or the height or shape of a mountain range from which the glacier originated. This could help reinforce the idea weathering and erosion rates are far slower than the rate at which the glacier moves, something that may seem obvious to an experience geoscientist for a novice geology student may be more difficult.

Even if the time-scale of a geologic process is appropriate for capture with time-lapse, there may still be some barriers to using it to increase student understanding of the process. The flip-side of the purported advantage of time-lapse mentioned above, the fact that time-lapse is “real”, is that a time-lapse video will necessarily be much more complex than a simplified animation or cartoon of the process. The real-world complexity and possible distractions in a time-lapse video may make it more difficult for students, especially novice geology students, to focus in on only the most important and relevant information.

If not carefully made, time-lapse videos can also be potentially deceptive in the way that they present data. For example, a time-lapse video in which a month or two of images is missing (due to a technical glitch/missing data) can cause slow, gradual changes to appear more rapid and sudden to the viewer of the video. Time-lapse videos, because they depict the real world, can also be more complicated than a cartoon animation. As stated by the Earth Science Literacy Initiative, “Earth’s systems interact over a wide range of temporal and spatial scales” meaning that multiple processes may be occurring at any given time in any given landscape. While a cartoon animation often focuses on a singular process for the sake of simplicity (and at the expense of authenticity), time-lapse videos may depict several
processes simultaneously, thus making it more difficult for a novice geology student to process.

Of the geology educators who participated in the April 2013 online survey who stated that they rarely or never use time-lapse videos in their courses, the majority cited the lack of lack of readily available data sets or an aversion to the amount of time that would be required on their part to create them as the primary reasons for foregoing their use. One respondent wrote: “the benefit to student learning would need to outweigh the time it takes for me to find them and the time used in the classroom to show them.” This statement encapsulates the fact that, while time-lapse video does show promise, the technological challenges and time required to incorporate them into the classroom merit a thorough study of its effectiveness as a teaching tool.
METHODS

After considering the advantages, disadvantages, and existing applications of time-lapse in the geology classroom, the research questions this thesis seeks to answer are:

1. Do novice geology students who view time-lapse videos of landscape change develop a better understanding of rates of landscape change, as measured by their ability to qualitatively and quantitatively compare the relative rates of several surficial geologic processes, than students who compare “before and after” photographs of the same landscape changes?

2. Does actively involving students in the process of creating time-lapse videos further increase their understanding of rates of landscape change, or does the added complexity detract from their ability to extract information about rates from the time-lapse videos?

3. Do novice geology students who use time-lapse videos to learn about rates of landscape change exhibit more interest and/or motivation to learn about rates of landscape change than students who use still photographs and other static methods to explore the same concepts?

A further objective of the study, in part to address question #3, is to develop an online software interface that can be utilized by students and faculty of all levels to generate custom time-lapse videos, using any input time-series of photographs.

Study Population

In order to address these research questions, data were gathered from a controlled, quasi-experimental study using a convenient sampling of students enrolled in undergraduate level Introduction to Geology (GEOL 101) and Physical Geology (GEOL 211) classes at Western
Washington University (WWU) during the 2013/2014 academic year. These two courses are targeted at students with little to no previous geology experience, with the primary difference being that GEOL 101 is targeted towards the non-science major, while GEOL 211 is targeted toward natural science majors and potential geology majors. These two courses also attract a wide cross-section of the WWU student body; 57.1% of students who received degrees at WWU during the 2013/2014 academic year took either GEOL 101 or GEOL 211 during their time at WWU (WWU Office of Institutional Research, personal comm). Furthermore, the majority of the students enrolled in these courses do not go on to take any additional geoscience courses at WWU (76.8%), making this course their only formal exposure to geology in college (WWU O. of I.R., personal comm).

Research has shown that many students in these types of courses have generally had little to no previous exposure to geology or earth science since elementary school (DeLaughter et al., 1998; Gilbert, 2012). While some have had exposure to earth science or geology in high school, it remains that students generally have a poor understanding of geologic time and rates of geological processes upon enrolling in an introductory geology class (DeLaughter et al., 1998; Libarkin, Kurdziel, et al., 2007), making this population an appropriate one in which to test the effectiveness of time-lapse video.

As mentioned previously, time-lapse videos frequently appear in popular media and are used to communicate information about rates of geologic processes to the public. The geoscience knowledge of a population of introductory geology students more closely approximates the general public than would a population of geology majors or advanced geology students. As noted above, the vast majority of such students will not take any future geology courses. Consequently, introductory geology students represent a population for
whom it is crucial to instill the basic tenets of geologic thinking. Introductory geology classes are an opportunity to educate a new generation of decision makers and policy makers about the rates of geologic processes, so that these students have the necessary tools to approach these issues in a critical and thoughtful manner, regardless of their future career choices.

**Overview of Study Protocol**

For the study, a pre-test/post-test design and random sampling within the population of introductory geology students was used (Figure 2). All participants took a pre-test upon beginning participation in the study in order to quantify their initial knowledge of the concepts being assessed, and an identical post-test after completing an activity designed to teach students about the rates of various geologic processes. The assessments (see below for detailed description of assessment development) focused on student understanding of the rates and magnitudes of landscape change in four different geologic environments: a tidewater glacier, a slow-moving landslide, a volcanic lava dome and crater, and a fluvial system. Time-lapse videos and photos documenting changes in these landscapes over 2-10 years formed the basis for the different treatment activities. Study participants were randomly divided into three treatment groups in order to compare the relative effects of three different interactive computer based activities on student comprehension of the rates of landscape change. Group 1 compared “before and after” photographs of the four landscapes using a “drag-able” slider. Two separate groups viewed time-lapse videos of the four landscapes, with one viewing a series of pre-made videos (hereafter referred to as Group 2) and another creating their own custom time-lapse videos (hereafter referred to as Group 3) using an online software interface originally developed by the Swift Creek Landslide Observatory and modified for use in this study.
Study design and preliminary testing of treatment activities and assessments took place between Fall quarter 2012 and Winter quarter 2014. Student participants for the main study were drawn from the two introductory geology classes during Winter and Spring quarters, 2014. GEOL 101 has an average total enrollment of 480 students each quarter (divided across four sections with different instructors) while GEOL 211 has a quarterly enrollment of about 90-100. Because human subjects were used in this research, a Human Subjects Research Exemption form and research protocol was filed with the WWU Institutional Review Board (IRB) in May 2013 and approved on May 31 2013 (Appendix B). A revised version of the protocol was approved on January 14, 2014. (Appendix B)

All students enrolled in the two courses were given the opportunity to participate in the research project, although the fact that participation was completely voluntary was emphasized to students. During the first week of classes, I gave a short, in-person, introduction to the research project at the end of class and had interested students sign and return informed consent forms (Appendix C) prior to leaving class. All students who signed an informed consent form indicating intent to participate were enrolled in a Canvas (WWU’s online learning management system) course created for the purpose of managing and contacting study participants.

Three weeks into the quarter, participants were sent an email with a link to an online “Predictions Quiz” (hereafter referred to as the “pre-test, but known as the “Predictions Quiz” to study participants). The pre-test contained questions to collect demographic information about the participants as well as questions designed to gauge students’ initial level of understanding of rates of geological processes. Once enrolled in the Canvas course, and prior to completing the pre-test, participants were randomly assigned into one of the
three aforementioned treatment groups. Treatment took place in university computer labs which were reserved for the purposes of this study. Participants had a two-week window (during the 5th and 6th weeks of the academic quarter) to sign up for a one-hour time slot during which they would come to a computer lab to complete the treatment activity and post-test under the supervision of the researcher. Participants were directed to complete the pre-test prior to arriving in the computer lab; if they failed to do so, they were given the opportunity to do so in the computer lab prior to beginning treatment.

All three groups completed the treatment phase by navigating to a website designed for this study (Appendix D). Three versions of the website were created, one for each treatment group. Participants were only given access to the webpage for the group they were assigned to. The websites were secured using passwords that were provided to participants only upon arrival in the computer labs. Passwords were changed daily throughout the study so that students could not provide passwords to non-participating students or students in another group.

Each website was divided into four sections (one for each of the landscapes) which contained directions (Appendix D, Figure D.1), background information on each landscape (Appendix D, Figure D.2), and then a series of before/after photos (Appendix D, Figure D.3), or time-lapse videos (Appendix D, Figure D.4) depicting changes in the landscape over time. Participants were given a sheet of conceptual questions (the same questions for each group) to guide their interaction with the time-lapse videos and photos (Appendix E) but did not have access to the test questions while looking at the photos/videos. This was done deliberately in an attempt to quantify how the photos and videos affected student
understanding of rates of geological processes and how well they were able to retain this information when taking a post-test a short while later.

Students were not given a prescribed amount of time to spend looking at the time-lapse photos or videos although the time they spent on the treatment activities was tracked. After students had finished viewing the time-lapse photos/videos, they were provided a link to the post-test which contained identical questions to the pre-test as well as a short questionnaire asking them to reflect on the treatment activities and their participation in the study.

All three groups received identical general instructions, guiding questions, and background information on the landscapes covered by the activities. The only differences in the instructions provided related to the type of treatment being administered. For example, participants in Group 1 were given instructions on how to use the slider to compare the before/after images, while students in Group 3 were given a short tutorial on how to use the interactive time-lapse generator. The pre- and post-tests taken by the three groups were also identical, apart from replacing the word “photo” with “video” for students in groups 2 and 3. All three groups had the freedom to watch as many videos as they wished, and also to replay/pause/rewind videos as often as they liked. No group was forced to watch any of the videos or look at any of the photos.

As the primary researcher, I was present in the computer lab during the entirety of the treatment and post-test in order to assist with technical difficulties and ensure that students were following the directions provided and not utilizing outside resources (i.e., Google, smartphones) to answer assessment questions. All participants were provided with their choice of a $10 coffee gift card or free movie ticket upon leaving the computer lab as compensation for their time.
Description of Treatment Activities

Group 1: Before/after photo group

Students assigned to this group did not receive any exposure to time-lapse videos within the context of the study and in some ways served as a “control” group. However this group still completed treatment activities so it is not a control group in the strict sense of the term and will not be referred to as such. Students in this group used a series of “before-and-after” image pairs from the same data sets that were used to create the time-lapse videos used by Groups 2 and 3. Rather than presenting static side-by-side images, the images were overlaid and a JavaScript slider was utilized in order to allow students to easily compare the two images (Figure 3). The images used in these photo pairs were selected so as to match as closely as possible the periods of time and the changes represented in the time-lapse videos used by the other two groups. For each landscape, several pairs of photos representing different intervals of time were presented, allowing students to gauge how much the landscape had changed after differing periods of time. The capture date of both images in each pair was clearly displayed, both in the image itself and in accompanying text.

Group 2: Passive time-lapse group

Students in Group 2 viewed a series of 14 pre-made time-lapse videos, ranging in length from 14 seconds to 2.5 minutes, to explore changes in the four landscapes over time. All videos were created by myself and contained an embedded date stamp that afforded the viewer a sense of the length of time represented by the video. Students had the ability to pause, stop, and re-play all videos. Students could also use the time-slider to manually play the video or watch a specific part of the video.
**Group 3: Interactive time-lapse group**

Students in Group 3 used an online webpage to create their own time-lapse videos of the four landscapes. Students in this group were able to manipulate a number of different parameters that influenced the resulting video. Students were able to choose the starting and ending dates for the video, the playback duration, frame rate, and whether or not to selectively include photos from certain times of day (Figure 4). As with Group 2, students in this group had the ability to pause, stop, and re-play all videos that they created. All students in this group were given a short (~two minute) tutorial on how to use the time-lapse generator before beginning treatment. Because the students in Group 3 generated their own time-lapse videos, they videos they created and viewed are unlikely to have matched the pre-made videos shown to Group 2 and the photo pairs shown to Group 1.

**Selection of Time-lapse Data Sets:**

Due to the inherently time-consuming and expensive nature of producing long duration time-lapse data sets, a number of existing data sets were utilized for this project. Data sets were chosen with several factors in mind. First of all, potential data sets needed to consist of a continuous series of images taken across an extended period of time, preferably several years, in order to produce time-lapse videos that showed substantial changes in the landscape, and yet changes that would not be readily apparent to a human observer in the same location. Data sets with large gaps would be inappropriate because they would cause slow, steady changes to appear to occur rapidly and make it difficult for a novice geology student to determine how long the change actually took to occur.

Secondly, ideal data sets depicted processes or landscapes that contain features that will be recognizable to beginning geology students (Jolley, 2010). For example, most students,
regardless of their prior geological knowledge, would be able to identify a moving glacier or volcano in a photograph or video, whereas a time-lapse video depicting lava flow inflation might be of great use to a volcanologist, but less recognizable and relevant to a novice geology student. Data sets that depicted locations in the Pacific Northwest were also desired. Because more than 90% of the student body of WWU is from the state of Washington (Western Washington University, 2013), data sets that depicted locations in the Pacific Northwest were desired so students might view the activities as more relevant to their lives.

While a number of existing data sets met these criteria, obtaining access to and permission to use the raw time-lapse images proved difficult. Ultimately, four time-lapse data sets were chosen for the project (Table 1):

1. **Columbia Glacier, Alaska.** Several years of time-lapse data depicting changes in the Columbia Glacier along the coast of Alaska were made available by the Earth Observing Laboratory (EOL), a division of the National Center for Atmospheric Research (NCAR). The Columbia Glacier is a large, fast-moving tidewater glacier originating in the Chugach Mountains of southern Alaska which flows into Prince William Sound. Several different surface processes are depicted in the Columbia Glacier data set. The continuous forward movement of the glacier is perhaps the most obvious, and seasonal variations in the slip rate of the glacier can be observed. From the terminus camera, a number of large calving events are evident, although most are not actually captured in progress due to the extremely quick nature of the events. Because images were captured hourly, the rise and fall of the tide relative to the glacier front is also visible. These images also include a rocky outcrop and hillslope
in the foreground which allows a comparison between the rate of movement of the glacier and the much slower rate of erosion.

Time-lapse data is available from several different camera angles and spans the years 2004-2011, although the highest quality and best temporal resolution was from the years 2007-2011. Time-lapse images from cameras AK01 and AK02 were used in this project. Permission to use this data for educational purposes is provided by NCAR/EOL under sponsorship of the National Science Foundation (http://data.eol.ucar.edu/).

2. **Swift Creek landslide, Whatcom County, Washington.** Time-lapse data captured by the Swift Creek Landslide Observatory at Western Washington University depicting the movement of the Swift Creek Landslide dates back to 2004. The Swift Creek landslide is a deep-seated, slow-moving (~3-4 m/yr) landslide in highly weathered serpentinite bedrock on the west side of Sumas Mountain in the foothills of the Cascade range in Washington state (Bayer and Linneman, 2011). The time-lapse camera used for this project is aimed at the toe of the landslide where shallower movement can exceed 40m/yr (Bayer and Linneman, 2011). Movement of landslide material is highly seasonal, and the time-lapse cameras readily capture the increase rate of movement of the landslide in the winter months when precipitation is more plentiful and the landslide slope is saturated (McKenzie-Johnson, 2004). The time-lapse cameras also show that movement of the material is continuous, yet slower, during the dry summer months. The time-lapse camera also shows the differential rate of movement across the landslide, with finer grained material in the foreground moving at a significantly faster rate than an area of boulders in the background.
3. **Elwha River Restoration Project, Olympic Peninsula, Washington.** Using a series of webcams, the National Park Service and United States Geological Survey has captured time-lapse data sets depicting the decommissioning of the Elwha and Glines Canyon Dams on the Elwha River SW of Port Angeles, Washington. 10 webcams have monitored the changes that have occurred from mid-2011 to the present along various stretches of the river as Lake Aldwell and Lake Mills, the reservoirs formerly impounded behind the dams, have been drained and the Elwha River re-establishes its course. These data sets depict a rapidly changing fluvial system and the restoration of a natural riparian ecosystem that began to be altered when the Elwha Dam was built in 1910. While this data set is shorter than the others, it offers an opportunity for students to see the effect of human activity on the rates of geological processes. Date from the Lake Aldwell Delta and Lake Mills Delta cameras were used in this project.

The Elwha River cameras capture typical patterns of river channel migration, albeit accelerated to some degree by the removal of the dams. Time-lapse videos made from these cameras show the large variations in river discharge over the course of a year, and how the rate of riverbank erosion and channel migration is correlated with higher discharge. The greater rate of erosion along cut banks (outside bend of a meander) is also clearly visible. Some small shrubs and trees in the foreground of the images also provide context for the rate of changes along the river. Growth in the vegetation can be observed over several months to years, and the vegetation grows enough in several years that it begins to obtrude the field of view near the end of the videos.
4. Mt. St. Helens, Washington. The United States Geological Survey maintained a webcam from 2007-2011 which monitored lava dome growth and growth of the Crater Glacier in the summit crater formed by the 1980 eruption of Mt. St. Helens. These images were made available via CD-ROM by the Cascade Volcano Observatory. USGS images are in the public domain, allowing them to be used in this project.

Preparation of Time-Lapse Data Sets

All of the raw time-lapse data sets acquired for use in this project required extensive editing and processing in order to obtain a product that was useful for educational purposes. Because one of the goals of this project was to create several time-lapse data sets suitable for use in the introductory geology classroom, what follows is a description of the process used to process and edit the time-lapse data sets, as well as the procedure used to create the time-lapse videos and the webpages used for treatment.

Acquiring images: Two of the four time-lapse data sets used in this project were no longer capturing images at the time of the study (Columbia Glacier and Crater Glacier) and thus the data sets were obtained in their entirety via FTP and a CD-ROM respectively. Images from the Elwah River and Swift Creek landslide time-lapse cameras were still being actively collected as of March 2014. Data from the Elwah River cameras were originally obtained via hard drive in January 2013. Updated imagery was obtained via the internet using a modified version of the Linux script “wget”. This script takes advantage of the fact that each image in the Elwah River data set can be accessed via a unique URL. A text file available online lists the unique path suffix for each image which can be appended en masse to the base URL using Microsoft Excel. Once this is done, the full URL for all images can be
copied into a .txt file which can be referenced in the “wget” command line allowing the
script to automatically download the image found at each URL to a user-specified directory
on a local hard drive. Images were collected in this manner through January 14 2014 for use
in the study. Updated images of the Swift Creek landslide were obtained from a hard drive in
the WWU Geology Department.

**Data reduction:** With the exception of the Crater Glacier data-set, the image sets
obtained consisted of all of the raw images obtained by the time-lapse cameras. (Images in
the Columbia Glacier data set had been time-corrected and compressed). Raw images, which
varied considerably in original resolution, were downsized to a universal width of 800 pixels;
sufficiently large enough for web viewing and video creation and small enough to maintain
manageable file sizes, a necessity given the large quantity of images in each data set. All
images were renamed using “date created” metadata embedded in the images. A consistent
file naming scheme was created in the form of YYYY-MM-DD_HH_MM_SS.jpg. All
images were renamed using the free online utility “Bulk Rename Utility”.

Many of the raw images (as much as 20% in some data sets) were unusable due to
darkness or equipment error/failure. While time-lapse systems are generally designed to only
take photos during daylight hours, the sensors that accomplish this are not foolproof and
often the camera will take photos during periods of darkness, especially if moonlight is
present, leading to a number of useless images which must be removed before making a
video. Many images also contain fog, rain drops on the lens, or snow accumulations in front
of the lens, all of which can partly or wholly obscure the view of the target landscape (Figure
5). Time-lapse videos made with such images included can be very distracting to watch, so
for the sake of producing watchable videos, images in which the target landscape was not
visible due to any combination of the above reasons (and less commonly lens flare, extremely high dynamic range, insets, or human hands/other appendages) were removed from the data set.

**Image Processing**

The most significant challenge encountered during data processing was dealing with the inherently large dynamic range (ratio between maximum and minimum light intensities in a digital image) present in many of the images. Any time-lapse camera recording long-term (months to years) changes in a landscape will be operating in a wide range of weather and lighting conditions. Many of these lighting conditions are not ideal for capturing photographs of a landscape. For example, overcast days generally produce the best photos, as shadows are minimal and the landscape is fairly evenly illuminated. Potentially obscuring/distracting shadows can be prevalent on sunny days and the shadows change in length and angle as the Sun traverses the sky over the course of a day. Images taken at sunset and sunrise can exhibit extremely high dynamic range; if the camera exposes for the sky, the foreground landscape is likely to be underexposed by several stops, but if the camera exposes for the landscape, the sky can become so overexposed that light can bleed into the foreground ruining the image.

Compositing images that exhibit a wide range in brightness’s into a time-lapse video leads to a phenomenon known as “flicker”, where the rapid shift from lighter to darker images over the duration of the video can make the animation difficult to watch. Steps to prevent flicker can be taken when gathering short-duration time-lapse data sets (although a small amount of flicker is nearly unavoidable), but is difficult to control for in extremely long-duration time-lapses where the camera is operated remotely and must be set to “AUTO”. Much of the image processing undertaken in this project focused on attempting to
minimize the dynamic range present in the raw time-lapse images; in other words, brightening the shadows and dimming the highlights in order to produce an image that is more evenly toned. Adobe Lightroom was utilized for its ability to apply the same adjustments to thousands of images simultaneously. Lightroom’s “Auto White Balance” and “Auto Tone” features were applied to nearly all of the raw images which eliminated the need to go through every single image by hand. In cases where the Auto commands did a poor job, thousands of individual images were edited by hand to achieve the desired result. While obtaining a video completely free of flicker given the high dynamic range present in the data sets is impossible, the steps taken above did result in noticeably easier to watch and more aesthetically pleasing videos compared to videos made using the raw images. Editing each individual image by hand would likely have produced even better results, however, given the large size of many of the data sets (10’s of thousands of images) this was not feasible in this project. For comparison, the time-lapse videos produced for this project are comparable in terms of flicker to those produced by the Extreme Ice Survey using the same raw images of the Columbia Glacier (Extreme Ice Survey, 2009)

Another technique for combating the dynamic range issue is to make time-lapse videos using only images from a certain time of day. In order to compress long durations into short videos at normal frame rates, it is often impossible to include all the images from a given date range; some must be removed. By including only images from a certain time of day (say 11-1 for example, when the Sun is nearly overhead and shadows are at their smaller), the dynamic range issues and distracting shadows associated with the change in position of the Sun over the course of the day are minimized. While dynamic range issues due to changing weather are still present, time-lapse videos made in this manner often look much “smoother”
than ones where images from all hours of the day are incorporated. The ability to selectively choose images from a certain time-of-day is one of the feature that is present in the online time-lapse generator used by Group 3, and thus was used to make several of the videos shown to Group 2 as well.

Changes in camera angle during data collection also presented challenged during image processing. In some cases, these changes were deliberate, to keep up with a rapidly retreating glacier for example, and in other cases the result of wind or other factors moving the camera. Regardless of the reasons, using images that are not all taken from exactly the same spot to make a time-lapse video causes there to be abrupt jumps in the position of features in the landscape. In some ways large changes are almost better than small ones, because a large shift is clearly the result of the camera being moved, whereas small shifts can be interpreted as an actual change in the landscape.

Extensive processing was done in Photoshop and Lightroom to match up the perspective of the images as best as possible. This involved cropping, rotating, and scaling images but not all shifts in camera position could be entirely mitigated. Some of the more complex shifts involved both translational and rotational components of movement, in many cases also accompanied by a change in scale, likely due to either a lens change or a change in the zoom level of the camera lens. The parallax errors associated with the position of the foreground on these more complex changes could often not be completely eradicated, an important factor to consider given that a slight change in the positioning of the foreground or background could be perceived by a novice geology student as an actual landscape change.

In all data sets except for Elwah River, the “Mogrify” plug-in for Lightroom was used to overlay a datestamp in the upper right-hand corner of the image. The Mogrify plugin uses
imbedded metadata to embed the month, day, and year that each image was taken. Ideally all four data sets would have contained an identical date stamp, however the Elwah River images did not have metadata embedded in the images but did have an existing date stamp, which although smaller and a different font, was sufficiently large enough to see in the time-lapse videos.

**Rendering Videos**

Once editing of the raw images was complete, sequences of JPEG images were imported into Adobe AfterEffects for video creation. It should be noted that AfterEffects contains a variety of plug-ins that can perform many of the same dynamic range-reducing functions that were performed in Lightroom, thereby reducing flicker in the videos. However these functions could not be utilized because of the desire to have the videos used by Group 3 (using the time-lapse video generator) be as identical as possible to the videos viewed by Group 2. The online time-lapse generator relies solely on input images to produce a video; it cannot apply any effects to the images themselves as is possible via AfterEffects. For this reason, all editing done with the intent of minimizing the high dynamic range present in the raw images had to be done at the individual image level so that the edited images could be loaded into the time-lapse generator, thus affording both Groups 2 and 3 the benefit of videos made with equivalently improved images.

A frame rate of either 30 or 60 frames per second was used for all videos, depending on the desired duration of the video and the number of raw images to include. All time-lapse videos were exported as .mp4 files, a common compressed video file format that had the advantage of relatively small file size, and wide compatibility with common internet browsers such as Google Chrome and Mozilla Firefox.
Creation of Before and After Photo Pairs

Preparing the before and after images pairs for Group 1 took place after rendering of the time-lapse videos. Pairs of photos were chosen so that the information presented was as similar as possible to the time-lapse videos. While significantly less time-intensive than the creation of the time-lapse videos, selecting and making the image pairs still involved some challenges, most of which revolved precisely aligning the images so that viewers do not interpret slight shifts in image alignment as actual landscape changes (Karpilo Jr. et al., 2006). The slider utilized a free jQuery script that was obtained from http://www.catchmyfame.com/catchmyfame-jquery-plugins/jquery-beforeafter-plugin/ which I then modified in order to meet the needs of this project.

Design of Website

Because the entirety of the treatment would take place online, attention was paid to research on designing effective online learning experiences during the development of the website (Siragusa et al., 2006). The treatment webpages were written using HTML5 and CSS and hosted on my university-provided network storage space. This method proved fast enough for videos to load with little or no lag time even when multiple users accessed the same video simultaneously.

Upon arriving at the website (from Canvas), participants were presented with a welcome page which included instructions for the type of treatment they were about to undertake (Appendix D, Figure D.1). Site navigation was kept simple; four buttons along the top of the screen corresponded to each of the four landscapes. Students could easily click on these buttons to move between landscapes. Each landscape page began with a brief description of the landscape and any background information needed to interpret the changes occurring in
the landscape (Appendix D, Figure D.2). An annotated photo of each landscape was also included, with labels identifying the different geological features in the landscape, and scale where possible (Appendix D, Figure D.2). In some cases, the scale of the photograph varies too widely (scale is different in the foreground than in the background) to include a graphical scale, and a verbal scale was provided instead that gave the dimensions of a particular reference feature in the landscape (i.e., the height of the glacier terminus is 50 meters). Comparisons to recognizable objects were also included in order to help students internalize a particular distance (i.e., 10 meters is approximately the length of a city bus). At the top of the page was a “Home” button that allowed students to return to the directions/welcome page if necessary and a button titled “Take Quiz” which students were instructed to click on after they had finished looking at the time-lapse photos/videos which would then take them to the post-test (Appendix D, Figure D.1).

Surveys of online learners have shown that the organization and structure in which information is presented on an educational webpage is extremely important in facilitating learning (Siragusa et al., 2006). Visual elements (photos and videos) are generally preferable to large quantities of text on webpages devoted to learning. Care was taken to make navigating through the pages as simple as possible. The site was beta tested for usability prior to implementation by a number of geology students and faculty. The site was also tested for compatibility on both Firefox and Chrome, the two browsers available on the computer that would be used by participants to complete treatment. Another feature of the website was hyperlinks to a glossary (hosted on Canvas) that explained any geologic terms that participants might be unfamiliar with. The definitions in this glossary were taken from introductory geology textbooks, and augmented as needed.
Assessment Development and Instrument Design

Because a validated and reliable assessment for probing student understanding of rates of landscape changes does not currently exist, a primary outcome of this project was to develop an assessment tied as closely as possible to the specific processes depicted by the chosen time-lapse data sets.

The first, and arguably most important, step in designing an effective assessment instrument is to identify desired learning outcomes. These learning outcomes outline broad themes that study participants would ideally have a good understanding of after interacting with the time-lapse photos and/or videos. A list of desired learning outcomes was developed by reviewing the aforementioned Earth Science Literacy Principles, a variety of introductory geology textbooks, and through conversations and revision with geology faculty at WWU:

- Earth is continuously changing.
- Earth changes according to physical laws. These changes may be small or large, continuous or sporadic, and gradual or catastrophic.
- Earth’s surface is shaped by geologic processes that occur at different rates.
- The “rate” of a geologic process is defined as the amount of change we observe per unit time.
- Geologic processes can occur rapidly, with consequences for living organisms.
- Many geologic processes occur too slowly for a human to observe in person, yet can have consequences for humans and society.
- Humans can change the rate at which geologic processes occur.
- The rate of change for a given geologic process is not always constant. It may change based on geographic location, climate, season, tectonic stress, and other factors.
- Landscapes represent a balance between processes that form (such as mountain building or volcanism) and processes that destroy (such as erosion and weathering).
- In certain situations, geologists can use the rate of a process to predict what a landscape might look like in the future.
While creating a list of learning goals is useful for guiding the initial phases of assessment design, assessing “conceptual understanding” of broad statements such as the ones above can be difficult unless the desired learning outcomes are transformed into clearly stated and observable performance goals (Reif, 2010). In other words, the above concepts must be operationalized; we must “specify what one would actually need to do to determine how well the desired performance has been achieved” (Reif, 2010). Once development of the time-lapse photos and videos was complete, a list of operationalized learning goals was developed (Table 2). This list of tasks takes the learning outcomes above and categorizes them into practicable skills that can more easily be measured via an assessment.

Using best practices for writing assessment items found in the literature (Frey et al., 2005; Taylor and Smith, 2009; Libarkin and Ward, 2011), a 22-item (plus sub-items) assessment was developed containing a variety of different question types including multiple choice, matching, Likert-scale, and open-ended (Appendix G). The integration of both quantitative and qualitative questions, a so-called “mixed-methods” approach, was used because it offers the greatest combination of statistical power and insight into student understanding (Johnson and Onwuegbuzie, 2004; Kortz et al., 2011).

Each assessment item was tied to one or more of the learning outcomes presented in Table 2. Most questions specifically referenced the landscapes presented in the time-lapse videos and photos; however, general questions probing student ideas about rates of geological processes were also included. Multiple choice items (Table 3) made up the majority of the questions on the assessments due to ease with which they can be scored and used to produce a numerical score for each participant which can then be statistically
analyzed. Furthermore, well-written multiple choice questions have been shown to be good indicators of student understanding, especially when their development is informed by knowledge of student preconceptions on the topic (Sadler, 1998; Bardar et al., 2006; Libarkin, Anderson, et al., 2007; Libarkin and Ward, 2011). In order to most effectively reveal changes in student understanding, assessments should incorporate preconceptions that are held by a significant number of the study population. Knowledge of these preconceptions can come from a variety of sources (Libarkin and Ward, 2011). In this study, personal experience, previous literature on common misconceptions held by novice geology students (Francek, 2013), answers from the preliminary survey of GEOL 101 students administered during Spring 2013 quarter, and student comments during think-aloud interviews held during assessment design (see next section) were relied upon extensively to guide assessment design and generate multiple-choice distractors.

A number of qualitative or open-ended questions (Table 4) were also included because they can offer additional insight into student thoughts than even a well-designed multiple-choice item, although the process of coding and categorizing responses takes longer and can be more subjective. In this case, the intended sample size was small enough (a target of 180 at the time of assessment development) that the amount of time required to code and classify qualitative responses was outweighed by the additional insight that would be gained. Several multiple-choice items included an add-on open-ended text box that asked students to explain their rationale for choosing a particular multiple-choice option. Finally, a series of Likert-scale questions (Table 4) were included to probe student agreement or disagreement with various statements about rates of geological processes.
Note that several assessment items were designed simply to elicit student’s thoughts or level of understanding about a particular topic and do not have a “correct” answer. Item numbers which do not have a correct answer are indicated by bold text in Table 2.

A 13-question demographic questionnaire was added to the beginning of the pre-test (Appendix F) to collect basic information about participants. A short questionnaire with Likert-scale and open-ended questions was added to the end of the post-test (Appendix H) in order to probe student attitudes towards the treatment activities, such as their level of comfort using the software interface, how much they enjoyed the activity, and to what extent they gave their best effort to answer the questions.

The pre- and post- versions of the assessments were identical apart from changing the tense of some questions where appropriate. The versions of the assessments administered to each of the three groups were also identical, apart from the substitution of the words “photos” and “videos” depending on the type of treatment each group was to receive. *SurveyMonkey* was used to distribute the assessments and tabulate responses. All assessments were anonymous at the request of the IRB. Participant’s pre- and post-tests were matched with each other by having the participant enter the last four digits of their student ID number at the beginning of the test. Because I did not have access to students’ full ID numbers, this method of tracking ensured anonymity while allowing student responses on the pre- and post-tests to be matched with each other.

**Think-Aloud Interviews and Revision**

It is well established that students do not always interpret test questions, especially multiple choice questions, as intended by the test-writer or researcher (e.g., Harlow and Jones, 2004). Therefore, establishing the communication validity of items (i.e., does the test
taker interpret the question in the same way as intended by the test-developer?) is a crucial step in designing a valid assessment (Clark and Libarkin, 2011). Once a draft version of the assessment was created, a series of one-on-one interviews were conducted with 25 student volunteers during Fall 2013 quarter in order to test the communication validity of assessment questions so that revisions could be made (Beatty and Willis, 2007; Libarkin and Ward, 2011). Approximately 25 students from GEOL 101, GEOL 211, and an earth science education course participated in 20-40 minute long cognitive “think-aloud interviews” as part of this study. In these interviews, students were given a draft copy of the assessment and asked to read aloud each item along with any multiple choice answers before proceeding to answer the question. Students were encouraged to verbally describe their thought process while answering each question.

These interviews served several purposes. First, they allowed the text of the questions to be revised, in some cases significantly, in order to make questions clearer and less ambiguous. A key tenet of designing effective assessment questions is ensuring that the language used is appropriate for the study population (Clark and Libarkin, 2011) so any terms that were not well understood by introductory geology students were removed. Secondly, the interviews provided substantial insight into the item validity of the assessment items. Careful attention was paid to student responses to ensure that students who identified correct answers were able to do so because they truly understood the concept associated with the item, rather than simply guessing. Finally, the interviews provided further insight into existing preconceptions about rates of geological processes held by the study population. Some of the preconceptions uncovered during the interviews were subsequently incorporated into the assessments as multiple choice item distractors.
Revision of assessment items was ongoing throughout the two weeks during which interviews took place. As a result, four different versions of the assessment were tested over the course of the interviews. Items which, even after multiple revisions, continued to exhibit concerns related to communication validity or item validity were removed from the final version of the assessments.

Following the interviews, text boxes were added to several of the multiple-choice items on the final version of the assessments. These test boxes asked participants to “Please briefly explain why you chose the answer that you did”. Adding these text boxes served as a further check on the validity of the items and allow additional qualitative insight into why students chose a particular multiple choice answer (Reif, 2010).

Two forms of the assessment were piloted during the interviews: a paper version, and a computer-based version using SurveyMonkey, in order to see which version students expressed greater comfort using. While student comments were varied as to whether they preferred taking electronic or paper assessments, ultimately most interview participants expressed satisfaction with whichever method (paper or online) they had been randomly selected to use during the interview. Several of the interview volunteers were also asked to complete a beta version of the treatment exercises which involved viewing a series of time-lapse videos or photos and then briefly revisiting their answers to the corresponding assessment items. Several geology graduate students and non-geologists also took beta version of the assessments and offered important comments and perspectives.

Assessment Length

Yet another function of the think-aloud interviews was to gauge the amount of time that would be required for students to complete the assessments. Managing the total cognitive
load on study participants was a major concern during the assessment and study design process. Test fatigue has been a documented issue in similar studies where students subjected to treatments and tests lasting more than an hour have expressed that they did not give their full effort because they became fatigued or sick of taking the test (Malone, 2005). As a result, the desire was that the pre-test would be able to be completed by a typical student in less than 30 minutes, in order to avoid test fatigue and decrease the overall cognitive load required by participants (Malone, 2005; Reif, 2010). Treatment activities were also designed to be completed in a relatively short amount of time (20-45 minutes) so that the total time commitment required by participants would be between 60-90 minutes, split into two different sessions. While less data will be produced with a shorter assessment, the data will be of a higher quality if participants are remain happy and engaged through the entire study.

**Development of Answers and Rubrics**

Correct/acceptable answers to assessment items were determined by reviewing the corresponding time-lapse videos, as well as by consulting current geologic literature on the rates of the different processes depicted in the videos. Correct/acceptable answers are highlighted in bold in Table 3.

It is important to note that the rate of many of the processes which students viewed in the time-lapse videos can vary widely depending on various factors. Landslides are a good example. Depending on the geologic setting, landslides can occur quickly or slowly. Because assessment questions referred specifically to the processes observed in the videos/photos, and because the goal of this project was to test how much information students could extract from the videos/photos, acceptable answers were considered to be those that reflected the rate of the process as shown in the videos/photos. For example, while landslides can occur in
seconds or minutes, such an answer would be considered incorrect on the questions that ask about the rate of the Swift Creek landslide, which moves at a much slower rate. Below is a list of the range of acceptable answers for each process depicted in the time-lapse videos (item #22a-h) along with any external references that were used to establish the acceptable range. Because students had limited time to view the time-lapse videos, a range of acceptable answers is allowed for each.

- **The tide going in and out once**: Hours (Tarbuck and Lutgens, 2005)
- **The formation of a volcanic lava dome**: Months, Years (Smith et al., 2011) (Holland et al., 2011)
- **Complete wearing down of a mountain range by weathering and erosion**: Millions of years, billions of years (Egholm et al., 2013). Note: because this process occurs on time-scales not easily capture with time-lapse, the goal here was not to test what students knew about long-term erosion rates, but rather to test whether students noticed that large-scale weathering and erosion of the mountain range was NOT visible in the time-lapse, and thus were able to deduce that the rate is much slower, relatively speaking, than any of the other processes covered on the assessment. While the ideal outcome would be for students to understand the upper limits of the process, since weathering and erosion of the mountain range is not depicted in the time-lapse, there is no way for students to differentiate between millions and billions of years in this exercise. For this reason, any student that answered millions or billions of years was considered to have answered the question correctly, even though the exact rate of weathering and erosion of a mountain range can vary widely.
• **Uplift of a large mountain range from a flat plain:** Millions of years, billions of years (Burns and Surveys, 1991) (Jolley, 2010). See previous note for explanation.

• **Soil, boulders, and trees moving downhill in a landslide (Swift Creek landslide):** Weeks, Months, Years (Bayer and Linneman, 2011)

• **A river channel changing its course:** Days, Weeks, Months, Years (Draut et al., 2008) (Draut et al., 2011).

• **A large piece of ice breaks off a tidewater glacier forming an iceberg:** Seconds, Minutes (Orlowski, 2012).

• **A tidewater glacier moves 10 meters:** Hours, Days (Walters and Dunlap, 1987) (Ahn and Box, 2010).

**Anticipated Threats to Validity**

In any experimental study, a major concern is the “validity” of the study design, which, broadly speaking, refers to the appropriateness of the inferences that are made using obtained data (Shadish et al., 2001; Gay and Airasian, 2003). It is important to consider possible threats to validity prior to implementation of the study in order to reduce the number that may have an effect on the final results (Shadish et al., 2001). While no experiment can avoid all possible threats to validity, a careful analysis of those that are most likely to be important in the context of this study was a crucial element of the study design process. Shadish et al. (2001) identifies four main types of validity: internal validity, statistical conclusion validity, construct validity, and external validity:

**Internal Validity:** Internal validity (sometimes referred to as “conclusion validity” in the literature) refers to whether a causal link between a dependent and independent variable can be reasonably inferred and is potentially the most important type of validity to consider in
this type of study (Shadish et al., 2001). To claim internal validity, it needs to be shown that there is no other plausible explanation for any observed relationship between the independent and dependent variables. In this study, the independent variable is the type of instruction utilized by the different treatment groups (before and after photos vs. passive time-lapse vs. interactive time-lapse) while the dependent variable is student understanding of rates of geological processes as measured by the assessments described in the previous section. Suppose the observation is made that students in the time-lapse groups (2 and 3) perform better on the assessments than the students in Group 1; is this actually a result of differences in the treatment that was applied to these groups or could the difference be caused by some other factor that was not properly controlled for in the study design?

One of the most common threats to internal validity is selection bias (Shadish et al., 2001). If the members of one group differ in their initial abilities compared to another group, this can compromise the ability to make inferences about between-group differences in performance on the assessments. In most cases, random assignment of participants to treatment groups eliminates this concern, especially with larger sample sizes because any differences in the initial state of randomly formed groups are due to chance only (Shadish et al., 2001; Gay et al., 2008). Using a pre-test/post-test design allows helps address this concern as it allows the difference in student scores to be analyzed rather than a single score. The decision to collect demographic information from study participants was motivated primarily by the concern of internal validity. Demographic data were collected to ensure that variables other than treatment type that could possibly affect the performance of study participants could be quantified. Factors that were identified during study design as being most likely to affect student performance on the assessments were previous exposure to
geological concepts, overall GPA, and confidence using new or unfamiliar forms of technology.

Previous exposure to geological concepts will affect how much a participant already knows about the concepts being assessed (and thus control their performance on the pre-test) while GPA will be an indicator of the overall academic prowess of the student. Because the treatment activities involve using technology in ways which many students may not be familiar (especially in the case of the interactive time-lapse group), participant confidence in using and applying new forms of technology may control how much students are able to learn from the treatment activities. Asking about these factors in advance allows us to see if each of the three treatment groups are equal or close to equal prior to treatment, and if they are not, allows us to quantify the differences so that scores can be interpreted accordingly.

Other demographic data which will be collected includes gender, major or academic interest, confidence in science classes, as well as lecture instructor and lab T.A.

Another internal validity concern is that of “history effects”, or other events occurring concurrently with the treatment that could contribute to any observed effect or outcome. History effects are best controlled for by “isolating respondents from outside events OR by choosing dependent variables that could rarely be affected by the world outside” (Shadish et al., 2001). Complete isolation is rarely possible in the real-world, nor is it necessarily desired, especially in educational studies. In this study, the primary history concern is that some students may obtain additional information about rates of geological processes, either via their own personal research or from their instructor, in between the administration of the pre- and post-tests which could cause their score to increase. These effects can be mitigated, although not completely eliminated, by minimizing the amount of time in-between the
administration of the pre- and post-tests, and attempting to minimize the amount of relevant information the subjects are exposed to in lecture during the time in-between the pre-test and post-test. This threat is also minimized because students were randomly assigned to treatment groups and therefore any history effects would be expected to affect all three groups equivalently. Maturation effects, defined as naturally occurring changes in the study population over time that can confused with a treatment effect (Shadish et al., 2001) are not a major concern in a study lasting only a few weeks.

Another validity concern is that participants will be taking an identical test twice in a short period of time. “Testing effects”, in which taking a test for a second time can influence scores on the second administration, has been documented in the literature (Shadish et al., 2001). Unfortunately there is not really a good way to address this validity concern because any pre-test/post-test design requires that students take the identical test twice. It is hoped that the qualitative questions will be important in establishing that students have truly achieved the learning outcomes associated with each item. As with history effects, testing effects would be expected to affect all three groups equivalently, and therefore would not affect any differences observed between the groups.

Other possible threats to internal validity include test fatigue, lack of student motivation to participate in the study, and simply the amount of time spent by each student on the treatment (time-on-task). Time on task is expected to differ between the groups. It is natural to expect that the interactive time-lapse group will require more time to view the same number of videos due to the increased amount of time required to make the videos themselves. SurveyMonkey will allow tracking of this variable which will be crucial in establishing internal validity.
**Statistical conclusion validity:** Statistical conclusion validity concerns the appropriateness of statistical techniques used to analyze data and look for correlations between variables. In order to satisfy these criteria, all data will be analyzed using the proper statistical techniques for the given level of measurement (categorical, ordinal, or scale) of a variable (McCrum-Gardner, 2008). It also important to quantify the magnitude of any effect observed rather than just report the statistical significance (Shadish et al., 2001). For this reason, effect sizes will be calculated and reported where possible rather than simply reporting a p-value indicating presence or lack of statistical significance (Fan, 2001). Another statistical concern is low statistical power. Statistical power is defined as the probability that a test will reject a false null hypothesis (Shadish et al., 2001). Statistical power is dependent on the sample size and the size of the observed effect. A test involving a small sample size and a small effect may not be able to reject a false null hypothesis. It is important to remember that failure to reject the null hypothesis does not necessarily mean that there is “no effect”, another reason why reporting effect sizes is of such great importance.

**Construct validity:** The goal of the study is to measure “student understanding of rates of geological processes”. The difficulty is that “understanding” is a trait that is not directly observable without developing a construct that underlies the variable measured (Gay et al., 2008). Construct validity thus refers to how well our testing instrument measures our desired construct, in this case, student understanding. In other words, construct validity is the “degree to which a test measures an intended hypothetical construct” (Gay et al., 2008). Establishing construct validity thus involves asking, is the testing instrument used actually reflecting how much students know about rates of geological processes or is it measuring something else instead/as well? Establishing construct validity in education domains is particularly
challenging because there is not a universally accepted definition of how to measure how much a student “knows” or “understands”.

Contributing to construct validity are the ideas of “content validity” and “communication validity” which both concern the validity of individual items on the assessments used in the study. Content validity is the extent to which items reflect the content or teaching area being measured. This is normally established by reviewing items with “experts” familiar with the concepts in question, an approach known as “face validity” or by using more advanced statistical techniques such as factor analysis after the assessment has been administered. Content validity can also be established by conducting think-aloud interviews with potential participants to test whether the items are accurately assessing the intended concept. Communication validity concerns whether or not the items are interpreted in the manner desired by the researcher (Libarkin and Ward, 2011) and is also established by conducting think-aloud interviews as described above.

**External validity**: External validity refers to whether any causal relationship observed in the study population can be extrapolated or generalized to individuals outside the study population (Shadish et al., 2001). For example, if it is determined that time-lapse videos are more effective at teaching introductory geology students about rates of geological processes, can this conclusion be extended to say that time-lapse videos would also be more effective at teaching geology majors about rates of geological processes, or the general public about rates of geological processes?

In general, there is a balance that must be struck between external validity and internal validity. Experiments that rigidly control the conditions experienced by study participants are more likely to have strong internal validity, but the tradeoff is that such experiments are less
realistic and generalizable, and thus have weaker external validity (Gay et al., 2008). However, Gay et al (2008) suggests that, while the classroom is a more realistic setting, the challenges of conducting a study that is internally valid in that environment may outweigh the benefits of realism. For this reason, the generalizability of this study will likely be limited to the study population, namely predominately white, suburban, introductory geology students.
RESULTS

A total of 328 students signed an informed consent form indicating intent to participate in the study (160 during Winter quarter 2014, 168 during Spring quarter 2014 quarter). Of these, 130 students (67 during Winter quarter 2014, 63 during Spring quarter 2014) successfully completed the pre-test, treatment, and the post-test and thus are included in the final results. An additional 30-40 students completed the pre-test, but did not come to a computer lab to undergo treatment or take the post-test. Responses provided by these students are not included in the pre-test results described here. Two students completed the treatment and post-test but were later found to have either not completed the pre-test or submitted incomplete answers; the responses of these students are also omitted.

The obtained sample size of 130 students is a sufficient number to perform statistical analysis on the results of the multiple choice portion of the assessment results. A sample size of 5-10 times the number of items on an assessment is desired to obtain viable data for statistical analysis (Bardar et al., 2006; Nunnally, 1967). Using this value, the desired sample size for this assessment would be 110-220 students. A combination of null hypothesis significance testing (where the null hypothesis is that no between-group differences exist) and reporting of effect sizes are used to explore possible correlations between treatment group and performance on assessments (Fan, 2001; Shadish et al., 2001). A significance level of $\alpha=0.05$ was used in all statistical tests and parametric tests were used only when the data were interval or ratio level and distributed normally. Microsoft Excel was used to tabulate student responses; all statistical tests were performed using the IBM SPSS Statistics 22 package. Effect sizes were calculated using the G*Power stats package (Faul et al., 2007).
The number of participants was distributed nearly evenly across the three treatment groups (Figure 6). Groups 1 and 2 had 44 participants, while Group 3 had 42 participants. The vast majority of participants were from GEOL 101 classes due to the much higher quarterly enrollment of this class compared to GEOL 211 (Figure 7). Group 1 had a higher proportion of GEOL 211 students (Figure 7) compared to Groups 2 and 3. Participants were distributed across all lecture instructors and lab T.A.’s; however lecture instructors C and F who taught sections of GEOL 101 and/or 211 during both quarters that the study was carried out, thus explaining the greater number of participants drawn from their classes (Figures 8, 9).

**Demographics of Study Population**

A summary of demographic statistics, compared to the overall WWU student body, is presented in Table 5. For most demographic variables, the study population represents a reasonably good sample of the overall WWU student body. This is to be expected given the large enrollment of the courses participants were drawn from.

Females made up nearly 70% of the study population, significantly higher than the percentage of females in the overall WWU student body (55.6%) (WWU 2014). However, the female to male ratio was consistent across the three groups (Figure 10, Table 5). The median age of study participants was also slightly lower than the median age of all WWU students (Table 5). Self-reported geology majors comprise nearly 10% of Groups 1 and 2, however no students in Group 3 reported being a declared geology major. One-way ANOVA tests on the mean age (p=0.689) and number of college credits completed (p=0.407) taken show no significant difference between the three groups. A chi-square test on the distribution of reported GPA ranges also shows no significant differences between the three groups.
(p=0.366) and the mean GPA of each group is comparable to the mean GPA of all graduating students, suggesting that the overall ability of study participants is comparable to the average WWU student. Most participants were from the state of Washington (85.4%), with California, Colorado, and Oregon being the only other states represented by more than one participant (four each).

The vast majority of study participants had no previous formal education in geology or earth sciences in either college (93.1%) or high school (82.3%) (Figure 11), echoing previous research showing that students in introductory geology classes have generally had little recent exposure to the subject (DeLaughter et al., 1998; Gilbert, 2012). Most of the participants who reported taking a previous earth science or geology course in college had only taken a geography or environmental science course, although a few participants from GEOL 211 had previously taken GEOL 101 at WWU. The distribution of students with prior earth science/geology is fairly even between the three groups (Figure 11).

A series of Likert-scale questions were included on the demographic questionnaire to gauge participant’s initial familiarity with geologic concepts, confidence in science classes, and confidence using new forms of technology (Figures 12a-f). Even though most participants were not science majors, the majority in each group still reported being “Somewhat Confident” or “Very Confident” in their ability in science classes (Figure 12e). Kruskal-Wallis H tests on the distribution of responses between groups showed no significant differences on five of the six Likert-scale questions (Table 6). Group 2 reported higher levels of confidence using new and unfamiliar forms of technology (p=0.003).
Duration of Treatment Activities

Because time spent on treatment activities was identified as a possible predictor of student performance on the assessments, the amount of time spent by participants on treatment activities was estimated using two separate methods, which were then compared and combined in order to produce a final estimate of treatment duration for each participant. Students self-reported the amount of time they spent looking at the time-lapse photos or videos (in 10 minute bins from 0-60+ minutes) on the post-test. In addition, SurveyMonkey records the start time for each survey. Because all treatment appointments began at the top of the hour and participants did not begin the post-test until after they had finished viewing the photos/videos, the embedded start time in SurveyMonkey for each post-test provides an approximation of the amount of time a student spent on treatment. For example, if a student arrived in the computer lab at 10:00, and began taking their post-test at 10:35, then their treatment duration was approximately 35 minutes.

The estimates of treatment duration obtained via this method likely overestimate somewhat the actual treatment duration because most students spent several minutes logging in to the workstation and Canvas. This method also fails to account for the fact that some participants arrived early or late, although the majority showed up within five minutes of their scheduled time.

Because neither method of estimating treatment duration is especially robust, the times obtained from the two different methods were compared against each other to judge their accuracy. Overall, self-reported treatment durations and the estimates obtained from SurveyMonkey are generally consistent with each other. The mean SurveyMonkey treatment duration of students responding to each self-reported time interval is shown in Table 7. For
the most commonly selected time intervals, 10-20 minutes and 20-30 minutes, the SurveyMonkey mean falls within the self-reported interval, indicating that for the majority of participants, the two methods of estimating treatment duration are internally reliable. For individual cases where the SurveyMonkey time was significantly different from the self-reported time (i.e., outside the self-reported interval), the mid-point of the self-reported treatment duration interval was used due to the aforementioned issues with obtaining treatment duration from SurveyMonkey. After an estimate of treatment duration was obtained for all participants, extreme outliers were removed from each group before the times were averaged.

While participants were not given a prescribed amount of time to complete the treatment (other than that they would not need to spend more than one hour of their time in the computer lab), nearly all participants completed the assigned tasks in less than one hour (Figure 13). Mean treatment duration for Group 3 was higher (ANOVA p=0.000, LSD vs. Group 1=0.000, vs. Group 2=0.003) than for Groups 1 and 2 although Group 3 had a significantly higher standard deviation than the other two groups (Figure 13, Table 8). The total running time of the 14 videos available to Group 2 was 16 minutes while the mean estimated treatment duration for Group 2 was just under twenty minutes, suggesting that the majority of students spent very little time, if any replaying the videos or looking at them more closely.

Time spent taking the pre- and post-tests was calculated using embedded times in SurveyMonkey (submission time minus start time). After removing extreme outliers (time of several hours, likely due to participants not finishing the test in one sitting), there were no significant differences between the three groups with regard to the amount of time
participants spent taking either the pre- and post-test (Table 9). All three groups completed the post-test in a shorter amount of time, presumably because they were already familiar with the directions and content.

**Multiple Choice/Quantitative Questions**

The assessments contained 23 multiple choice or short-answer items and sub-items that had one or more correct or acceptable answers. Student scores on these questions were tabulated using Microsoft Excel and a total score (# of correct answers) was obtained for each participant for both the pre-test and post-test. A summary of response patterns for each of these items is shown in Table 3. Mean scores on the pre- and post-test for each group are shown in Table 10.

Multiple choice assessment items spanned a wide range of difficulty as indicated by the percentage of participants who identified the correct answer on the pre-test (Table 3). P-values (the fraction of students who correctly answered an item on the pre-test) ranged from 0.07 to 0.78 with an average of 0.4.

Participant scores on the pre-test, post-test, and score gain (post-test score – pre-test score) all approximate a normal distribution (Figure 14) which is necessary in order to perform parametric statistical tests on the results. Pre-test mean scores ranged from 8.62 points (out of a possible 23) for Group 3 to 9.91 points for Group 1. A one-way ANOVA on the pre-test mean scores returns a p-value of 0.052. Because the p-value is >0.05, the hypothesis that there is no statistically significant difference in the mean pre-test scores between the three groups can be accepted, but only barely.

Because of this “almost significant” difference in pre-test scores, **score gain**, calculated by subtracting a participant’s pre-test score from their post-test score, rather than absolute
post-test score is used as a more representative metric by which to measure changes in performance from pre-test to post-test. All three groups exhibited statistically significant score gains (p=0.000) from pre-test to post-test on the multiple choice portion of the assessment (Table 11, Figure 15). Effect sizes for Group 2 (d=1.677) and Group 3 (d=1.398) were very large, according to the guidelines for interpreting effect size given in Cohen (1988). The effect size for Group 1 (d=1.045) was large according to the same guidelines. Group 2 exhibited the greatest mean score gain, 4.68 points, out of the three groups but the differences in score gain between groups is not significant (p=0.144) and the effect size was small (f=0.172). No participants in Group 2 exhibited a negative score gain while several negative score gains were observed in both Group 1 and Group 3 (Figure 14). Normalized gains, defined as a student’s score gain divided by the maximum gain that could be achieved given their pre-test score (Prather et al., 2009), were also calculated and again no large or significant differences exist between the three groups (Table 11).

Pre-test score was a reasonably good predictor of post-test score (R=0.433). A weak negative correlation exists between pre-test score and score gain (R=-0.397, p=0.000) for all three groups (Table 12). In other words, participants who scored highly on the pre-test were less likely to increase their score by a large amount than participants who scored poorly on the pre-test. No significant differences were found when comparing the mean pre-test, post-test, and score gains across the two different quarters that the assessment was administered (Table 11).

**Correlations with Predictor Variables**

Overall, no significant correlation was found (R=0.023, p=.796) between estimated treatment duration and score gain (Table 13, Figure 16). However when broken down by
group, a significant positive correlation exists between treatment duration and score gain for Group 1 (r=0.401, p=0.007), but not for Groups 2 and 3 (Table 13). A moderate but significant negative correlation exists between score gain and the elapsed time between pre-test and treatment/post-test (R=-0.323, p=0.000) (Figure 17). The greater density of participants at shorter durations on this graph is due to treatment being spread out over only one week instead of two when the experiment was run during Spring 2014 quarter. The mean elapsed time between pre-test and post-test for the three treatment groups is nearly equivalent (p=0.958) (Table 14).

While it was postulated that GEOL 211 students would be more advanced and score better on the assessments, GEOL 211 and 101 students had almost exactly the same mean score gain, although GEOL 211 students had a mean post-test score about 1.5 points higher than students in GEOL 101. Statistical tests on participant mean score gains sorted by reported GPA, lecture instructor, gender, and previous geology courses in either high school or college failed to reveal any significant differences (Table 15). No significant correlation exists between the amount of time participants spent taking either assessment or their or their score or score gain (Table 16). None of the Likert-scale questions on the demographic questionnaire were significantly correlated with score gain, although level of interest in geology and the earth sciences and confidence in science classes both showed small to moderate significant correlations with pre-test score and post-test score (Table 16).

Analysis of Individual Items

Table 3 presents a breakdown of participant responses to the 23 questions used to produce the scores discussed in the previous section. The number of participants responding to each answer choice is shown for both the pre-test and post-test. Correct answers, or
answers which most closely match what is observed in the time-lapse photos or videos used by the participants, are highlighted in bold. Shaded numbers indicate either a decrease in correct responses or an increase in incorrect responses for a particular multiple choice answer choice. The column titled “p” indicates the fraction of participants that responded correctly to an item on the pre-test, giving an indication of the relative difficulty of each individual item.

While there are only small differences in the aggregate scores and score gains between the three groups, performance on individual assessment items between groups often varies considerably (Figure 18). All bars in Figure 18 were normalized to a sample size of n=44 for the purposes of comparing the change in number of correct answers for each group. Note that while several items (i.e., 13, 15, 22f) show similar gains across the three groups, many other items (i.e., 5, 14, 22b) show one or more groups performing better than the others. Group 1 showed an increase in number of correct responses on 17 out of 23 items, but exhibited the lowest gains (relative to the other two groups) on 12 of the 23 items. Group 2 also increased correct responses on 17 out of 23 items, but exhibited the highest (or tied for highest) gains on 12 items. Group 3 increased correct responses on 15 of 23 items, and exhibited the lowest (or tied for lowest) gains for 11 out of the 23 items.

Of note are the several items for which there was a net decrease in the number of correct answers from pre-test to post-test. Two of the Columbia Glacier questions and one rate question show negative gains for all three groups. In general, the highest gains were realized on items relating to the Elwah River and the Swift Creek Landslide. No negative gains are observed for any of the questions relating to these two landscapes. Gains on the Columbia Glacier questions tend to be minimal or even negative indicating that the time-lapse photos
and videos were not as effective at increasing student understanding of this landscape and even that misconceptions may have arisen from the treatment.

The final section of the assessment asked participants to quantify how long they thought it would take for several processes depicted in the videos to occur. Gains on these questions show a mix of positive and negative gains. Students were given 11 answer choices in a drop down menu corresponding to different time intervals ranging from “Seconds” to “Billions of years” (Figures 19-26). The range of acceptable answers for each item is indicated by the black box, making it easier to compare whether more or fewer students selected an acceptable answer following treatment. For most of the landscapes, the pattern of responses shifted towards shorter durations, with the exception of the Swift Creek landslide (Figures 19-26).

Because each assessment item was tied to a specific operationalized learning outcome, participants were assigned sub-scores indicating their performance on items relating to each of the different outcomes. These scores were determined by totaling the number of correct answers on all the questions that related to a particular outcome (i.e., all the questions that asked participants to “characterize spatial variations in the rate of a geologic process). A one-way ANOVA was performed on the score gain from pre-test to post-test for each of the seven operationalized outcomes represented by the multiple choice questions (Table 17). As with the aggregate scores, the differences in score gain across the three groups show low effect sizes and are not statistically significant. Nevertheless, Group 2 did have the highest mean score gain for six out of the seven content areas (Table 18).
Likert-Scale Questions

A series of nine content-related Likert-scale questions were included on the assessment in order to gauge the effect that the treatment activities had on level of student agreement with various statements about the rate of landscape changes on Earth. Phrasing of Likert-scale questions varied, with some being phrased as documented student misconceptions about rates of geological processes found in Francek (2013) and others phrased as scientifically accurate statements. Because the Likert-scale questions used a “Neutral” category, and because the distribution of responses was not always normal, parametric statistical tests (i.e. t-tests, ANOVA) are not appropriate for analyzing differences in the response patterns between groups and from pre-test to post-test (Roberson et al., 1995; McCrum-Gardner, 2008). Non-parametric statistical tests appropriate for non-normal, ordinal-level data were used to analyze Likert-scale responses; Wilcoxin signed rank tests to compare pre-test vs. post-test responses (paired responses) within a group, and Kruskal-Wallis H tests for comparing responses between groups (Roberson et al., 1995; Gay and Airasian, 2003; McCrum-Gardner, 2008). Table 19 shows the significance values and effect sizes obtained from these tests. Cells in green represent questions where there was a statistically significant shift in responses from a given group. Cells in red represent questions where the response pattern on a given question was not significantly different on the post-test. “P” and “N” represent the number of responses which became more positive (i.e. more likely to agree) and negative (i.e. more likely to disagree) on the post-test. The distribution of responses to the Likert-scale questions is also shown in graphical form (Figures 27a-h).
Group 1 exhibited a statistically significant shift in responses on seven out of the nine Likert-scale questions, Group 2 on eight out of nine questions, and Group 3 on just five out of nine. An overview of the changes in responses patterns is provided below:

“Geologic time is measured in millions of years because that is how long it takes landscapes to change significantly”: participants in all three groups were less likely to agree with this statement after treatment. The effect size for all three groups was moderate, while Group 3 had the highest percentage of participants selecting “Disagree” or “Strongly Disagree” on the post-test.

“The landscape around us is constantly changing”: Nearly all participants responded either “Agree” or “Strongly Agree” on the pre-test, however the number of participants selecting “Strongly Agree” was significantly higher on the post-test for Groups 1 and 2. Group 3 also saw an increase in the number of students selecting “Strongly Agree” but the increase was not statistically significant. Effect size was small for Groups 2 and 3 and moderate for Group 1.

“Landscapes change at a constant rate through time”: No statistically significant changes in response pattern were observed on this question. A closer look at the data reveals that most participants did change their answer to this question on the post-test, but that roughly the same number of participants became more likely to agree as became less likely to agree.

“Catastrophic events are more important in sculpting the Earth than slow, gradual processes that occur every day”: The majority of participants disagreed or strongly disagreed with this statement on the pre-test, but the percentage of students choosing “strongly disagree” was significantly higher on the post-test for Groups 2 and 3. The
responses pattern for Group 1 was nearly identical on the post-test. Effect sizes for Groups 2 and 3 were moderate.

“Landscapes can change significantly over the course of an average human lifetime”: All three groups were significantly more likely to agree with this statement on the post-test. Effect sizes for Groups 1 and 3 were moderate while the effect size for Group 2 was large.

“Humans can alter the rate at which landscapes change”: Participants in Groups 1 and 2 were more likely to strongly agree with this statement on the post-test. Effect sizes for Groups 1 and 2 were small, while the response pattern for Group 3 was not significantly different on the post-test.

“Moving water (such as rivers or waves) can only change the surface of the Earth over long periods of time (i.e. more than one year)”: All three groups were more likely to disagree or strongly disagree with this statement on the post-test. Effect sizes for all three groups were moderate.

“Water only changes the surface of the Earth during rare events, such as large floods or tsunami”: Most participants disagreed or strongly disagreed with this statement on the pre-test. Participants in Groups 1 and 2 were significantly more likely to choose strongly disagree on the post-test. Effect sizes for all three groups were small, and the shift in response pattern was not significant for Group 3.

“Apart from human activity, Earth’s landscape looks similar today as it did a few million years ago”: Participants in all three groups were significantly more likely to disagree or strongly disagree with this statement on the post-test. Effect sizes for Groups 1 and 3 were moderate while the effect size for Group 2 was small.
Qualitative Questions

Several multiple choice questions included open-ended text boxes asking students to explain why they chose the answers that they did. After an initial review of the open-ended responses provided, five categories were developed that encapsulate the range of responses. Responses were categorized on the basis of whether the explanation provided was accurate, and also based on the concept of observational responses vs. explanatory responses. In an observational response, a student states that they chose a certain answer choice simply because they saw evidence of that answer choice in the photos or videos. In an explanatory response, reference is made to underlying factors that cause a certain answer choice to be correct. Explanatory responses are higher-level statements that provide evidence that a student truly understands their answer. To illustrate the distinction between these types of responses more clearly, consider assessment item #12:

Which of the following statements do you think best describes the rate of erosion along rivers in the Pacific Northwest (including the Elwah River)?

A. The rate of erosion remains constant throughout the year.
B. Erosion occurs all year, but occurs faster in the winter than in the summer
C. Erosion occurs all year, but occurs faster in the summer than in the winter
D. Erosion occurs only during the summer
E. Erosion occurs only during the winter

The correct answer to this question is B: “Erosion occurs all year but occurs faster in the winter than in the summer”. The difference in the rate of bank erosion and channel migration between summer and winter months is clear in both the time-lapse videos and photos provided to participants. Erosion and channel migration is greater during the winter months than during the summer months, primarily due to higher river discharge associated with precipitation events that are common during the winter, but rare during the summer
months. By summer, the discharge of the river is on average much lower and it follows that the rate of erosion along the river channel will be lower.

In a correct explanatory response to this question, a student would state that they observed more erosion during the winter months, due to the greater amount of water in the river channel during this time. Observing the root cause of a correct answer (in this case, that erosion rate seems to be correlated with river discharge) is a higher level observation compared to a student who says something along the lines of “Because I saw more erosion in the winter”. In a purely observational response, students have not really provided any additional explanation for why they chose a particular answer beyond what was already stated in the chosen multiple choice option. A purely observational response is not necessarily bad; after all, the goal of the activities was to get students to make just such observations, but identifying which of the treatment groups are more likely to make higher-level explanatory responses may help shed light on which groups gained the most from the videos and photos. Further examples of the distinction between the different types of responses can be found in Tables 20 and 21 which summarize the responses to these questions.

This rubric was applied to all questions for which an explanatory text box was present. Analysis of student responses to these (and all other qualitative questions) was done blind, i.e., the student’s group number was removed from the spreadsheet so as not to influence the researcher’s perception of the responses. Only after all responses had been classified into the five categories were the responses tabulated by group.

A summary of the student responses by category is shown in Tables 20 and 21. For the Elwah River question, explanatory responses dominated, with most students seemingly
recognizing that the rate of erosion was tied to river discharge (even if students did not use the term “discharge”). However, incorrect responses outnumbered correct responses; many students erroneously stated that discharge was higher in the summer due to snowmelt, which is clearly not the case in the photos and videos. Furthermore, the ratio of observational responses to explanatory responses is breakdown of responses by category was roughly even between the three groups, although incorrect responses outnumbered correct response in Groups 2 and 3 but were roughly even in Group 1.

The opposite was true of the question asking participants to characterize the rate of movement of the Swift Creek landslide. Explanatory responses were much less common than observational responses, especially in Group 2, however this makes sense because while the rate of the Swift Creek landslide does increase during wetter months (McKenzie-Johnson, 2004), the connection between moisture and rate of landslide movement is not as obvious in the videos as is the connection between discharge and erosion in the Elwah River photos and videos. Correct answers slightly outnumbered incorrect answers for Groups 1 and 2, however incorrect answers outnumbered correct answers 20 to 9 in Group 3.

One question at the end of each landscape section asked students to list factors that they thought might control the rate of the process in question. Students were directed to put the factor they thought was most important in the first box, 2nd most important in the second box and so on. In order to tabulate these responses, three points were assigned to factors listed as most important, two points to factors listed as second most important, and one point for the least important factor. A summary of the 10 most common responses for each group by number of total points is presented in Tables 22, 23, and 24. Unfortunately a more detailed
analysis of the level of sophistication of the responses to these questions was not possible because the vast majority of responses to were one or two word answers.

For the Columbia Glacier, temperature and global climate change were listed as the top two factors controlling the rate of glacier movement by all three treatment groups. Other common responses include climate, weather, amount of snowfall, and angle of the slope upon which the glacier sits, all reasonable explanations. “Tides” was either the third or fourth most common response for each group and it is unclear what role participants thought the tides played in the movement of the glacier.

For the Elwah River, all three groups identified river discharge (even if they did not use that specific term) as one of the most important factors controlling erosion. Group 3 identified it as the most important factor whereas it ranked third and second in Groups 1 and 2 respectively. All of the commonly listed factors are reasonable, with the possible exception of temperature. Interestingly, “dam removal/human activity” did not appear on a large number of responses, even though the information provided to students about the Elwah River discusses the fact that the entire Elwah River landscape is undergoing accelerated change as the dams are decommissioned.

For the Swift Creek landslide, all three groups identified amount of rainfall/saturation of the ground as the most important factors that control the rate of landslide slippage. Responses citing fundamental physical properties controlling slope stability (as opposed to environmental factors such as rainfall or vegetation), such as gravity, cohesion of material, and slope angle were also much more common that for the other landscapes. Human activity was also a commonly cited factor by students in Groups 1 and 2, even though unlike the Elwah River, no mention was made of human activity in the background information.
provided to participants about the landslide. This suggests some level of initial knowledge about the role of human activity (e.g. logging) in landslide activity.

Two additional open ended items (#1, #4) produced erratic results that failed to elicit any coherent results or trends after analysis. Most responses to item #1 simply restated the prompt given to students and both questions showed few changes from pre-test to post-test. Better wording and more testing prior to implementation likely would have increased the usefulness of these items.

**Post-Test Questionnaire**

At the conclusion of the post-test, students completed a short questionnaire (via *SurveyMonkey*) with questions asking about their overall impression of the time-lapse activities. Seven of these questions were Likert-scale questions. As with the Likert scale questions on the assessment, non-parametric statistical tests such as the Kruskal-Wallis H test were used to compare the response pattern on these questions across the three treatment groups. While no statistically significant differences were found (Table 25), it is interesting to note that Group 2 had the highest percentage of students select “Strongly Agree” on all of the Likert scale questions (Figures 28a-g).

Participant’s impressions of the treatment activities were dominantly positive. Participants almost universally reported that the directions provided were clear and concise, with only one participant (out of 130) disagreeing with that statement. Only three participants agreed with the statement “I found this activity confusing and/or frustrating” while only one participant disagreed with the statement “I felt comfortable using the computer-based portion of this activity. More than 90% of participants in all three groups thought that the time-lapse photos/videos were a good way to learn about how quickly landscapes change.
Several open-ended questions on the questionnaire asked about what participants found most useful about the activities, and ways in which the activity was confusing or could be improved. Similar responses to the open-ended questions were grouped together and a summary is found in Table 26 and discussed below:

“**What did you find most useful about this activity?**” *(Table 26a):* In each group, the most common response referenced looking at the photos or watching the time-lapse videos. In Groups 2 and 3, the second most frequent response referenced gaining increased perspective on how quickly landscapes can change. This sentiment was present, but less common, in responses from Group 1. A number of students in Groups 1 and 3 referenced unique aspects of the treatment in their responses, the drag-gable image slider and the ability to make custom time-lapse videos respectively.

“**Did you learn anything during this activity that you found particularly surprising or interesting?**” *(Table 26b):* The most common theme in responses to this question was surprise regarding how quickly various landscapes changes in the photos and videos. Many students did not reference a specific landscape, but rather simply said that they were surprised how quickly things changed. Others provided a specific example of a landscape that they were surprised to see change so quickly, with the Columbia Glacier and Elwah River channel being the most frequently cited examples. A number of students also expressed surprise regarding the relatively slow movement of the Swift Creek landslide. This was most prevalent in responses from Groups 1 and 3.

“**Were there any parts of this activity that you found especially confusing or unclear?**” *(Table 26c):* The vast majority of participants either did not respond to this question or wrote “no”. Few responses were mentioned by more than one participant. The

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most frequent complaints of Group 1 pertained to difficulty in seeing changes in some of the photo pairs of the Swift Creek landslide. Five students in Group 3 expressed frustration with the slow generation of time-lapse videos and/or the instructions provided on how to use the time-lapse generator.

“What could be added to or changed about this activity to make it better?”

(Table 26d): As with the previous question, the most frequent response in each group was “no” or “not sure”. The most common suggestions for improvement were to have scale in the images or videos rather than in explanatory text (all groups), faster generation of time-lapse videos (Group 3), the ability to look at photos/videos while taking the test (all groups), and more background information on the different landscapes (all groups). A number of suggestions requested features and/or information that were already present in the activities or instructions. These responses are indicated by italics in Table 26d.

“What was your primary motivation for agreeing to participate in this study?”

(Table 26e): Most students indicated that they participated in this project primarily to receive the compensation that was awarded (gift card or movie ticket) or out of a desire to help out a fellow student with their research. A smaller percentage of students in each group indicated that they participated primarily because the subject was of interest to them or that they thought participating would give them knowledge that would help their grade in GEOL 101 or 211.
INTERPRETATION AND DISCUSSION OF RESULTS

Summary of Results and Evaluation of Validity

As would be expected from random assignment of participants to treatment groups, analysis of demographic data collected on the pre-test revealed no significant differences between the students in each of the three treatment groups. One exception is that Group 1 contained larger number of students enrolled in GEOL 211 students and students who had taken a previous college geology class, but neither of these factors was found to correlate with performance on the assessments.

The mean scores for each group on the multiple choice portion of the pre-test ranged from 37-43% of the total possible points. Given that most multiple choice questions had four possible answer choices (each sub item on #22 had 11 possible choices, but several possible acceptable answers), the pre-test scores show that students performed somewhat better on the pre-test than would be expected from simply guessing. This suggests that at least some study participants possessed some degree of initial knowledge of glacial, fluvial, and volcanic landscapes, possibly due in part to the use of all Pacific Northwest landscape with which students may have been at least marginally familiar prior to participation.

Only small differences are observed in the between-group score gain across the three treatment groups and at first glance there is no data to support rejection of the null hypothesis that all three groups performed equally on the assessments. While using $\alpha=0.05$ makes the likelihood of the Type I error (rejecting a true null hypothesis or inferring an effect when none exists) very small, setting such a high threshold in combination with the relatively small sample size in each group results in low statistical power, which is defined as the probability of rejecting a false null hypothesis. Failure to reject a false null hypothesis is known as a
Type II error. The calculated statistical power of the ANOVA method for testing the difference in mean score gain between the three treatment groups is 0.396. In other words, given the size of the effect observed and the sample size, there is only a 40% chance that the test will reject the null hypothesis if it is indeed false. As a result, more attention should be given to the actual effect sizes, which are small, than the p-values. Because the effect sizes are small and the results are not significant, simply based off of the multiple choice scores, it is not possible to draw any conclusions about which treatment method is most effective at increasing student understanding of geologic rate (Fan, 2001).

Assessment scores were correlated with the demographic variables and other metrics obtained during data collection. Few of these factors correlate well with assessment scores. Most notably, no significant correlations or differences were found between score gain and GPA, confidence using new forms of technology, or previous classes in geology or earth science, all of which were hypothesized to be important predictor variables prior to data collection. Treatment duration is significantly correlated with score gain only for Group 1 (r=0.401), suggesting that the amount of time spent using the before/after photos is more important than the amount of time spent watching the time-lapse videos. A significant inverse correlation exists between score gain and number of days between pre-test and treatment/post-test which suggests that students who took the pre-test shortly before looking at the photos or videos may have had a better recollection of the questions and had a better sense of what to look for in the photos and videos. However, the mean number of days between pre-test and post-test is equivalent for the three groups so this correlation does not likely affect the between-group gain scores.
Assessment scores were also broken down by the learning outcomes associated with each item in order to test whether certain groups performed better in specific content areas. Of the 7 tasks/learning outcomes identified in the assessment, a comparison of scores across the three groups showed small effect sizes on all seven and none of the mean differences were statistically significant. This suggests that there were no major differences in group performance on the different types of tasks present on the multiple choice portion of the assessments.

Some of the most striking differences were observed in student responses to the Likert-scale questions but for the most part these differences were observed across all three groups. Groups 1 and 2 did show more significant changes than Group 3 on these questions, possibly indicating that the photos and static time-lapse videos had more of an impact on student perceptions about rates of landscape change than did the interactive time-lapse videos.

Responses to the post-test questionnaire were dominantly positive, and make it clear that vast majority of participants were easily able to follow the directions provided and complete the assessments and treatment without difficulty. This is important for establishing study validity because if a large proportion of students had struggled to complete the activity or expressed confusion, this would throw into serious question the quality of the data collected. Many of the suggestions listed by participants on the post-test questionnaire related to ways to better implement or present the time-lapse videos and photos; several of these were wrestled with during study design and will be discussed below in the section of ways to improve the integration of time-lapse videos into educational experiences.

Another finding of the post-test questionnaire is that a large number of students expressed surprise at how quickly changes in the landscapes occurred (comparatively few expressed
surprise at how slowly changes occurred, with the exception of references to the Swift Creek landslide). While this is largely a byproduct of the fact that processes suitable for capture with time-lapse generally are on the faster side, this is still important given the desire to impress upon students the entire range of rates at which geologic processes operate. The misconception that the Earth’s surface only experiences significant change over long periods of time has been established by previous research (see introduction) and by some results from the pre-test (Figures 27a, 27e, 27f). The misconception that all geologic processes occur slowly may tempt students into thinking that geologic hazards are not something that are of concern in our short lives. The tendency of students to state on the post-questionnaire that they were surprised how fast changes occurred, the results from the Likert-scale questions, and the fact that the pattern of responses on many multiple choice-items shifted towards shorter durations on the post-test demonstrates that both before/after photos and time-lapse videos are effective at communicating to students that many geologic processes operate relatively quickly and combating the misconception that geology only “happens” over millions of years. The surprise exhibited by students in this study about the rapid nature of many landscape changes supports the idea that many students were not fully conscious of the rapidity with which some geologic changes can occur. This is significant because ultimately it is the processes that occur on shorter timescales, such as landslides or fluvial erosion, that are most likely to impact student’s lives in the future and society in general.

**Remaining Threats to Validity**

Before any major conclusions can be made from the data, the idea of validity must be revisited in order to be confident that the assessments did a good job of measuring student understanding of rates of geological processes, and that there are no other causal explanations
for the scores observed. As discussed in the “Methods” section, steps to minimize possible threats to validity were incorporated into the study design. What follows is a discussion of the successfulness of these precautions and a review of possible threats to validity that remain:

**Selection bias:** Students who volunteered for this study were randomly assigned to one of the three groups. Analysis of demographic data collected at the outset of the study showed no major differences between the three treatment groups. The most concerning initial difference between the three groups was the higher ratio of 211/101 students in Group 1 but analysis of mean score gains sorted by enrollment in these two courses were nearly identical (Table 15). Also of note is that despite their being few science majors among the participant pool, the majority of students in all three treatment groups self-rated as either “somewhat confident” or “very confident” regarding their ability in science classes. This suggests that there may have been a self-selection effect as far as which students from the GEOL 101 and 211 classes volunteered for the research project.

**Attrition:** While 328 students signed a consent form indicating intent to participate, only 130 students fully completed participation in the study. However because random assignment to groups was done using the initial group of 328, the number of students who dropped out was roughly equal across the three groups. Demographic information is not available for the vast majority of the students who did not complete participation (except for a few dozen who completed the pre-test but not the post-test) so a demographic comparison of those who dropped out vs. those who participate is not possible.

**History:** All participants in this study were enrolled in an introductory geology course (either GEOL 101 or 211) during the entirety of their time spent participating in this
study. The content disseminated in the lecture portion of these two courses is very similar, although the exact scope of information students are exposed to varied depending on their instructor and T.A. The proportion of students from each of the different lecture sections was comparable across the three groups so it is highly unlikely that history effects had any impact on between-group comparisons of performance on the assessments. Is it possible though that history effects may have contributed to the gains exhibited by each individual group? Could the large increase in scores from pre-test to post-test simply be due to the fact that students were enrolled in a geology class during the time between assessments?

In an effort to reduce possible history effects, all GEOL 101 and 211 instructors agreed to refrain from showing any time-lapse videos in class during the course of the study. The study was also deliberately scheduled for a period when the content being covered during lecture and lab was not particularly relevant to the concepts being assessed in this study. For example, most of the lectures that students were exposed to between the time they took the two assessments revolved around the rock cycle, igneous, sedimentary, and metamorphic rocks, rather than on topics directly relevant to the assessment questions such as geologic time, landscape evolution, or glaciers.

It remains that participants, simply by nature of continued exposure to geologic concepts, could have gained knowledge from lecture that contributed towards their better performance on the post-test. However, the average elapsed time between pre- and post-tests for all groups was just four days, enough time for only 1 or 2 lecture periods and not likely enough time for history effects to become a major consideration, especially in light of the above precautions. As noted above, there was a weak negative correlation between score gain and number of days in between pre-test and post-test. If material learned in class was really
contributing strongly to student performance on the assessments, a large positive correlation between these two variables would likely be observed as opposed to a negative one.

It is also possible that students could have studied after taking the pre-test, but the fact that the vast majority of student who originally signed up to participate in the study did not even bother to take the pre-test makes it seem improbably a large number of students would have expended significant time and effort studying for the post-test. Furthermore, the types of questions on the assessments are not the type that can be easily “googled” or obtained from other sources.

Taking the above considerations into account, combined with positive student attitudes towards the time-lapse photos and videos on the post-test questionnaire and the large within-group effect sizes, confidence that the majority of the gains achieved between pre-test and post-test for each group are the direct result of the treatment activities rather than any external factors is merited.

**Testing:** Taking two identical tests in short succession can cause some subjects to become more familiar with the content and thus answer questions more accurately (Shadish et al., 2001). While the role of testing effects cannot be entirely discounted in a pre-test/post-test design, several steps were taken to minimize them. The order of answer choices on multiple choice questions were randomized where possible and the environment in which participants took the two tests was different. Students were able to take the pre-test from any location they chose, while the post-test was taken in a university computer lab under my supervision. Including a true control group in the research design (i.e. a group to which no treatment was administered) would have helped clarify the role of testing effects in the study design.
**Participant attitude and motivation:** Participant performance on the pre- and post-tests was not tied in any way to a participant’s grade in their respective classes. Students were also compensated regardless of their performance or how long they spent on the treatment activities. These were both requirements of the IRB. However, with so little at stake for the study participants, one concern is that student performance on the assessments may have been compromised simply by a desire to get through the activities and tests as quickly as possible. Estimates of mean treatment duration for Group 2 are only slightly longer than the cumulative running time of all videos available to that group, suggesting that students did not spend very much time looking at the videos in-depth.

While students were directed to read all questions carefully and study the time-lapse videos and photos in detail, undoubtedly, some students expended more effort than others. Even though participants nearly unanimously self-reported that they gave their best effort on the assignments, in reality it is possible that even higher score gains would have been realized had actual grades been at stake. The fact that large and significant gains were realized in all three groups even on such a short (time-wise) and low-stakes activity could be interpreted as a testament to the power of time-lapse videos and before/after photos as instructional tools.

Alternatively, it is possible that gains were skewed towards the positive simply because of the inherent selection bias in a study that relies on volunteers. Those students that volunteered for the study may overall be more confident and more motivated to learn about rates of geologic processes than student who didn’t volunteer. If all students enrolled in GEOL 101 and 211 had been required to participate, it is possible that the score gains would have been diluted as a result regardless of the effect on a student’s grade.
Construct validity: All assessment items were extensively revised based on think-aloud interviews with introductory geology students and conversations with geology faculty before use in the study. Multiple choice answer options were written using best practices guidelines for composing multiple choice answer options. In addition, responses to open-ended questions generally indicate that students understood what the questions were asking. Furthermore, participant interaction with the time-lapse videos and photos was guided by a series of questions that pertained directly to the content covered by the assessments. This leads to high confidence that the assessments were valid in that they were probing student knowledge about rates of geological processes and that incorrect answers did not stem from confusing or ambiguously worded questions.

Reliability: To address potential reliability concerns relating to the assessment (and also to increase sample size), the study was run twice, once during Winter quarter 2014 and once during Spring quarter 2014, using the same protocols. The relative schedule across which the study was conducted was identical between the two administrations of the assessments. As Table 11 shows, there are no statistically significant differences between the mean assessment scores in Winter quarter vs. Spring quarter.

Two Possible Interpretations

While all three treatment groups improved from pre-test to post-test, in order to answer our research questions, ultimately it is the difference in performance between the three groups that is important. The results from the multiple choice portion of the assessments show no large or significant differences in the gains between the before and after photo group, the static time-lapse group, and the interactive time-lapse group. Qualitative and Likert-scale questions do hint at some differences, although these differences are not large or
consistent. Assuming this result is valid, this lack of a major difference between the treatment groups can be interpreted in two different ways:

1. Before and after photos and time-lapse videos are more or less equivalent in their inherent ability to communicate information about rates of geological processes to students. Adding an interactive component to the time-lapse videos does not result in any significant increase in student learning over viewing pre-made time-lapse videos.

2. Either time-lapse videos or before and after photographs ARE better for teaching students about geologic rate, but due to a flaw in the study design, small sample size, or deficiencies in implementation of the time-lapse videos, the difference was not detectable in this study.

Given the myriad of different ways in which the experiment could have been designed, and all the considerations that went into preparing and presenting the time-lapse videos and photos, explanation 2 seems to be the more conservative conclusion. Nevertheless, the following discussion will cover the ramifications of both possible conclusions as well as the lessons that each can offer future users of time-lapse videos and before/after photos in geoscience education. The following discussion can be divided into two parts: a discussion of the possible limitations of time-lapse (which would support conclusion #1) and a discussion of the limitations of the study design and how the time-lapse videos were implemented (which would support conclusion #2). There is some overlap between these two conclusions; for example, many of the inherent limitations of time-lapse can be overcome, if not easily, by making changes and alterations to the way in which they are implemented.
Possible Limitations of Time-lapse: Cognitive Considerations

The lack of any statistically significant differences in test scores or striking differences in open-ended responses between the three groups is intriguing given the supposed advantages of time-lapse video discussed in the Introduction. What potential limitations of time-lapse video, or advantages of static photos, may have been overlooked?

Complicating the comparison of before/after photos and time-lapse videos is the fact that the two methods are not “informationally equivalent” (Tversky et al., 2002). In other words, students in the time-lapse groups are receiving significantly more information (i.e. a more complete picture of the geologic process) than the students in the before/after photo group which makes a direct comparison difficult. To illustrate, a 30 second time-lapse video (at a standard frame rate of 30fps) contains 900 individual frames or images; in contrast a student in the before and after photo group would see just two of those 900 images. Is it really possible that just as much knowledge can be gleaned from a comparison of two frames as from a video consisting of 900? Previous research on the cognitive science behind using computer animations and visualizations, of which time-lapse is a form, as teaching tools may offer some clues.

Tversky et al. (2002) cites a number of education-themed studies in which the use of static graphics was found to increase student performance more than text alone, but in which animated graphics used to depict complex systems were not found to increase student performance above and beyond static graphics (Schnozt et al., 1999; Morrison and Tversky, 2001; Lowe and Schnozt, 2008). While rates of geological processes would, on the surface, seem to be an ideal concept for applying the power of animation, Tversky et al. (2002) focus
on a variety of reasons why animations “may be distracting, or even harmful, to conveying important ideas” in situations where they would seem to be most appropriate.

One of the factors most relevant to time-lapse videos is the idea that, in order to be effective, animations must occur slowly enough that the viewer can effectively process “movements, changes, and their timing” (Tversky et al., 2002). This is an area in which time-lapse video inherently falls short. While the frame rate of a time-lapse video can be adjusted, by their very nature, time-lapse videos present large quantities of information to the viewer in a relatively short amount of time. Even at slower frame rates, changes in the landscape can occur in the video very quickly and thus may be difficult for students, especially novice geology students, to adequately process. However, Tversky et al. (2002) suggests that this shortcoming of animation can be overcome by adding an element of interactivity to the animation, specifically in the form of allowing learners to control the speed of the animation, stop the animation, and re-play parts which were confusing, etc. Interestingly, such options were afforded to students in both of the time-lapse treatment groups: Group 2 could easily pause, play, rewind, and use a drag-able slider to move through the video at a custom rate while Group 3 had the additional option to specify the frame rate (10, 20 or 30 fps) of all the videos they generated. According to Tversky et al. (2002), such accommodations should help these students be able to processes the videos better, however in practice they do not appear to have made much of a difference as scores for the time-lapse groups were very similar to the photo group. It is also possible that, despite being prompted in the directions, students in Groups 2 and 3 did not utilize these functions, in particular the options to vary the frame rate, as much as desired, as the program did not allow tracking of how frequently such functions were used.
So while it is true that the time-lapse videos present the student with more information than a corresponding before/after photo, it is conceivable that time-lapse presents too much information too rapidly for students to have the chance to thoroughly process and internalize it, even with the ability to re-play or slow down the video. Some evidence for this hypothesis is seen in open-ended question responses. For example, many students correctly made the observation that erosion occurs more rapidly along the Elwah River in the winter than in the summer, yet a similar number of students reported observing the exact opposite. How can two students view the exact same videos and come to such opposing conclusions, especially when participants were specifically prompted to explore seasonal changes in the rate of erosion? One explanation would be that the time-lapse videos are presenting information too quickly for many students to adequately process and comprehend it.

Comparing a pair of static images is admittedly much less daunting than watching a fast-moving time-lapse video which contains thousands of frames displayed in a matter of seconds. The failure of the time-lapse groups to perform better on the assessments could be the result of inherent limitations in our cognitive ability to process a quickly changing scene. Earth’s landscapes change in complex ways, with multiple different processes interacting to produce observed changes over time. Experienced geoscientists are especially adept at working with and conceptualizing complex systems (Manduca and Kastens, 2012) and thus such individuals might be more easily able to use a time-lapse video of a changing landscape to their benefit than an introductory geology student. In other words, from the perspective of geoscientists time-lapse is a great tool because we are already used to dealing with complex systems; for a student who is not, the advantage of time-lapse video may not be as significant. The logical extension of this cognitive model would be that time-lapse may hold
more promise as teaching tool when used with more advanced geology students, however because this study doesn’t address that population, it is impossible to know for sure without further research. In addition, this model would suggest that slowing down the time-lapse videos even further (i.e. lowering the frame rate below 10 fps) could help overcome some of these cognitive barriers and allow novice users to notice and process more subtle changes.

Another supposed advantage of time-lapse videos is that they are “real” rather than a computer simulation. However, some of the student comments on the post-questionnaire suggest that assumption is not necessarily merited and that not all students comprehend this fact. Comments such as “Include time-lapses that span 100,000 or a million years” suggest that some students may think that time-lapse videos are still computer animations that can be manipulated at will to show how processes occur over many thousands or millions of years, or that students still have a very poor fundamental grasp of time in general. The realism of time-lapse videos may also contribute toward the comprehension issues mentioned above. Real-world scenarios are inherently more complex than simplified representations and some previous researchers have suggested that animations should avoid realism and err on the side of schematic simplicity (Tversky et al. 2002).

Possible Limitations of Time-lapse: Student Enjoyment of Time-Lapse vs. Before & After Photos

As mentioned in the introduction, one of the strongest motivations for using time-lapse videos in the classroom is the anecdotal evidence that suggests that students enjoy viewing time-lapse videos and are enthusiastic about using them to learn about geology. Some authors have suggested that student enjoyment of animations is reason enough to use them even if
they do not result in significant advances in learning over an alternative method (Rieber, 1991). However, with regard to time-lapse, this view should be approached with skepticism.

Results from the post-test questionnaire did not conclusively show that students enjoyed using time-lapse videos any more than they enjoyed using the slider to compare the before and after images. Response patterns to the questions “I enjoyed completing this activity” or “This activity increased my understanding of how quickly landscapes change” were nearly identical across the three groups and student in all three expressed a high level of satisfaction with the activities. Nearly all of the students in the before and after photo group expressed how the photo pairs gave them new insights into the rates of geologic processes, a higher proportion than for their counterparts in the time-lapse groups. Furthermore, several students in the time-lapse groups suggested adding before/after photos as a way to improve the activity.

Student enjoyment is an important factor to consider because, as described in the “Methods” section, time-lapse videos are extremely time-consuming for the instructor or animator to produce (and expensive to gather in the first place), considerably more so than before and after photo pairs. In the absence of any significant quantitative evidence showing that time-lapse videos result in greater understanding amongst novice geology, it becomes more difficult to justify the large amount of time needed to produce high-quality time-lapse videos, although such videos may still be of value to more advanced students who can process them more efficiently.

While the results from the post-test cast some doubt on whether students really do prefer time-lapse videos over comparing before and after photos, it is important to remember that the opinions shared on the post-test are from students who used one or the other, not both. An
interesting extension of the study would have been to subject some students to both before/after photos and time-lapse videos and see which one they preferred using.

**Possible Limitations of Time-lapse: Misconceptions Arising from Treatment**

While student performance on assessment items generally improved at least modestly from pre-test to post-test, on all items there nevertheless remained a number of students who chose incorrect distractors. Although on most items the number of incorrect answers decreased, in several cases the number of participants choosing an incorrect distractor actually increased on the post-test, suggesting that the treatment activities led some students to come away with a new misconception about a particular concept.

The most extreme example of an item with a negative gain was item #5, which asked students to characterize the rate of movement of the Columbia Glacier. Seventy one percent of students answered this question correctly on the pre-test, while just 52% answered the item correctly on the post-test. Group 1 showed the largest negative gain on this item, going from 33 to 18 correct responses. The increase in incorrect responses was due mostly to increased number of participants choosing the distractor “The glacier occasionally flows backwards in response to global warming” in Group 1 and Group 3, and “The ice will always flow toward the ocean at a constant rate” in Group 2, both of which careful observation of the time-lapse videos and photos show to be incorrect.

The negative gain for Group 1 is somewhat easy to explain given that the before and after photos make it obvious that the glacier terminus is retreating, but not immediately obvious which direction the glacier is moving. Even in the time-lapse groups though, more students stated that the ice within the glacier was moving backward on the post-test than on the pre-test. Dove (1998) suggests that misconceptions such as this can often stem from a use of
everyday language in a scientific context. However based on feedback in the think-aloud interviews, the text of this item was revised to make it clear that the question was referring to the “ice within the glacier” rather than the glacier terminus so this is likely not the issue here. More likely is that many participants do not fully understand that a glacier, by definition, is a field of ice that is constantly moving downslope, adding an additional hurdle that needs to be overcome in order to make sense of the time-lapse videos.

This example is ultimately a good illustration of the need to be very cautious in assuming both prior knowledge and what students will and will not notice in a time-lapse video of a changing landscape. In this case, it was incorrect to assume that students would notice that the terminus of the glacier is retreating due to mass being lost via calving, rather than the glacier itself moving backwards. This is an example of a situation in which multiple processes are occurring simultaneously and contributing to landscape change; students may have difficulty compartmentalizing each one. Research has shown that younger students frequently do not notice much of the information that a computer animation contains, so it is conceivable that introductory geology students may simply not notice information or motions than an “expert may see as obvious” (Rieber, 1990, 1991). As mentioned previously, the accelerated (quickly changing) nature of time-lapse videos means that several important things can be happening simultaneously, making it difficult for the student to know what to focus on without additional guidance. In the absence of such guidance, such as narration or annotation, to focus student attention on processes of interest, it is easy for students to come away with information that is at best incomplete, and at worst completely wrong.

Unfortunately, many time-lapse videos available to students or the public online include little to no expert commentary, context, or narration, drastically increasing the likelihood that
individuals will come away from viewing the videos with misconceptions. Even the official video of Columbia Glacier retreat found on the EIS webpage does not make any mention of the fact that the glacier is always flowing towards the ocean, and that retreat of the terminus is caused by calving, not the glacier actually moving backwards. One respondent in the April 2013 online survey of geology educators, when asked how they incorporate time-lapse videos into their class said “Usually I provide a commentary, point out important features, then let them view it again. Often there will be questions to answer after viewing the video”. This is precisely the sort of approach that is needed to help novice geology students’ process time-lapse videos. While time-lapse can be powerful, its complexity requires additional effort on the part of the instructor in order to unpack its contents for the students. Instructors need to be acutely aware of what sorts of misconceptions are held by students about the process being depicted, so that they can be addressed while the video is being viewed, especially is the misconception is one that is strongly held. Additional care is needed when the time-lapse video will be viewed independently of the instructor, in the context of an online course or MOOC for example, in which case a virtual form of narration that can direct the student’s viewing, address possible misconceptions, and possibly even instruct them to re-play a portion of the video, should ideally be provided to prevent existing misconceptions from persisting or new ones from forming.

One thing especially striking about the responses to open-ended questions was that many explanations provided by participants directly contradict what is visible in the time-lapse videos. Furthermore, many responses did not even reference the videos or photos, but seem to be based entirely on pre-existing ideas or misconceptions about the process in question (i.e. “Landslides do not move then stop”). Such responses suggest that student’s
misconceptions were not adequately addressed by the photos and videos, providing yet more evidence that more guidance (e.g. narration) is needed when using time-lapse videos with novice geology students.

Another misconception that became more prevalent on the post-test was that the rate of the Swift Creek Landslide is constant over time. This misconception increased in frequency in all three groups, but slightly more so in Group 3. A number of students also said that the Columbia Glacier moves at a constant rate through time, yet both the Columbia Glacier and Swift Creek landslide exhibit significant seasonal variations in their movement rates. Somewhat surprisingly, the videos and photos did not seem to impress this upon many students. Furthermore, responses to the Likert-scale question “Landscapes change at a constant rate over time” were mixed, with many students more likely to agree on the post-test, suggesting some confusion on this idea. Finally, as discussed in the “Results” section, many students struggled to explain variations in the rate of erosion along the Elwah River in the open-ended questions, with many students incorrectly stating that erosion occurred faster in the summer. All of these lines of evidence point towards discerning variations in the rate of a process over time as a consistent problem area that could possibly be improve by providing more guidance to participants or possibly rewording questions to make them more clear.

Most other incorrect answers were due to an inability to discern a precise quantitative rate of a given process rather than a misconception per se. For example, a large percentage of students responded incorrectly to item #6 (Approximately how long do you think it would take ice within the Columbia Glacier to move ten meters (approximately the length of a city bus)?) on the post-test but the most common incorrect answer on the post test was “1 month”
rather than “1-year” on the pre-test. This indicates that while many students were not able to obtain the correct answer from the videos/photos, they were at the very least able to get closer to the correct answer of “1 day” and/or realize that the glacier was moving fast enough that their initial prediction was likely to be an overestimate of the actual time required.

While instances where the number of incorrect answers increased are limited, on several other items, gains were minimal and many of the misconceptions present on the pre-test persisted through treatment to the post-test. This persistence of misconceptions even after instruction is a common phenomenon (Vosniadou, 2007; Reif, 2010). The very short duration of the treatment activities was likely not long enough to allows all students to experience conceptual change (Mikkilä-Erdmann, 2001), thus allowing many misconceptions to persist even after treatment. While these factors likely account for at least some of the misconceptions still present on the post-test, it also suggests a major shortcoming of the treatment activities used in this study: the inability to customize the time-lapse videos and photos to incorporate student’s preconceptions about rates of geological processes. Persistence of misconceptions is often prevalent when there is a failure to incorporate students pre-existing knowledge structure into the education process. Making students aware of their own misconceptions is crucial to overturning them (Reif, 2010). It has been demonstrated that conceptual change occurs most readily when a student’s misconception is explicitly addressed during the learning process and an explanation provided showing why the misconception is wrong (Kendeou and Van Den Broek, 2005; Rapp and Uttal, 2006). In the case of the Columbia Glacier, this would have involved acknowledging the misconception that glaciers can flow backward, and countering it by discussing that a glacier is a field of moving ice which cannot flow uphill, perhaps followed by an animated or
narrated time-lapse video showing that the forward movement of the glacier continues regardless of how fast calving occurs and the terminus retreats.

In the context of the activities used in this study, this was difficult to accomplish. Participants varied so much in their initial knowledge state that it would have been difficult to incorporate all initial misconceptions into the videos and photos. While with enough time misconceptions could be incorporated into the type of exercises used in this study, this is more of a concern when time-lapse videos are shown casually in class. Students in a large lecture class will have all sorts of preconceptions and it is impossible to even be aware of them all much less address them all.

**Improvements to Time-Lapse Implementation**

While there are cognitive limitations to using time-lapse videos with novice geology students and while study participants generally expressed satisfaction with the treatment activities as a method for learning about rates of landscape change, the occurrence of items with negative gains, minimal gains, and erroneous answers to open-ended questions leaves no doubt that there is plenty of room for improving how time-lapse videos and photos are used to facilitate student learning. Most of these improvements center around ways to help students comprehend and process the rapid changes that occur in many time-lapse videos, as discussed earlier. These improvements can be broadly separated into suggestions that pertain to the creation of the time-lapse videos themselves, and suggestions for instructors to improve the implementation of time-lapse videos in their courses:

**Suggestions for Instructors**

On a most basic level, more time for students to explore the time-lapse photos and video would likely increase the amount of learning that occurs. While no correlation was observed
between treatment duration and score gain for either of the time-lapse groups (a moderate positive correlation between treatment duration and score gain was observed for Group 1, suggesting that the amount of time spent using the image sliders is more important than the amount of time spent watching the videos), the reality is that the mean treatment duration for both time-lapse groups was under 30 minutes, a very short amount of time to expect much learning to take place. Many students commented on the post-test questionnaire that more time to look at the videos would have been welcome, although giving students more time would likely have started to introduce issues of test fatigue. Ideally, the treatment would have lasted longer, but been split up into several sessions to minimize the cognitive load required of students at any one time.

Comparing mean treatment durations for Group 2 vs the total duration of the time-lapse videos available to students suggest that most participants spent very little time, if any replaying the videos or looking at them more closely. However, the lack of a significant correlation between treatment duration and score for the time-lapse groups suggests that simply watching the videos multiple times does not increase understanding. More likely, structuring the use of time-lapse videos in such a way that encouraged students to engage in a second or closer viewing of key portions of the videos could lead to greater increases in understanding.

Many participants expressed the desire to be able to watch the videos while taking the post-test. As discussed in the methods section, this was something that was wrestled with during study design. While it is likely that students likely would have performed better on the assessments had they been given simultaneous access to both the assessment and test and the videos/photos, allowing students to look at the questions and photos/videos at the same time
would have turned the activity into something more akin to a scavenger hunt, and would not have tested the extent to which students are able to retain (rather than simply recite) information learned from the time-lapse videos and photos even a short time later.

Furthermore, time-lapse videos are frequently used in geology classes during lecture, rather than as a stand-alone, independent activity and so allowing students to take the test while looking at the videos and photos would not have as closely matched how time-lapse videos are normally used by geoscience educators. Because the research goal was to test what sorts of things students would notice from viewing a time-lapse video and how what they noticed would affect their understanding of rates of geological processes, giving students a list of conceptual questions that focused student interactions with the photos/videos in such a way that it was still possible to correctly answer the questions was determined to be the best compromise.

As the use of online videos becomes more common outside the classroom (in settings such as flipped classrooms and MOOCs), a recent trend has been to embed opportunities for testing and self-assessment into videos and multimedia. Research has shown that online video lectures that incorporate these kinds of opportunities for periodic self-evaluation can help maintain student focus over longer periods of time and promote learning (Szpunar et al., 2013). It seems reasonable that this strategy could enhance what students are able to learn from time-lapse videos as well. In hindsight it would have been interesting to find a way to integrate the viewing of the time-lapse videos and photos with the assessments more seamlessly in a way that would still test how students were able to retain information. Many of the persisting misconceptions documented previously could have been the result of students forgetting what they had seen by the time they finished looking at the videos/photos.
and took the post-test. Integrating the assessments with the videos could also allow scaffolding of questions that encourage students to view key portions of the videos more closely as mentioned above in order to gain a deeper understanding.

**Suggestions for Time-Lapse Creation**

Based on suggestions provided on the post-test questionnaire, several minor changes to the way in which time-lapse videos were presented to the students could increase student comprehension of the rates of processes occurring in the videos. Having a scale-bar in the images/videos themselves rather than in the introductory text and annotated photographs for each landscape would have made it easier for students to make quantitative estimates of rate without having to scroll away from the video itself. The process of adding such a scale bar to the images would be straightforward, but is complicated by the fact that scale can vary widely across an image. In many cases a single scale bar is not sufficient, and including multiple scale bars could be confusing.

Another change that could facilitate student learning is to annotate the first and last frames of the time-lapse videos. In the treatment activities, a still photograph with scale information and annotations was provided at the top of the page containing the time-lapse videos in order to provide necessary context and introduction. However, as with the scale bar issue, incorporating such information directly into the video itself eliminates the need to scroll back and forth between the video and the annotated photo in order for students to make sense of their observations. Correct interpretation of the time-lapse videos and photos required that students read the accompanying text and look at the accompanying annotated photo. There was no way to ensure that students did this in all cases, so incorporating some of the information that was presented alongside the videos into the videos themselves may
help students gain more from the videos. This suggestion for improvement aligns with two of the multimedia design principles outlined by Mayer (2001): the spatial contiguity principle and the temporal contiguity principle, which state that students learn more when related photos and text are presented in the same place at the same time.

Some students also seemed to struggle using the date-stamp on the time-lapse videos to interpret what they were seeing in the landscape. In open-ended responses to the item asking about seasonal changes in erosion rate along the Elwha River, most students made the correct observation that erosion occurs faster when river discharge is higher, but more than half of students misidentified discharge as being greatest in the summer when it is actually much greater in the winter and spring.

Some ideas for improving the date stamp would be to make it larger (the pre-embedded date stamp on the Elwha River images was smaller than the date-stamp that was manually added to the other three time-lapse data sets) or to slow down the frame rate of the videos to make it easier for students to comprehend what time of year it is. An additional overlay explicitly stating what season it is might also be helpful, especially considering that there is some ambiguity in the popular usage of terms such as “summer” and “spring”.

In light of the cognitive obstacles to processing time-lapse videos discussed above, making time-lapse videos with slower frame rates may also help student’s process information more effectively. Using variable frame rates within a video could help emphasize important changes in the landscape that might otherwise go unnoticed.

Time-lapse videos can also be improved by exerting extra care during the collection of time-lapse data sets themselves. Robust mounting systems that ensure the position of the camera does not change over time can minimize the amount of necessary post-processing and
distracting parallax shifts in the videos. Many newer digital cameras contain CCD chips with better dynamic range capabilities and internal algorithms that can smoothen out images with large variations in brightness. Ensuring that a full suite of image metadata is collected can make it easier to add features such as customizable date stamps, which was not possible with the Elwah River data set because no metadata was included. Finally, including objects for scale in the field of view of the time-lapse camera can also provide valuable context for students who view the resulting videos.

Ultimately, with any of these additions or changes to the time-lapse videos themselves or their implementation, it is necessary to consider whether any resulting increases in learning are due to the time-lapse videos themselves, or due to the other “stuff” that is added on. For example, adding opportunities for self-assessment into the videos may very well increase learning and student scores. But in such a case, the increase would be due to the addition of opportunities for self-assessment rather than any inherent advantages or disadvantages in the medium (time-lapse vs. photos) itself. It seems likely that adding any of these types of features to the before/after photos may result in equally large increases in student scores, and if an addition or change results in increased learning in all three groups, then there is still no strong evidence that one method is any better than another.

**Limitations of Study Design**

One of the factors that must be balanced in an experimental education study is the need to effectively isolate the variable being measured, in this case the effectiveness of time-lapse videos, while simultaneously maintaining a learning environment that is as natural, comfortable, and realistic as possible for the student. Determining what type of learning environment is most realistic is challenging because time-lapse videos can be used in many
different ways, from being shown in class to being assigned as part of a homework activity. In the case of this study, the decision was made to conduct the experiment outside the context of the classroom. By doing this, a multitude of threats to validity were minimized or eliminated. However, the compromise is that the treatment activities completed by the students were not directly related to, or integrated into material being covered in their introductory geology classes. Completing an hour long activity in a computer lab under the supervision of the researcher is not necessarily representative of how learning takes place in a traditional classroom-based geology course, although it may more closely mimic how such videos would be used in an online geology class or MOOC, both of which are becoming increasingly popular. So while such a controlled, experimental setting works well for controlling possible confounding variables, it does so at the expense of creating a perfectly natural learning environment for the student. Nevertheless most participants stated that they enjoyed the activities and that the time-lapse videos and photos were a good way to learn so it does not appear as though the somewhat artificial environment was a major inhibition towards learning from the videos and photos.

Ideally, a wider variety of time-lapse data sets that better captured the temporal variability of a given geologic process would have been incorporated into the treatment activities. For example, the behavior exhibited by a tidewater glacier (such as the Columbia Glacier) is different from the behavior exhibited by a ground-based alpine glacier, most notably in the fact that the advance and retreat of tidewater glaciers is not tied as closely to climate change (Post et al., 2011). Numerous attempts were made to secure permission to use a time-lapse data set of various terrestrial alpine glaciers with no success. Similarly, while the Swift Creek landslide is an example of a slow-moving, creeping landslide, many landslides
occur much more rapidly, so rapidly in fact that they are not appropriate for capture with time-lapse photography. While most students seemed to understand that not all landslides and glaciers are the same, analysis of the qualitative data suggested that some did not fully comprehend the fact that the rate of a given process can vary considerably depending on a variety of external factors. That is to say, not all landslides move at the same rate, not all glaciers move at the same rate, and not all river channels migrate with the same frequency. This concept is difficult to communicate to students when only one example of a given process is shown. While this leaves open the possibility of some misconceptions, exposing students to all possible types of glaciers, rivers, or other features was unfortunately not feasible in a study of this magnitude, both due to time constraints, cognitive load concerns, and availability of data sets. Future research that focuses on one specific geologic process, and where multiple examples of that process are presented via time-lapse video would be warranted.

The types of questions that could be included on the assessments were also somewhat limited due to the SurveyMonkey software. For example, it would have been preferable to have a way for students to show their work on the item that involved mathematical calculation (item #20). Showing work would have allowed more insight into incorrect answers but no provisions for this type of question existed in SurveyMonkey.

Another consideration was the timing of the treatment and the post-test. Some authors have suggested that assessments administered immediately after a period of instruction are “unrealistic” because they do not address how well students retain the information and are able to apply their knowledge to new situations and real-life problems (Reif, 2010). Administration of a delayed post-test was considered however several factors prevented this
from occurring. A lower than expected participation rate and high subject attrition during Winter quarter 2014 necessitated another administration of the study during Spring 2014 when the delayed post-test was originally scheduled to take place.

In addition, several major validity concerns were identified with a possible delayed post-test. Any delayed post-test would have been completely voluntary as not enough funds were left to compensate students for participating. Consequently, the participation rate on a delayed post-test would likely have been extremely low (even lower than the main study) and not enough to make any significant conclusions. Furthermore, any data gathered would have likely suffered from a very large selection bias due to the voluntary nature of the delayed post-test. Likely, students who performed well on the initial assessments, were very interested in geology, or enjoyed the initial activity the most would have been the most likely to participate which would have severely skewed the results. Retention was tested to a very limited extent due to the fact that the post-test was administered after students had finished viewing the photos or videos, rather than while students were viewing the photos and videos. This prevented students from scouring a particular video to find the answer to a question but rather tested their ability to notice and retain information from the videos.

One concern with the interactive time-lapse group was that they were not prescribed time-lapse videos to watch, whereas the photos and videos shown to Group 1 and Group 2 were designed with the assessment items in mind. In other words, the performance of the interactive time-lapse group depended heavily on their ability to determine what kinds of videos they need to make in order to answer the questions. The nearly equivalent performance of Group 3 versus the other groups suggests that students were able to effectively accomplish this. Ideally, the interactive time-lapse software would have been able
to track both how many videos each student made and the parameters of each one in order to see how the videos they created compared to what was seen by Groups 1 and 2.

**External Validity:**

The external validity of this controlled study is difficult to establish. While the study was carried out using a population that seems to be a good sample of the overall student body at WWU, many participants in the think-aloud interviews noted that they would have been much less comfortable with the assessment questions had they not taken GEOL 101 or 211. The assessments used in this study were designed assuming that participants possess a basic understanding of geological terms which somewhat limits our ability to generalize the results of the study beyond introductory geology students. It is likely that the fact that all participants were concurrently enrolled in a geology class made the activities and assessments easier to digest than for an individual who has no previous geology experience. While the results show that both time-lapse videos and before/after photos allow viewers to better gauge rates of geological processes, without being able to assume that viewers have some geology background, the set of challenges involved in designing time-lapse videos and photos that are effective at communicating information about rates of geological processes to the general public would likely be somewhat different than what was discussed here.

Finally, as discussed previously, time-lapse videos can be incorporated into geology courses in a multitude of different ways. This study tested the effectiveness of time-lapse when used as a stand-alone, interactive, individual activity that focused on students using time-lapse to evaluate their predictions about landscape change. Therefore, the results of this study are not necessarily generalizable to the effectiveness of time-lapse when shown in
different contexts, although it is likely that many of the conclusions about how to make effective time-lapse videos will apply regardless of the setting.
CONCLUSIONS

Because all three treatment groups (the before/after photo group, passive time-lapse group, and interactive time-lapse group) showed large or very large and statistically significant gains in understanding of rates of landscape change, as measured by scores on the multiple choice portion of the assessments, the use of time-lapse videos or before/after images to convey rates of geological processes is an effective teaching tool. Likert-scale questions also indicated that the treatment activities were effective at changing qualitative student perceptions of rates of geological processes for all three groups, slightly more so for Groups 1 and 3. Students in all three groups were better aware of the range of rates of geological processes after the treatment activities, in particular that many geologic processes can occur on human timescales. Qualitative (or open-ended) questions did not reveal any especially striking differences in understanding of rates of geological processes between the three treatment groups, but did illuminate some of the difficulties students had in making interpretations from the time-lapse videos, most notably in discerning temporal variations in the rate of a given geologic process. Furthermore, both the quantitative and qualitative assessment questions demonstrate that both before and after photos and time-lapse videos are effective at combating the misperception or notion that geology happens” over millions of years.

Based on the steps described above to establish internal validity of the conclusions, there is a high degree of confidence that the majority of the gains experienced by students on the multiple choice questions were the result of the treatment activities rather than external factors. However between-group comparisons of performance on the assessments have small effect sizes and are generally not statistically significant given the obtained sample size. As a
result, it is difficult to make any strong claims about the superiority of any of the different treatment methods over another.

Instead, strategically designed before and after photos appear equally effective at increasing student understanding of rates of landscape change as compared to passive and interactive viewing of time-lapse videos, although the method used here (interactive before and after image sliders) is likely more effective than using static side-by-side images because it involves an element of interactivity that makes comparing the two images easier and causes changes in the landscape to appear more striking. Students who used before and after photos were just as likely to report that they enjoyed the activity as students who used time-lapse videos.

These are significant findings because using before and after photo pairs to depict landscape change is much less time-consuming, less expensive, and possible in a much wider variety of geologic settings than long-duration time-lapse video. While in some ways before/after photos do not represent a given process as completely or in as much detail as a time-lapse video, the simplicity of a before/after photo-pair may in some ways be easier for a novice geology student to interpret than a rapidly changing time-lapse video and consequently just as effective at helping a student understand rates of landscape change. In some cases (i.e. Columbia Glacier), a time-lapse video may convey crucial information that the before/after photo pair cannot offer and thus help reduce misconceptions if presented along with appropriate narration or text background information.

Adding additional levels of interactivity by allowing students in Group 3 to create their own time-lapse videos and modify the parameters (such as frame rate) of the videos did not result in any substantive increase in student scores over the passive time-lapse group,
although it was not possible to track the extent to which these features were utilized by study participants.

Ultimately, all three methods tested here show promise for increasing student understanding of rates of landscape change, which is encouraging given that understanding of rates of geological processes is something that has ramifications far beyond the geology classroom. Rates of geological processes are involved in many decisions facing our society today. While in an ideal world, these decisions would be made, or at the very least informed by experienced geologists, unfortunately that is not always the case. Therefore, it is instrumental to work towards promoting a populace that understands the basic and most important principles of earth science, of which the rates of geologic processes is one. Introductory geology classes are a key venue for instilling an appreciation for, and understanding of, the wide variety of rates of landscape change in a large cross section of the population given that most students in such classes will never take another earth science course. Both time-lapse videos and before/after photos are effective tools that can be used to emphasize the importance of understanding rates of geologic processes in introductory geology courses. It is hoped that the lessons learned from this thesis will help and encourage geology educators at all levels to apply these technologies more effectively, both inside and outside the classroom, in order to help their students gain a better understanding of rates of geological processes.
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Table 1: Summary of time-lapse data sets used in the study

<table>
<thead>
<tr>
<th>Camera</th>
<th>Location</th>
<th>Start Date</th>
<th>End Date</th>
<th>Image Interval</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Mills Delta</td>
<td>Elwha River, Washington</td>
<td>9/01/2011</td>
<td>1/12/2014</td>
<td>1 hour</td>
<td></td>
</tr>
</tbody>
</table>
Table 2-List of assessment items sorted by associated operationalized learning outcome. Items in bold do not have a “correct” answer:

<table>
<thead>
<tr>
<th>Learning outcome:</th>
<th>Corresponding item numbers:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand the concept of a geologic rate</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td><strong>Qualitatively</strong> characterize and/or describe the rate of a geological process.</td>
<td>5, 12, 15, 17, 18</td>
</tr>
<tr>
<td><strong>Quantitatively</strong> characterize the rate of a geological process.</td>
<td>6, 19, 20</td>
</tr>
<tr>
<td>Characterize the temporal variation in the rate of a geological process.</td>
<td>5, 12, 17</td>
</tr>
<tr>
<td>Characterize spatial variation in the rate of a geological process.</td>
<td>14, 18</td>
</tr>
<tr>
<td>Compare and contrast the rates of several different geological processes occurring in a single landscape.</td>
<td>10</td>
</tr>
<tr>
<td>Compare and contrast the rates of several different geological processes occurring in disparate landscapes.</td>
<td>22</td>
</tr>
<tr>
<td>Use the observed rate of a geological process to predict possible future landscape changes.</td>
<td>7, 8, 9, 13, 15</td>
</tr>
<tr>
<td>Identify factors that control/affect the rate of a geological process</td>
<td>11, 16, 21</td>
</tr>
</tbody>
</table>
Table 3: Summary of responses to multiple choice items on the pre-test and post-test (correct answers in **bold**):  

<table>
<thead>
<tr>
<th>Question</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>(note: answer choices without letters were randomized on the assessments)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Which of the following is the mathematical definition of “rate”:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>distance/time</strong></td>
<td>31</td>
<td>34</td>
<td>31</td>
<td>33</td>
</tr>
<tr>
<td><strong>speed/time</strong></td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td><strong>time/distance</strong></td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>velocity/distance</strong></td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5. Which of the following statements best describes how ice within the Columbia Glacier moves over time:</td>
<td></td>
<td></td>
<td></td>
<td>0.71</td>
</tr>
<tr>
<td><strong>The ice will always flow toward the ocean but its speed will vary with time</strong></td>
<td>33</td>
<td>18</td>
<td>29</td>
<td>27</td>
</tr>
<tr>
<td>The ice is frozen to the ground so it will not move</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>The ice will occasionally flow backwards as it retreats due to global warming</td>
<td>7</td>
<td>24</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>The ice will always flow toward the ocean at a constant rate</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>6. Approximately how long do you think it would take ice within the Columbia Glacier to move <strong>ten meters</strong> (approximately the length of a city bus)?</td>
<td></td>
<td></td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>a) 1 hour</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>b) 1 day</td>
<td>3</td>
<td>12</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>c) 1 month</td>
<td>11</td>
<td>24</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>d) 1 year</td>
<td>30</td>
<td>5</td>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td>7. What do you think the Columbia Glacier will look like from this location <strong>100 years</strong> from now?</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>The glacier will look more or less the same</strong></td>
<td>6</td>
<td>2</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td><strong>The glacier will have disappeared completely</strong></td>
<td>3</td>
<td>25</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td><strong>The glacier will be visibly smaller</strong></td>
<td>34</td>
<td>16</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td><strong>The glacier will be visibly larger</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
8. What do you think the Chugach Mountains will look like from this location **100 years** from now?
   - The mountains will look more or less the same: 33, 21, 28, 31, 32, 25, N/A
   - The mountains will have disappeared completely: 0, 1, 2, 0, 0, 0
   - The mountains will be smaller or shorter: 5, 10, 7, 6, 7, 14
   - The mountains will be larger or taller: 5, 12, 7, 7, 3, 3

9. What do you think the Chugach Mountains will look like from this location **100,000 years** from now?
   - The mountains will look more or less the same: 4, 3, 4, 5, 6, 4, N/A
   - The mountains will have disappeared completely: 3, 7, 5, 2, 4, 7
   - The mountains will be smaller or shorter: 26, 26, 21, 25, 17, 24
   - The mountains will be larger or taller: 11, 8, 14, 12, 15, 7

10. There are several geologic processes occurring in this image:
    - Pieces of ice breaking off the terminus of the glacier, forming icebergs (fastest): 6, 12, 6, 11, 4, 6, 0.76
    - The tide going in and out: 5, 14, 8, 8, 4, 8, 0.12
    - Movement of the Columbia Glacier: 33, 21, 28, 27, 27, 22, 0.13
    - Weathering and erosion of the Chugach Mountains (slowest): 37, 38, 33, 40, 29, 38, 0.68

Using your mouse, drag the following events into order based on how long you think they would generally take to occur. Put the fastest event at the TOP and the slowest event at the BOTTOM:
12. Which of the following statements do you think best describes the rate of erosion along rivers in the Pacific Northwest (including the Elwha River)?

<table>
<thead>
<tr>
<th>Statement</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>0</th>
<th>4</th>
<th>3</th>
<th>0.33</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) The rate of erosion remains constant throughout the year.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) <strong>Erosion occurs all year, but occurs faster in the winter than in the summer</strong></td>
<td>17</td>
<td>23</td>
<td>12</td>
<td>16</td>
<td>14</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>c) Erosion occurs all year, but occurs faster in the <strong>summer</strong> than in the winter</td>
<td>25</td>
<td>18</td>
<td>27</td>
<td>28</td>
<td>24</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>d) Erosion occurs only during the summer</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>e) Erosion occurs only during the winter</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

13. If you were to return to this same location and take another photograph 50 years from now, which of the following is most likely to be true:

- The river will follow the same path, but will have carved a deeper channel.
- **The river will follow a different path across the valley floor.**
- The river, valley, and channel will look nearly the same as it does today.
- Floods will have deposited sediment and the river valley will be shallower than it is today.

<table>
<thead>
<tr>
<th>Statement</th>
<th>25</th>
<th>6</th>
<th>26</th>
<th>7</th>
<th>23</th>
<th>7</th>
<th>0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) The river will follow the same path, but will have carved a deeper channel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) <strong>The river will follow a different path across the valley floor.</strong></td>
<td>6</td>
<td>33</td>
<td>8</td>
<td>35</td>
<td>6</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>c) The river, valley, and channel will look nearly the same as it does today.</td>
<td>5</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>d) Floods will have deposited sediment and the river valley will be shallower than it is today.</td>
<td>8</td>
<td>5</td>
<td>7</td>
<td>0</td>
<td>10</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

14. Which of the following statements do you think best describes the rate of erosion in this photograph?

- The rate of erosion is the same everywhere on the valley bottom
- **The rate of erosion is greatest along the banks (sides) of the river channel**
- Erosion is occurring everywhere in the photograph at the same rate
- The rate of erosion is greatest along the base (bottom) of the river channel

<table>
<thead>
<tr>
<th>Statement</th>
<th>2</th>
<th>2</th>
<th>1</th>
<th>2</th>
<th>1</th>
<th>2</th>
<th>0.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) The rate of erosion is the same everywhere on the valley bottom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) <strong>The rate of erosion is greatest along the banks (sides) of the river channel</strong></td>
<td>29</td>
<td>31</td>
<td>25</td>
<td>38</td>
<td>24</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>c) Erosion is occurring everywhere in the photograph at the same rate</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>d) The rate of erosion is greatest along the base (bottom) of the river channel</td>
<td>13</td>
<td>11</td>
<td>15</td>
<td>4</td>
<td>16</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

15. If you were to stand and watch this landscape for an extended period of time, which of the following is most likely to be true:

- I would be likely to observe growth in the vegetation before I observed any changes in the river channel.
- I would be likely to observe changes in the river channel before I observed any growth in the vegetation.
- I would likely observe changes in the river channel and growth in the vegetation after approximately the same amount of time.

<table>
<thead>
<tr>
<th>Statement</th>
<th>29</th>
<th>7</th>
<th>22</th>
<th>1</th>
<th>29</th>
<th>4</th>
<th>0.21</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) I would be likely to observe growth in the vegetation before I observed any changes in the river channel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) <strong>I would be likely to observe changes in the river channel before I observed any growth in the vegetation.</strong></td>
<td>9</td>
<td>28</td>
<td>13</td>
<td>37</td>
<td>5</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>c) I would likely observe changes in the river channel and growth in the vegetation after approximately the same amount of time.</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>
17. Which of the following statements do you think best describes the movement of the Swift Creek Landslide:

- Landslide movement is continuous, and has a constant rate
- Landslide movement is continuous, but the rate of movement varies with time
- Landslide movement starts and stops repeatedly over time
- Landsides only move once during a quick burst and then remain stationary

<table>
<thead>
<tr>
<th></th>
<th>2</th>
<th>11</th>
<th>4</th>
<th>12</th>
<th>4</th>
<th>16</th>
<th>0.35</th>
</tr>
</thead>
</table>

18. Which of the following statements do you think best describes the rate at which different parts of the Swift Creek landslide move:

- All parts of the landslide move at approximately the same rate
- Region A moves faster than Region B
- Region B moves faster than Region A
- Neither region moves fast enough for humans to detect

<table>
<thead>
<tr>
<th></th>
<th>2</th>
<th>1</th>
<th>3</th>
<th>3</th>
<th>0</th>
<th>4</th>
<th>0.55</th>
</tr>
</thead>
</table>

19. Which of the following is closest to the amount of time it would take a piece of rock in Region B of the Swift Creek landslide to move downhill a distance of **10 meters** (approximately the length of a city bus)?

|   | 2 | 1 | 2 | 0 | 1 | 1 | 0.33 |

22. Finally, consider all of the landscapes you just looked at. How long do you think it would take, on average, for each of the following geologic events to occur? Use the drop down menu to select an approximate answer for each event:

A. The tide going in and out once
B. The formation of a volcanic lava dome
C. Complete wearing down of a mountain range by weathering and erosion:
D. Uplift of a large mountain range from a flat plain:
E. Soil, boulders, and trees moving downhill in a landslide (Swift Creek landslide):
F. A river channel changing its course:
G. A large piece of ice breaks off a tidewater glacier forming an iceberg:
H. A tidewater glacier moves 10 meters:

|   | 7 | 11 | 11 | 8 | 6 | 3 | 0.66 |

|   | 0.25 |

|   | 0.78 |

|   | 0.68 |

|   | 0.35 |

|   | 0.15 |

|   | 0.25 |

|   | 0.13 |
### Table 4: Open-ended and Likert-scale assessment items:

<table>
<thead>
<tr>
<th>Question</th>
<th>Results:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In a sentence or two, describe in your own words what the word “rate” means in the following sentence: “The purpose of this study is to examine how students learn about the rate of geological processes.”</td>
<td>See Page 70 for explanation</td>
</tr>
<tr>
<td>2. Please indicate how much you agree or disagree with the following statements about changes in vegetation and falling/melting snow are not considered landscape changes.</td>
<td>See Table 19, Figure 27 (a-i)</td>
</tr>
<tr>
<td>A. Geologic time is measured in millions of years because that is how long it takes landscapes to change significantly; B. The landscape around us is constantly changing; C. Landscapes change at a constant rate through time; D. Catastrophic events are more important in sculpting the Earth than slow, gradual processes that occur every day; E. Landscapes change significantly over the course of an average human lifetime; F. Humans can alter the rate at which landscapes change; G. Moving water (such as rivers or waves) can only change the surface of the Earth over long periods of time (i.e., more than one year); H. Water only changes the surface of the Earth during rare events, such as large floods or tsunamis; I. Apart from human activity, Earth’s landscape looks similar today as it did a few million years ago;</td>
<td>See Page 70 for explanation</td>
</tr>
</tbody>
</table>

4. What are the slowest and fastest geological processes you can think of that can change the surface of the Earth?
<table>
<thead>
<tr>
<th>Question</th>
<th>Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. What are some factors that might control how quickly the Columbia Glacier moves? Enter up to three factors, one in each box. Place the factor you think is MOST IMPORTANT in box #1:</td>
<td>See Table 22</td>
</tr>
<tr>
<td>16. What are some factors that might control the rate of erosion along the Elwha River? Enter up to three factors, one in each box. Place the factor you think is MOST IMPORTANT in box #1:</td>
<td>See Table 23</td>
</tr>
<tr>
<td>20. Assume that the yearly rate of movement on the landslide remains constant. About how long would it take the patch of ground labeled “X” in the photo to reach the bottom of the landslide at lower left? Please type your answer in the box below (include units!):</td>
<td>Group:</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>21. What are some factors that might control the rate at which the Swift Creek landslide moves? Enter up to three factors, one in each box. Place the factor you think is MOST IMPORTANT in box #1:</td>
<td>See Table 24</td>
</tr>
</tbody>
</table>
Table 5- Comparison of study population demographics to the overall WWU student body:

<table>
<thead>
<tr>
<th></th>
<th>Group 1 (photos)</th>
<th>Group 2 (passive TL)</th>
<th>Group 3 (inter. TL)</th>
<th>WWU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Female:Male ratio</strong></td>
<td>70:30</td>
<td>68:32</td>
<td>69:31</td>
<td>56:44</td>
</tr>
<tr>
<td><strong>Median age</strong></td>
<td>19.23</td>
<td>19.2302</td>
<td>19.2314</td>
<td>21.7</td>
</tr>
<tr>
<td><strong>Median GPA</strong></td>
<td>3.22</td>
<td>3.11</td>
<td>3.18</td>
<td>3.16&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Avg. # of credits taken</strong></td>
<td>62.4</td>
<td>53.1</td>
<td>56.7</td>
<td>?</td>
</tr>
<tr>
<td><strong>Out of state %</strong></td>
<td>9.0%</td>
<td>25.0%</td>
<td>7.1%</td>
<td>9.6%</td>
</tr>
<tr>
<td><strong>Most common declared majors:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humanities/Social Sciences</td>
<td>45.5%</td>
<td>43.2%</td>
<td>42.9%</td>
<td>40.3%</td>
</tr>
<tr>
<td>Science/Tech (non-Geology)</td>
<td>18.2%</td>
<td>9.1%</td>
<td>14.3%</td>
<td>16.2%</td>
</tr>
<tr>
<td>Business/Economics</td>
<td>4.5%</td>
<td>11.4%</td>
<td>14.3%</td>
<td>15.3%</td>
</tr>
<tr>
<td>Fine/Performing Arts</td>
<td>6.8%</td>
<td>4.5%</td>
<td>4.8%</td>
<td>9.8%</td>
</tr>
<tr>
<td>Education</td>
<td>4.5%</td>
<td>11.4%</td>
<td>16.7%</td>
<td>8.9%</td>
</tr>
<tr>
<td>Environmental Studies</td>
<td>11.4%</td>
<td>9.1%</td>
<td>4.8%</td>
<td>4.9%</td>
</tr>
<tr>
<td>Interdisciplinary Studies</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>2.5%</td>
</tr>
<tr>
<td><strong>Geology</strong></td>
<td><strong>9.1%</strong></td>
<td><strong>9.1%</strong></td>
<td><strong>0.0%</strong></td>
<td><strong>2.2%</strong></td>
</tr>
<tr>
<td>Undeclared</td>
<td>0%</td>
<td>2.3%</td>
<td>2.4%</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>a</sup>For students receiving degrees during the 2013/2014 school year
Table 6-Tests for statistical significance on the distribution of student responses to Likert-scale questions on the demographic questionnaire:

<table>
<thead>
<tr>
<th>Question:</th>
<th>p-value&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Significant Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of interest in geology and the earth sciences:</td>
<td>0.344</td>
<td>None</td>
</tr>
<tr>
<td>Knowledge of geology and geologic processes:</td>
<td>0.898</td>
<td>None</td>
</tr>
<tr>
<td>Knowledge of how the earth changes over time:</td>
<td>0.387</td>
<td>None</td>
</tr>
<tr>
<td>Confidence in science classes:</td>
<td>0.309</td>
<td>None</td>
</tr>
<tr>
<td>Confidence using computers and the internet:</td>
<td>0.062</td>
<td>None</td>
</tr>
<tr>
<td>Confidence using new and unfamiliar forms of technology:</td>
<td>0.003</td>
<td>Group 2&gt;Group 1</td>
</tr>
</tbody>
</table>

<sup>a</sup>Kruskal-Wallis H test

Table 7-Comparison of self-reported treatment duration to treatment duration estimates obtained from embedded metadata in SurveyMonkey:

<table>
<thead>
<tr>
<th>Self-reported treatment duration bin:</th>
<th>Mean of estimated treatment duration (SurveyMonkey):</th>
<th>N</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10 minutes</td>
<td>15.71</td>
<td>7</td>
<td>9.44</td>
</tr>
<tr>
<td>10-20 minutes</td>
<td>19.12</td>
<td>62</td>
<td>10.19</td>
</tr>
<tr>
<td>20-30 minutes</td>
<td>26.31</td>
<td>44</td>
<td>9.53</td>
</tr>
<tr>
<td>30-40 minutes</td>
<td>24.92</td>
<td>13</td>
<td>10.63</td>
</tr>
<tr>
<td>40-50 minutes</td>
<td>41.66</td>
<td>3</td>
<td>18.50</td>
</tr>
<tr>
<td>50-60 minutes</td>
<td>16.00</td>
<td>1</td>
<td>---</td>
</tr>
</tbody>
</table>

Table 8-Mean estimated treatment duration for each group after removal of extreme outliers:

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean treatment duration (minutes)</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (photos)</td>
<td>44</td>
<td>17.86</td>
<td>7.703</td>
</tr>
<tr>
<td>Group 2 (passive TL)</td>
<td>44</td>
<td>19.68</td>
<td>6.994</td>
</tr>
<tr>
<td>Group 3 (inter. TL)</td>
<td>42</td>
<td>25.17</td>
<td>10.272</td>
</tr>
</tbody>
</table>
Table 9-Comparison of pre-test and post-test duration across the three treatment groups after removal of extreme outliers:

<table>
<thead>
<tr>
<th></th>
<th>Valid N</th>
<th>Mean (min)</th>
<th>p-value&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-test duration</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1 (photos)</td>
<td>40</td>
<td>29:09</td>
<td>0.322</td>
</tr>
<tr>
<td>Group 2 (passive TL)</td>
<td>40</td>
<td>27:24</td>
<td></td>
</tr>
<tr>
<td>Group 3 (interactive TL)</td>
<td>41</td>
<td>24:27</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>121</td>
<td>26:59</td>
<td></td>
</tr>
<tr>
<td><strong>Post-test duration</strong></td>
<td></td>
<td></td>
<td>0.529</td>
</tr>
<tr>
<td>Group 1 (photos)</td>
<td>44</td>
<td>19:43</td>
<td></td>
</tr>
<tr>
<td>Group 2 (passive TL)</td>
<td>44</td>
<td>18:16</td>
<td></td>
</tr>
<tr>
<td>Group 3 (interactive TL)</td>
<td>41</td>
<td>18:44</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>129</td>
<td>18:55</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>One-way ANOVA

Table 10-Comparison of mean scores and score gains on the multiple choice portion of the pre-test and post-test. Normalized gain is computed by dividing the maximum possible gain for a group based on its mean pre-test score by the actual score gain for that group:

<table>
<thead>
<tr>
<th>Group #:</th>
<th>Assessment</th>
<th>Pts. Possible</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (before/after images)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n=44)</td>
<td>Pre-test</td>
<td>23</td>
<td>9.91</td>
<td>2.41</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>23</td>
<td>13.43</td>
<td>3.57</td>
</tr>
<tr>
<td></td>
<td>Score gain:</td>
<td></td>
<td>3.52</td>
<td>3.37</td>
</tr>
<tr>
<td></td>
<td>Normalized gain:</td>
<td></td>
<td>0.27</td>
<td>0.25</td>
</tr>
<tr>
<td>2 (passive time-lapse)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n=44)</td>
<td>Pre-test</td>
<td>23</td>
<td>9.11</td>
<td>2.87</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>23</td>
<td>13.80</td>
<td>2.83</td>
</tr>
<tr>
<td></td>
<td>Score gain:</td>
<td></td>
<td>4.68</td>
<td>2.79</td>
</tr>
<tr>
<td></td>
<td>Normalized gain:</td>
<td></td>
<td>0.33</td>
<td>0.18</td>
</tr>
<tr>
<td>3 (interactive time-lapse)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n=42)</td>
<td>Pre-test</td>
<td>23</td>
<td>8.62</td>
<td>1.99</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>23</td>
<td>12.31</td>
<td>2.42</td>
</tr>
<tr>
<td></td>
<td>Score gain:</td>
<td></td>
<td>3.69</td>
<td>2.64</td>
</tr>
<tr>
<td></td>
<td>Normalized gain:</td>
<td></td>
<td>0.25</td>
<td>0.17</td>
</tr>
</tbody>
</table>
**Table 11-Summary of statistical tests performed on pre-test and post-test scores:**

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Test type</th>
<th>Group</th>
<th>p-value*</th>
<th>Result</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean pre-test scores for the three groups will be identical</td>
<td>One-way ANOVA</td>
<td>N/A</td>
<td>0.052</td>
<td>Accept</td>
<td>0.213^b</td>
</tr>
<tr>
<td>Mean post-test scores for the three groups will be identical</td>
<td>One-way ANOVA</td>
<td>N/A</td>
<td>0.060</td>
<td>Accept</td>
<td>0.207^b</td>
</tr>
<tr>
<td>The mean pre-test and mean post-test scores for Group ___ will be identical.</td>
<td>Two-tailed, paired t-test</td>
<td>1</td>
<td>0.000</td>
<td>Reject</td>
<td>1.045^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.000</td>
<td>Reject</td>
<td>1.677^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.000</td>
<td>Reject</td>
<td>1.398^a</td>
</tr>
<tr>
<td>The mean score gain for each of the three groups will be identical</td>
<td>One-way ANOVA</td>
<td>N/A</td>
<td>0.144</td>
<td>Accept</td>
<td>0.172^b</td>
</tr>
<tr>
<td>The normalized gain for each of the three groups will be identical</td>
<td>One-way ANOVA</td>
<td>NA</td>
<td>0.156</td>
<td>Accept</td>
<td>0.169^b</td>
</tr>
<tr>
<td>The winter and spring mean pre-test scores for each group will be identical</td>
<td>Two-tailed, independent sample t-test</td>
<td>1</td>
<td>0.135</td>
<td>Accept</td>
<td>0.459^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.269</td>
<td>Accept</td>
<td>0.338^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.268</td>
<td>Accept</td>
<td>0.358^a</td>
</tr>
<tr>
<td>The winter and spring mean post-test scores for each group will be identical</td>
<td>Two-tailed, independent sample t-test</td>
<td>1</td>
<td>0.772</td>
<td>Accept</td>
<td>0.080^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.082</td>
<td>Accept</td>
<td>0.537^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.423</td>
<td>Accept</td>
<td>0.253^a</td>
</tr>
<tr>
<td>The winter and spring mean score gain from pre-test to post-test for each group will be identical</td>
<td>Two-tailed, independent sample t-test</td>
<td>1</td>
<td>0.454</td>
<td>Accept</td>
<td>0.022^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.546</td>
<td>Accept</td>
<td>0.185^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.109</td>
<td>Accept</td>
<td>0.507^a</td>
</tr>
</tbody>
</table>

*All tests use α=0.05
^aCohen’s d
^bCohen’s f
Table 12-Correlation coefficients for pre-test score vs. score gain for the three treatment groups along with significance values:

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>r</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (photos)</td>
<td>44</td>
<td>-.272</td>
<td>0.074</td>
</tr>
<tr>
<td>Group 2 (passive TL)</td>
<td>44</td>
<td>-.500</td>
<td>0.001*</td>
</tr>
<tr>
<td>Group 3 (interactive TL)</td>
<td>42</td>
<td>-.479</td>
<td>0.001*</td>
</tr>
<tr>
<td>Total</td>
<td>130</td>
<td>-.397</td>
<td>0.000*</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed).

Table 13-Correlation coefficients for estimated treatment duration vs. score gain for the three treatment groups along with significance values:

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>r</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (photos)</td>
<td>44</td>
<td>0.401</td>
<td>0.007*</td>
</tr>
<tr>
<td>Group 2 (passive TL)</td>
<td>44</td>
<td>-0.096</td>
<td>0.534</td>
</tr>
<tr>
<td>Group 3 (interactive TL)</td>
<td>42</td>
<td>-0.077</td>
<td>0.626</td>
</tr>
<tr>
<td>Total</td>
<td>130</td>
<td>0.023</td>
<td>0.796</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed).

Table 14-Mean elapsed time between pre-test and post-test for the three treatment groups along with correlation coefficients for elapsed time vs. score gain:

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (days)</th>
<th>p-value</th>
<th>r vs. score gain</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (photos)</td>
<td>44</td>
<td>4.07</td>
<td>0.958</td>
<td>-0.247</td>
<td>0.021*</td>
</tr>
<tr>
<td>Group 2 (passive TL)</td>
<td>44</td>
<td>3.86</td>
<td></td>
<td>-0.267</td>
<td>0.080</td>
</tr>
<tr>
<td>Group 3 (interactive TL)</td>
<td>42</td>
<td>4.00</td>
<td></td>
<td>-0.490</td>
<td>0.001**</td>
</tr>
<tr>
<td>Total</td>
<td>130</td>
<td>3.98</td>
<td></td>
<td>-0.323</td>
<td>0.000**</td>
</tr>
</tbody>
</table>

*aOne-way ANOVA

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)
Table 15-Score gain vs. categorical predictor variables and associated statistical tests:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categories</th>
<th>Mean score gain</th>
<th>Std. Dev</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course</td>
<td>GEOL 101 (n=97)</td>
<td>3.99</td>
<td>2.99</td>
<td>0.660 b</td>
</tr>
<tr>
<td></td>
<td>GEOL 211 (n=32)</td>
<td>4.03</td>
<td>2.96</td>
<td></td>
</tr>
<tr>
<td>Lecture instructor</td>
<td>A (n=12)</td>
<td>4.25</td>
<td>3.25</td>
<td>0.185 a</td>
</tr>
<tr>
<td></td>
<td>B (n=8)</td>
<td>2.38</td>
<td>3.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C (n=32)</td>
<td>4.41</td>
<td>2.61</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D (n=16)</td>
<td>4.88</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E (n=13)</td>
<td>5.08</td>
<td>2.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F (n=33)</td>
<td>3.52</td>
<td>2.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G (n=15)</td>
<td>3.00</td>
<td>3.70</td>
<td></td>
</tr>
<tr>
<td>GPA</td>
<td>2.0 or below (n=4)</td>
<td>6.50</td>
<td>2.08</td>
<td>0.521 a</td>
</tr>
<tr>
<td></td>
<td>2.1-2.5 (n=10)</td>
<td>4.30</td>
<td>2.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.6-3.0 (n=40)</td>
<td>3.75</td>
<td>2.92</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.1-3.5 (n=37)</td>
<td>3.86</td>
<td>3.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.6-4.0 (n=38)</td>
<td>4.00</td>
<td>2.95</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Male (n=40)</td>
<td>4.65</td>
<td>2.58</td>
<td>0.082 b</td>
</tr>
<tr>
<td></td>
<td>Female (n=90)</td>
<td>3.67</td>
<td>3.10</td>
<td></td>
</tr>
<tr>
<td>Geology in College</td>
<td>Yes (n=9)</td>
<td>2.89</td>
<td>2.98</td>
<td>0.261 b</td>
</tr>
<tr>
<td></td>
<td>No (n=121)</td>
<td>4.05</td>
<td>2.97</td>
<td></td>
</tr>
<tr>
<td>Geology in HS</td>
<td>Yes (n=23)</td>
<td>4.17</td>
<td>2.59</td>
<td>0.718 b</td>
</tr>
<tr>
<td></td>
<td>No (n=107)</td>
<td>3.93</td>
<td>3.06</td>
<td></td>
</tr>
</tbody>
</table>

*One-way ANOVA

bIndependent samples t-test (two-tailed)
Table 16-Correlation coefficients for test duration and Likert-scale questions vs. test scores:

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>pre-test score</th>
<th>post test score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>score gain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test duration</td>
<td>0.041</td>
<td>---</td>
<td>0.150</td>
</tr>
<tr>
<td>Pre-test duration</td>
<td>---</td>
<td>0.095</td>
<td>---</td>
</tr>
<tr>
<td>Level of interest in geology and the earth sciences</td>
<td>0.025</td>
<td>0.280**</td>
<td>0.255**</td>
</tr>
<tr>
<td>Knowledge of geology and geologic processes</td>
<td>0.029</td>
<td>0.136</td>
<td>0.141</td>
</tr>
<tr>
<td>Knowledge of how the earth changes over time</td>
<td>0.052</td>
<td>0.110</td>
<td>0.142</td>
</tr>
<tr>
<td>Confidence in science classes</td>
<td>0.166</td>
<td>0.268**</td>
<td>0.384**</td>
</tr>
<tr>
<td>Confidence using computers and the internet</td>
<td>0.148</td>
<td>-0.053</td>
<td>0.102</td>
</tr>
<tr>
<td>Confidence using new and unfamiliar forms of technology</td>
<td>0.094</td>
<td>0.046</td>
<td>0.128</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
Table 17-Student performance on assessments by learning outcome/task:

<table>
<thead>
<tr>
<th>Learning outcome:</th>
<th>Corresponding item numbers:</th>
<th>p-value\textsuperscript{a}</th>
<th>Effect size (Cohen’s f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Qualitatively characterize and/or describe the rate of a geological process.</td>
<td>5, 12, 15, 17, 18</td>
<td>0.202</td>
<td>0.157</td>
</tr>
<tr>
<td>B. Quantitatively characterize the rate of a geological process.</td>
<td>6, 19, 20</td>
<td>0.921</td>
<td>0.040</td>
</tr>
<tr>
<td>C. Characterize the temporal variation in the rate of a geological process.</td>
<td>5, 12, 17</td>
<td>0.187</td>
<td>0.163</td>
</tr>
<tr>
<td>D. Characterize spatial variations in the rate of a geological process.</td>
<td>14, 18</td>
<td>0.184</td>
<td>0.161</td>
</tr>
<tr>
<td>E. Compare and contrast the rates of several different geological processes occurring in a single landscape.</td>
<td>10</td>
<td>0.824</td>
<td>0.055</td>
</tr>
<tr>
<td>F. Compare and contrast the rates of several different geological processes occurring in different landscapes.</td>
<td>22</td>
<td>0.380</td>
<td>0.124</td>
</tr>
<tr>
<td>G. Use the observed rate of a geological process to predict possible future landscape changes.</td>
<td>7, 8, 9, 13, 15</td>
<td>0.783</td>
<td>0.060</td>
</tr>
</tbody>
</table>

\textsuperscript{a}One-way ANOVA

Table 18-Student mean score gain sorted by operationalized learning outcomes listed in Table 17:

<table>
<thead>
<tr>
<th>Group number</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (photos)</td>
<td>.64</td>
<td>.80</td>
<td>.02</td>
<td>.23</td>
<td>.09</td>
<td>1.27</td>
<td>1.05</td>
</tr>
<tr>
<td>Group 2 (passive TL)</td>
<td>1.14</td>
<td>.70</td>
<td>.32</td>
<td>.57</td>
<td>.25</td>
<td>1.64</td>
<td>1.16</td>
</tr>
<tr>
<td>Group 3 (inter. TL)</td>
<td>.88</td>
<td>.79</td>
<td>-.05</td>
<td>.40</td>
<td>.24</td>
<td>1.24</td>
<td>1.05</td>
</tr>
</tbody>
</table>
Table 19- Results of matched pairs Wilcoxin Signed Ranks tests performed on the distribution of student responses to Likert-scale questions on the pre-test vs. post-test. Statistically significant shifts in response pattern are shaded. “P” represents the number of respondents who had a more positive response on the post-test compared to the pre-test (i.e., more likely to “Agree” or “Strongly Agree”) while “N” represents the number of respondents with a more negative response on the post-test (i.e., more likely to “Disagree” or “Strongly Disagree”).

<table>
<thead>
<tr>
<th>Group 1 (photos)</th>
<th>Group 2 (pass. TL)</th>
<th>Group 3 (inter. TL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilcoxin sig&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Effect size&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>A-Geologic time is measured in millions of years because that is how long it takes landscapes to change significantly:</td>
<td>0.000</td>
<td>0.409</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>B-The landscape around us is constantly changing:</td>
<td>0.003</td>
<td>0.318</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>C-Landscapes change at a constant rate through time:</td>
<td>0.371</td>
<td>0.095</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>D-Catastrophic events are more important in sculpting the Earth than slow, gradual processes that occur every day:</td>
<td>0.363</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>E-Landscapes can change significantly over the course of an average human lifetime:</td>
<td>0.000</td>
<td>0.444</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>2</td>
</tr>
<tr>
<td>F-Humans can alter the rate at which landscapes change:</td>
<td>0.020</td>
<td>0.248</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>G-Moving water (such as rivers or waves) can only change the surface of the Earth over long periods of time (i.e. more than one year):</td>
<td>0.000</td>
<td>0.403</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>27</td>
</tr>
<tr>
<td>H-Water only changes the surface of the Earth during rare events, such as large floods or tsunami:</td>
<td>0.007</td>
<td>0.286</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>I-Apart from human activity, Earth’s landscape looks similar today as it did a few million years ago:</td>
<td>0.003</td>
<td>0.322</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>22</td>
</tr>
</tbody>
</table>

<sup>a</sup> Significance value for Wilcoxin Signed Ranks test (matched samples), α=0.05
<sup>b</sup>Effect size r: r<sub>0.10</sub> (small), r<sub>0.30</sub> (med), r<sub>0.50</sub> (large), r<sub>0.70</sub> (very large)
Table 20- Summary of open-ended responses for item #12 (Which of the following statements do you think best describes the rate of erosion along rivers in the Pacific Northwest, including the Elwha River?), showing distribution of responses coded into each category along with example responses:

<table>
<thead>
<tr>
<th>Category:</th>
<th>Group #</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 photos</td>
</tr>
<tr>
<td>No response/unable to interpret response</td>
<td>2</td>
</tr>
<tr>
<td>Observational response (no reference to underlying process), correct</td>
<td>8</td>
</tr>
<tr>
<td>Observational response (no reference to underlying process), incorrect</td>
<td>4</td>
</tr>
<tr>
<td>Explanatory response (incorrect)</td>
<td>16</td>
</tr>
<tr>
<td>Explanatory response (correct)</td>
<td>14</td>
</tr>
<tr>
<td>Explanatory/observational ratio</td>
<td>30/12</td>
</tr>
<tr>
<td>Correct/incorrect ratio</td>
<td>22/20</td>
</tr>
</tbody>
</table>
Table 21- Summary of open-ended responses for item #17 (Which of the following statements do you think best describes the movement of the Swift Creek Landslide?), showing distribution of responses coded into each category along with example responses:

<table>
<thead>
<tr>
<th>Category:</th>
<th>Group #</th>
<th>1 photos</th>
<th>2 pass. TL</th>
<th>3 inte. TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>No response/unable to interpret response</td>
<td></td>
<td>6</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>• “don't know why”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• “random shifts”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observational response (no reference to underlying process), correct</td>
<td></td>
<td>10</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>• “There was at least a little movement year round”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• “The landslide is always changing, the rate at which it moves varies during different times.”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observational response (no reference to underlying process), incorrect</td>
<td></td>
<td>14</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>• “Seemed like that from the video”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• “because it seems that the seasons dont affect the rate of the landslide”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• “when I watched the video of the landslide movement, I noticed that it was constantly moving at a pretty constant rate.”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanatory response (incorrect)</td>
<td></td>
<td>5</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>• “I think it will only move with during a quick burst because it won't always have the driving energy that will push it down the hill.”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• “As the hillside flattens out the landslide will slow down.”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanatory response (correct)</td>
<td></td>
<td>9</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>• “In the video I created, I noticed that the landslide nearly stopped in the summer and sped up during the wetter seasons.”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• “I think that it moves quicker when the ground is more saturated with rainwater”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explanatory/observational ratio</td>
<td>14/24</td>
<td>8/25</td>
<td>11/18</td>
<td></td>
</tr>
<tr>
<td>Correct/incorrect ratio</td>
<td>19/19</td>
<td>19/14</td>
<td>9/20</td>
<td></td>
</tr>
</tbody>
</table>
Table 22—Summary of most common responses to item #11:

| What are some factors that might control how quickly the Columbia Glacier moves? |
|---------------------------------|---------------------------------|---------------------------------|
| *(1^st~factor=3pts, 2^nd~factor=2pts, 3^rd~factor=1pt)* |
| **Group 1 (photos):** | **Pts** | **Group 2 (passive TL):** | **Pts** | **Group 3 (inter. TL):** | **Pts** |
| • Temperature | 54 | • Temperature | 70 | • Temperature | 53 |
| • Climate change/global warming | 42 | • Climate change/global warming | 27 | • Climate change/global warming | 28 |
| • Tides | 18 | • Season | 24 | • Season | 22 |
| • Climate | 16 | • Tides | 22 | • Tides | 16 |
| • Season | 13 | • Weather | 20 | • Erosion | 13 |
| • Erosion | 11 | • Amount of snowfall | 15 | • Weather | 11 |
| • Sea level | 8 | • Amount of rainfall | 9 | • Sea level | 10 |
| • Angle of slope | 8 | • Erosion | 8 | • Amount of snowfall | 9 |
| • Amount of snowfall | 8 | • Sea level | 7 | • Amount of rainfall | 8 |

Table 23—Summary of most common responses to item #16:

| What are some factors that might control the rate of erosion along the Elwah River? |
|---------------------------------|---------------------------------|---------------------------------|
| *(1^st~factor=3pts, 2^nd~factor=2pts, 3^rd~factor=1pt)* |
| **Group 1 (photos):** | **Pts** | **Group 2 (passive TL):** | **Pts** | **Group 3 (inter. TL):** | **Pts** |
| • Season | 44 | • Amount of precipitation/rainfall | 50 | • River discharge | 45 |
| • Amount of precipitation/rainfall | 40 | • River discharge | 46 | • Amount of precipitation/rainfall | 27 |
| • River discharge | 30 | • Season | 38 | • Speed of water in river | 24 |
| • Vegetation | 15 | • Weather | 21 | • Season | 22 |
| • Glacier/snowmelt | 14 | • Speed of water in river | 13 | • Glacier/snowmelt | 20 |
| • Sediment/rock type | 13 | • Dam removal/human activity | 12 | • Temperature | 13 |
| • Dam removal/human activity | 12 | • Glacier/snowmelt | 12 | • Vegetation | 12 |
| • Speed of water in river | 11 | • Temperature | 12 | • Flooding | 9 |
| • Temperature | 10 | • Sediment/rock type | 7 | • Sediment/rock type | 8 |
Table 24—Summary of most common responses to item #21:

What are some factors that might control the rate at which the Swift Creek landslide moves? (1st factor=3pts, 2nd factor=2pts, 3rd factor=1pt)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Amount of rainfall/water</td>
<td>48</td>
<td>• Amount of rainfall/water</td>
<td>62</td>
<td>• Amount of rainfall/water</td>
<td>46</td>
</tr>
<tr>
<td>• Vegetation</td>
<td>25</td>
<td>• Composition of rock/sediment</td>
<td>29</td>
<td>• Gravity</td>
<td>22</td>
</tr>
<tr>
<td>• Seasons</td>
<td>22</td>
<td>• Weathering</td>
<td>16</td>
<td>• Vegetation</td>
<td>21</td>
</tr>
<tr>
<td>• Angle of slope</td>
<td>22</td>
<td>• Gravity</td>
<td>15</td>
<td>• Composition of rock/sediment</td>
<td>20</td>
</tr>
<tr>
<td>• Erosion</td>
<td>18</td>
<td>• Season</td>
<td>15</td>
<td>• Earthquakes</td>
<td>14</td>
</tr>
<tr>
<td>• Human activity</td>
<td>18</td>
<td>• Human activity</td>
<td>13</td>
<td>• Weight of overlying material</td>
<td>13</td>
</tr>
<tr>
<td>• Weather</td>
<td>15</td>
<td>• Weather</td>
<td>13</td>
<td>• Slope angle</td>
<td>12</td>
</tr>
<tr>
<td>• Composition of rock/sediment</td>
<td>12</td>
<td>• Angle of slope</td>
<td>12</td>
<td>• Weather</td>
<td>12</td>
</tr>
<tr>
<td>• Earthquakes</td>
<td>12</td>
<td>• Erosion</td>
<td>11</td>
<td>• Weathering</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 25—Tests for statistical significance on the distribution of student responses to Likert-scale questions on the post-test questionnaire:

<table>
<thead>
<tr>
<th>Question:</th>
<th>p-valuea</th>
<th>Significant Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>The directions provided were clear and concise:</td>
<td>0.179</td>
<td>None</td>
</tr>
<tr>
<td>I felt comfortable using the computer-based portion of this activity:</td>
<td>0.209</td>
<td>None</td>
</tr>
<tr>
<td>I found this activity confusing and/or frustrating:</td>
<td>0.859</td>
<td>None</td>
</tr>
<tr>
<td>I felt that the time-lapse photos/videos were a good way to learn about how quickly landscapes change:</td>
<td>0.069</td>
<td>None</td>
</tr>
<tr>
<td>This activity increased my understanding of how quickly landscapes change:</td>
<td>0.237</td>
<td>None</td>
</tr>
<tr>
<td>I enjoyed completing this activity:</td>
<td>0.317</td>
<td>None</td>
</tr>
<tr>
<td>I took this activity seriously and answered all questions to the best of my ability:</td>
<td>0.773</td>
<td>None</td>
</tr>
</tbody>
</table>

aKruskal-Wallis H test
Table 26-Summary of categorized student responses to open-ended questions on the post-test questionnaire

<table>
<thead>
<tr>
<th>What did you find most useful about this activity?</th>
<th># of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1 (photos, n=44):</strong></td>
<td></td>
</tr>
<tr>
<td>• Looking at time-lapse photos</td>
<td>18</td>
</tr>
<tr>
<td>• Drag-able image slider</td>
<td>11</td>
</tr>
<tr>
<td>• Increased perspective on the rates of landscape change</td>
<td>5</td>
</tr>
<tr>
<td>• Wide variety of times for comparison</td>
<td>4</td>
</tr>
<tr>
<td>• No response/unintelligible response</td>
<td>3</td>
</tr>
<tr>
<td>• Clear instructions</td>
<td>2</td>
</tr>
<tr>
<td>• Opportunity to apply knowledge from GEOL 101/211</td>
<td>1</td>
</tr>
<tr>
<td><strong>Group 2 (passive TL, n=44):</strong></td>
<td></td>
</tr>
<tr>
<td>• Watching time-lapse videos</td>
<td>18</td>
</tr>
<tr>
<td>• Increase perspective on the rates of landscape change</td>
<td>10</td>
</tr>
<tr>
<td>• Ability to watch videos from different camera angles</td>
<td>6</td>
</tr>
<tr>
<td>• Date stamp on videos</td>
<td>3</td>
</tr>
<tr>
<td>• Opportunity to revisit predictions after watching videos</td>
<td>2</td>
</tr>
<tr>
<td>• Seeing a glacier change</td>
<td>1</td>
</tr>
<tr>
<td>• Text descriptions of landscapes</td>
<td>1</td>
</tr>
<tr>
<td>• Opportunity to apply knowledge from GEOL 101/211</td>
<td>1</td>
</tr>
<tr>
<td>• Increased familiarity with Canvas</td>
<td>1</td>
</tr>
<tr>
<td>• Clear instructions</td>
<td>1</td>
</tr>
<tr>
<td><strong>Group 3 (interactive TL, n=42):</strong></td>
<td></td>
</tr>
<tr>
<td>• Watching time-lapse videos</td>
<td>16</td>
</tr>
<tr>
<td>• Increased perspective on the rates of landscape change</td>
<td>14</td>
</tr>
<tr>
<td>• Ability to make/control parameters of time-lapse videos</td>
<td>8</td>
</tr>
<tr>
<td>• Opportunity to apply knowledge from GEOL 101/211</td>
<td>1</td>
</tr>
<tr>
<td>• Easy to use</td>
<td>1</td>
</tr>
<tr>
<td>• Opportunity to revisit predictions after watching videos</td>
<td>1</td>
</tr>
<tr>
<td>• Ability to see real landscapes rather than simplified animation</td>
<td>1</td>
</tr>
<tr>
<td>Did you learn anything during this activity that you found particularly surprising or interesting?</td>
<td># of responses</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Group 1 (photos, n=44):</strong></td>
<td>(44)</td>
</tr>
<tr>
<td>- How quickly the ________ moved/changed/formed</td>
<td></td>
</tr>
<tr>
<td>- Columbia Glacier</td>
<td>17</td>
</tr>
<tr>
<td>- Elwha River channel</td>
<td>15</td>
</tr>
<tr>
<td>- Landscapes in general</td>
<td>7</td>
</tr>
<tr>
<td>- Lava dome</td>
<td>3</td>
</tr>
<tr>
<td>- Landslide</td>
<td>1</td>
</tr>
<tr>
<td>- Mountain ranges</td>
<td>1</td>
</tr>
<tr>
<td>- Landslides can move slowly</td>
<td>8</td>
</tr>
<tr>
<td>- “Yes”</td>
<td>2</td>
</tr>
<tr>
<td>- Inaccuracy of my predictions</td>
<td>1</td>
</tr>
<tr>
<td>- Lava dome grew slower than expected</td>
<td>1</td>
</tr>
<tr>
<td>- Increased height of mountain ranges</td>
<td>1</td>
</tr>
<tr>
<td>- Seasonal changes in erosion rate</td>
<td>1</td>
</tr>
<tr>
<td><strong>Group 2 (passive TL, n=44):</strong></td>
<td>(39)</td>
</tr>
<tr>
<td>- How quickly the ________ moved/changed/formed</td>
<td></td>
</tr>
<tr>
<td>- Columbia Glacier</td>
<td>12</td>
</tr>
<tr>
<td>- Landscapes in general</td>
<td>12</td>
</tr>
<tr>
<td>- Elwha River channel</td>
<td>8</td>
</tr>
<tr>
<td>- Lava dome</td>
<td>3</td>
</tr>
<tr>
<td>- Landslide</td>
<td>3</td>
</tr>
<tr>
<td>- Mountain ranges</td>
<td>1</td>
</tr>
<tr>
<td>- Rate of the landslide</td>
<td>4</td>
</tr>
<tr>
<td>- Landslides can move slowly</td>
<td>2</td>
</tr>
<tr>
<td>- Glacier movement</td>
<td>1</td>
</tr>
<tr>
<td>- Speed with which water can change land</td>
<td>1</td>
</tr>
<tr>
<td>- Watching glacier shrink was “stressful”</td>
<td>1</td>
</tr>
<tr>
<td>- The lava dome in Mt. St. Helens is re-growing</td>
<td>1</td>
</tr>
<tr>
<td>- Why/how calving occurs</td>
<td>1</td>
</tr>
<tr>
<td>- Better sense of rates of geological processes</td>
<td>1</td>
</tr>
<tr>
<td>- Landslides can move constantly, rather than in quick bursts</td>
<td></td>
</tr>
<tr>
<td><strong>Group 3 (interactive TL, n=42):</strong></td>
<td>(21)</td>
</tr>
<tr>
<td>- How quickly the ________ moved/changed/formed</td>
<td></td>
</tr>
<tr>
<td>- Elwha River channel</td>
<td>10</td>
</tr>
<tr>
<td>- Landscapes in general</td>
<td>6</td>
</tr>
<tr>
<td>- Columbia Glacier</td>
<td>3</td>
</tr>
</tbody>
</table>
Were there any parts of this activity that you found especially confusing or unclear?  

<table>
<thead>
<tr>
<th>Part</th>
<th># of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lava dome</td>
<td>1</td>
</tr>
<tr>
<td>Mountain ranges</td>
<td>1</td>
</tr>
<tr>
<td>Landslides can move slowly</td>
<td>5</td>
</tr>
<tr>
<td>Landslides can move constantly over time</td>
<td>4</td>
</tr>
<tr>
<td>Landslides</td>
<td>1</td>
</tr>
<tr>
<td>Magnitude of changes to river channel</td>
<td>1</td>
</tr>
<tr>
<td>How slow many processes are</td>
<td>1</td>
</tr>
<tr>
<td>Elwha River</td>
<td>1</td>
</tr>
<tr>
<td>Glaciers</td>
<td>1</td>
</tr>
<tr>
<td>How resistant mountains are to erosion</td>
<td>1</td>
</tr>
<tr>
<td>How quickly lakes can dry up</td>
<td>1</td>
</tr>
<tr>
<td>How bodies of Earth move or are eroded</td>
<td>1</td>
</tr>
</tbody>
</table>

Group 1 (photos, n=44):
- No/nothing                                                          28
- Hard to see movement of landslide                                   3
- Did not observe quick movement of landslide                          2
- Glacier vs. ocean unclear                                           1
- Factors which caused landscape change unclear                       1
- Glacier terminology unclear                                          1
- Hard to tell which photos was older vs. newer                       1
- Lack of scale                                                       1
- Hard to see movement/change in some photos                          1
- Hard to remember how long things took when taking quiz              1
- Mt. St. Helens photos hard to interpret                             1
- Some questions seemed like they had multiple correct answers        1

Group 2 (passive TL, n=44):
- No/nothing                                                          30
- Hard to picture scale in images                                     1
- Likert-scale questions confusing                                    1
- Different camera angles confusing                                   1
- Hard to pay attention to datestamp while watching videos            1
- Rate of weathering/erosion unclear                                  1
- Unclear what “tide moving in and out” meant                          1
- Not given enough time to absorb all information                     1
- Directions on how to start unclear                                  1
- Factors which caused landscape change unclear
- First part of activity because I don’t know how land changes
- “The amount of time it would take some figures to move”

**Group 3 (interactive TL, n=42):**
- No/nothing
- How to make videos confusing, but received help
- Questions about mountain erosion confusing
- Videos took a long time to generate
- Some assessment questions unclear/ambiguous
- Directions to computer lab were confusing
- Choosing start and end date for videos was confusing
- Multiple camera angles of the glacier was confusing
- Frame rate was confusing
- Not sure what to look for in videos
- Landslide was missing footage
- Video software was confusing
- Seemed as though some questions could not be answered

<table>
<thead>
<tr>
<th>What could be added to or changed about this activity to make it better?</th>
<th># of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (photos, n=44):</td>
<td></td>
</tr>
<tr>
<td>Nothing/not sure</td>
<td>11</td>
</tr>
<tr>
<td>Have scale in photos rather than just in text</td>
<td>4</td>
</tr>
<tr>
<td><em>Add time-lapse of a volcanic environment</em></td>
<td>2</td>
</tr>
<tr>
<td>More camera angles</td>
<td>2</td>
</tr>
<tr>
<td>More text telling us what to look for/why things are changing</td>
<td>2</td>
</tr>
<tr>
<td>Include time-lapse videos rather than just photos</td>
<td>2</td>
</tr>
<tr>
<td>Ability to look at photos while taking quiz</td>
<td>2</td>
</tr>
<tr>
<td>More background information on different landscapes</td>
<td>2</td>
</tr>
<tr>
<td>Longer duration (real-time) time-lapses</td>
<td>1</td>
</tr>
<tr>
<td>Computer predictions of what landscapes will look like in future</td>
<td>1</td>
</tr>
<tr>
<td>Add computer animation</td>
<td>1</td>
</tr>
<tr>
<td>Add time-lapse showing uplift/erosion of mountains</td>
<td>1</td>
</tr>
<tr>
<td>Take quiz immediately before looking at photos</td>
<td>1</td>
</tr>
<tr>
<td>More multiple choice questions, less open-ended questions</td>
<td>1</td>
</tr>
</tbody>
</table>
• Don’t have same questions on post-test 1
• Have old photo on left, newer photo on right 1
• Include photos showing seasonal changes 1
• More time to look at photos 1
• A glossary to help with vocabulary 1
• Have photos with more noticeable differences 1
• More questions about Mt. St. Helens 1

Group 2 (passive TL, n=44):
• Nothing/not sure 21
• More videos 3
• Ability to watch videos while taking quiz 2
• Include videos that span a longer period of time 2
• Have scale in videos rather than just in text 1
• Add sound 2
• Include before/after photographs for comparison 2
• Better/faster computers 1
• More background information on different landscapes 1
• Include text in videos telling what season it is 1
• Tell us why landscapes change so quickly 1
• More volcano time-lapse videos 1
• Make datestamp in videos easier to see 1
• Ability to see lakes before dams were removed 1
• Fewer videos 1
• Make videos go faster 1

Group 3 (interactive TL, n=42):
• Nothing/not sure 15
• Faster loading time for videos 7
• More background information on the different landscapes 2
• Ability to watch pre-made time-lapse videos 2
• More time-lapse videos 1
• Include timeline of events 1
• More options to control creation of videos 1
• Have fewer similar questions on the tests 1
• Ask more questions about what is changing in the videos 1
• More guidance on what to look for in the videos 1
• Don’t limit ability to select dates 1
• Another example of a landslide 1
• Ability to look at before/after photos 1
• See answers after taking quiz
• Time-lapse videos spanning 100-100,000 years
• An example completed activity
• Have scale in videos rather than just text

<table>
<thead>
<tr>
<th>What was your primary motivation for agreeing to participate in this study?</th>
<th>Group 1 (photos)</th>
<th>Group 2 (passive TL)</th>
<th>Group 3 (inter. TL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movie ticket/gift card</td>
<td>22</td>
<td>26</td>
<td>29</td>
</tr>
<tr>
<td>Desire to help out</td>
<td>22</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Interested in geology</td>
<td>8</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Study sounded interesting</td>
<td>5</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Participating might help performance in GEOL 101/211</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Desire to better understand geology</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Enjoy participating in research projects</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Enjoy helping the environment</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Nothing better to do</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
How often do you use time-lapse videos as an instructional aid in your geology courses?

- 33.3% Occasionally, one or twice per semester/quarter
- 33.3% Rarely, I've used them a handful of times in my career
- 28.6% On a weekly or daily basis, they are an integral part of my courses
- 4.8% Never

Figure 1- Results from an April 2013 online survey of college geology educators (n=43) regarding their use of time-lapse videos in geology courses.
Recruit students from study population (GEOL 101/211), obtain informed consent

Randomly assign participants to groups for treatment (Canvas)

Group 1
(before/after photos)

Group 2
(passive time-lapse)

Group 3
(interactive time-lapse)

Administer pre-test, collect demographic information (SurveyMonkey)

TREATMENT
(online activity, WWU computer lab)

Administer post-assessment (WWU computer lab, SurveyMonkey)

Data analysis

Figure 2-Flowchart outlining study protocol.
Figure 3—Annotated screenshot of an example before and after photo pair used by Group 1 to explore rates of landscape change. Primary feature is the drag-able slider (C) that allows users to compare and contrast the two images.

A-Time interval represented by photo pair: gives users an idea of the amount of time spanned by the two photos.

B-Datetstamp: indicates the date and time each individual image was captured.

C-Draggable slider: Allows user to compare and contrast the “before” and “after” photos.

D-Shortcuts to individual images: Allows user to view either just the “before” or just the “after” photo.
**A-Time-lapse data-set selector:** allows users to select from a list of six different landscapes to make a time-lapse video of. Number of individual frames in each data set is listed in parentheses.

**B-Date and time selector:** allows users to select the start and end date of the time-lapse video. Clicking on one of the date boxes brings up a small calendar from which users can select the desired date.

**C-Frame rate selector:** allows users to select a frame rate of either 10, 20, or 30 frames per second (fps) for the video.

**D-Time of day selector:** allows users to limit which images are used to make the video to a certain time of day. This can help remove images with distracting shadows or dramatic changes in dynamic range from the final video.

**E-Video length selector:** allows users to specify the duration of the final video (in seconds). If the number of images in the chosen date range exceeds the number of frames that can be shown in the specified length, the program will randomly remove frames in order to still show the changes that occur over the specified period of time.

**F-Video output:** after clicking “Generate”, the video appears on the right-hand side of the screen where it can be played, paused, or made full-screen. Student can also use the dragable slider to play through the video at a custom pace.

Figure 4-Annotated screenshot showing the features of the interactive online software program used by students in Group 3 to generate custom time-lapse videos.
Figure 5- Sample of time-lapse images taken under different lighting and weather conditions. 
(A)-Image taken on an overcast day with even lighting conditions across the entire landscape and no distracting shadows. 
(B)-Image taken on a sunny day, note presence of high dynamic range between the brightly lit background and shadowed foreground. 
(C)-Image taken in foggy conditions, obscuring the view of the river. 
(D)-Image taken with the Sun just outside the field of view, resulting in extreme lens flare. 
(E)-Image obscured by ice and snow accumulations on the camera lens. 
(F)-Nighttime Image from the Columbia Glacier, AK, likely triggered by light from the visible aurora. Note that glacier is difficult to see.
Figure 6 - Graph showing the distribution of study participants amongst the three treatment groups.

Figure 7 - Graph showing the ratio of students in GEOL 101 vs GEOL 211 in the three treatment groups.
Figure 8-Graph showing the distribution of participants by lecture instructor in the three treatment groups.

Figure 9-Graph showing distribution of study participants by lab T.A. in the three treatment groups.
Figure 10-Figure showing the distribution of male vs. female participants in each of the three treatment groups.

Figure 11-Graphs showing the distribution of students in each treatment group who have previously taken a geology course in college (left) or high school (right).
Figure 12(a-c)-Distribution of student responses to Likert-scale questions on the demographic questionnaire for each treatment group. Note that the number of responses is expressed in terms of percentages, rather than absolute numbers in order to take into account the slightly different sizes of the three groups.
Figure 12(d-f)-Distribution of student responses to Likert-scale questions on the demographic questionnaire for each treatment group. Note that the number of responses is expressed in terms of percentages, rather than absolute numbers in order to take into account the slightly different sizes of the three groups.
Figure 14 - Graph showing estimated treatment duration for each of the three treatment groups. Estimates obtained using the methods and proxies described in the text. Horizontal black line represents the median for each group, colored box spans from 25th to 75th percentile, whiskers show highest and lowest values that are not outliers while outliers shown as circles.

Figure 13 - Histograms showing distribution of gain in student scores on the multiple choice portion of the assessments from pre-test to post-test. Note lack of negative gains in Group 2 (passive time-lapse).
Figure 15- Comparison of student scores on the multiple choice portion of the pre-and post-test. Horizontal black line represents the median of scores, top and bottom of the colored boxes represent the 75th and 25th percentile respectively, and outliers are represented by open circles.
Figure 16- Scatter plot of score gain as a function of estimated treatment duration. Overall no correlation is observed, except for among participants in Group 1 (red dots) where a slight positive correlation is observed.
Figure 17- Scatter plot of score gain as a function of number of days in-between taking the pre-test and completing the treatment activities and post-test. Overall a slight negative correlation is observed, suggesting that students who had the pre-test questions fresh in their mind when completing treatment performed better on the post-test.
Figure 18- Graphs showing the net change in number of correct responses from pre-test to post-test for each multiple choice or short answer assessment item used to produce student scores. Item numbers are shown on the X axis. Bars which go below the origin represent questions where fewer students responded correctly on the post-test and thus are indicative of misconceptions arising from the treatment activities.
Figure 19- Bar graph showing comparing the distribution of responses to item 22a on the pre-test and post-test.

Figure 20- Bar graph showing comparing the distribution of responses to item 22b on the pre-test and post-test.
Figure 21 - Bar graph showing comparing the distribution of responses to item 22c on the pre-test and post-test.

Figure 22 - Bar graph showing comparing the distribution of responses to item 22d on the pre-test and post-test.
Figure 23- Bar graph showing comparing the distribution of responses to item 22e on the pre-test and post-test.

Figure 24- Bar graph showing comparing the distribution of responses to item 22f on the pre-test and post-test.
Figure 25- Bar graph showing comparing the distribution of responses to item 22h on the pre-test and post-test.

Figure 26- Bar graph showing comparing the distribution of responses to item 22g on the pre-test and post-test.
Figure 27(a-b)-Figures comparing the distribution of responses to Likert-scale questions on the pre-test vs. post-test.
Figure 27(c-d)-Figures comparing the distribution of responses to Likert-scale questions on the pre-test vs. post-test.
Figure 27(e-f)-Figures comparing the distribution of responses to Likert-scale questions on the pre-test vs. post-test.
Moving water (such as rivers or waves) can only change the surface of the Earth over long periods of time (i.e. more than one year):

- Group 1 (Pre-test) (photos)
- Group 1 (Post-test)
- Group 2 (Pre-test) (passive TL)
- Group 2 (Post-test)
- Group 3 (Pre-test) (interactive TL)
- Group 3 (Post-test)

Water only changes the surface of the Earth during rare events, such as large floods or tsunamis:

- Group 1 (Pre-test) (photos)
- Group 1 (Post-test)
- Group 2 (Pre-test) (passive TL)
- Group 2 (Post-test)
- Group 3 (Pre-test) (interactive TL)
- Group 3 (Post-test)

Figure 27(g-h)-Figures comparing the distribution of responses to Likert-scale questions on the pre-test vs. post-test.
Apart from human activity, Earth's landscape looks similar today as it did a few million years ago.

Figure 27(i)-Figures comparing the distribution of responses to Likert-scale questions on the pre-test vs. post-test.
Figure 28(a-c)-Figures showing distribution of student responses to Likert-scale questions on the post-test questionnaire. Note that the number of responses is expressed in terms of percentages, rather than absolute numbers in order to take into account the slightly different sizes of the three groups.
Figure 28(d-f)-Figures showing distribution of student responses to Likert-scale questions on the post-test questionnaire. Note that the number of responses is expressed in terms of percentages, rather than absolute numbers in order to take into account the slightly different sizes of the three groups.
Figure 28(g) - Figures showing distribution of student responses to Likert-scale questions on the post-test questionnaire. Note that the number of responses is expressed in terms of percentages, rather than absolute numbers in order to take into account the slightly different sizes of the three groups.
APPENDICES

Appendix A: Selected Results from Preliminary Knowledge Survey of Geology 101 Students (Spring 2013)

<table>
<thead>
<tr>
<th>What is the slowest geologic process you can think of?</th>
<th># of responses</th>
<th>What is the fastest geologic process you can think of?</th>
<th># of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate tectonics/continental drift</td>
<td>30</td>
<td>Earthquakes</td>
<td>15</td>
</tr>
<tr>
<td>Erosion</td>
<td>12</td>
<td>Volcanic eruptions</td>
<td>14</td>
</tr>
<tr>
<td>No response</td>
<td>7</td>
<td>Erosion</td>
<td>11</td>
</tr>
<tr>
<td>Mountain building/formation</td>
<td>6</td>
<td>Mudslide/Landslide/Rockfall</td>
<td>10</td>
</tr>
<tr>
<td>Planet formation</td>
<td>5</td>
<td>No response</td>
<td>7</td>
</tr>
<tr>
<td>Rocks forming</td>
<td>4</td>
<td>Rivers/movement of water/water erosion</td>
<td>4</td>
</tr>
<tr>
<td>Carving of Grand Canyon</td>
<td>3</td>
<td>Forests, ecosystem changes</td>
<td>3</td>
</tr>
<tr>
<td>Sea level change</td>
<td>2</td>
<td>Storms/weather</td>
<td>2</td>
</tr>
<tr>
<td>Cave formation</td>
<td>2</td>
<td>&quot;Rocks&quot;</td>
<td>2</td>
</tr>
<tr>
<td>Volcanic processes</td>
<td>2</td>
<td>Plate tectonics</td>
<td>2</td>
</tr>
<tr>
<td>Ocean sediment deposition</td>
<td>1</td>
<td>Weathering</td>
<td>2</td>
</tr>
<tr>
<td>Fossilization</td>
<td>1</td>
<td>&quot;Explosion&quot;</td>
<td>1</td>
</tr>
<tr>
<td>Subduction</td>
<td>1</td>
<td>Glacier erosion</td>
<td>1</td>
</tr>
<tr>
<td>Cooling of Earth</td>
<td>1</td>
<td>Mountain building/formation</td>
<td>1</td>
</tr>
<tr>
<td>Global warming</td>
<td>1</td>
<td>Asteroid impact</td>
<td>1</td>
</tr>
<tr>
<td>Glacier formation</td>
<td>1</td>
<td>&quot;Earth&quot;</td>
<td>1</td>
</tr>
<tr>
<td>Aging into carbon</td>
<td>1</td>
<td>Floods</td>
<td>1</td>
</tr>
<tr>
<td>Rock cycle</td>
<td>1</td>
<td>Tsunami</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Glaciers melting</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tides</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Catastrophes/natural disasters</td>
<td>1</td>
</tr>
</tbody>
</table>

N=79 *(some students provided >1 answer)*
Figure A.1 (a-f): Student responses to statements using a 5-point Likert-scale ($n=79$):

**a:** "Landscapes change on timescales that are too large for humans to comprehend"

**b:** "Geologic time is measured in millions of years because that is how long it takes for landscapes to change appreciably"

**c:** "The landscape around us is constantly changing"
d: "Sudden/catastrophic events play a major role in shaping the landscape around us"

Percentages:
- 1 (strongly disagree)
- 2
- 3
- 4
- 5 (strongly agree)

e: "Landscapes can change drastically over the course of a typical human lifetime"

Percentages:
- 1 (strongly disagree)
- 2
- 3
- 4
- 5 (strongly agree)

f: "Humans can alter the rate at which landscapes change"

Percentages:
- 1 (strongly disagree)
- 2
- 3
- 4
- 5 (strongly agree)
Figure A.2: Percentage of students responding correctly to the following questions from the Geoscience Concept Inventory, sorted by whether or not students had taken a geology or earth science class in high school:

3. If you could travel back in time to when the Earth first formed as a planet, approximately how many years back in time would you have to travel? *(circle one)*

A. 4 hundred years  
B. 4 hundred thousand years  
C. 4 million years  
D. 4 billion years  
E. 4 trillion years

4. Which of the figures below do you think most closely represents changes in life on Earth over time? *(circle one)*

A. 
B. 
C. 
D. 
E.
Figure A.3: Student predictions about the amount of change in the landscape below after 5 years. Students in the static group were shown a single static image of the glacier whereas students in the “Before and After” group were shown images of the glacier taken three years apart.
WESTERN WASHINGTON UNIVERSITY
Office of Research and Sponsored Programs

MEMORANDUM

TO: Zachary Schierl, Geology Department
FROM: Janai Symons, Office of Research and Sponsored Programs
DATE: 5/31/2013
SUBJECT: Human Subjects Review – Exemption Research Approval

Thank you for submitting a research protocol regarding your human subject research EX13-061 “Effectiveness of Time-Lapse Videos as a Method to Teach Geologic Rates and Time”, for review by the Human Subjects Review Committee (HSRC).

Approval: The HSRC has reviewed the materials you submitted and found the project described falls into Category #2: research involving survey or interview procedures. Although the research qualifies for exempt status, the investigators still have a responsibility to protect the rights and welfare of their subjects, and are expected to conduct their research in accordance with the ethical principles of Justice, Beneficence, and Respect for Persons, as described in the Belmont Report, as well as with state and local institutional policy. All students and investigators collecting or analyzing data must be qualified and appropriately trained in research methods and responsible conduct of research.

Determination Period: An exempt determination is valid for five years from the date of the determination, as long as the nature of the research activity remains the same. If the involvement of human subjects changes over the course of the study in a way that would increase risks, please submit a revised protocol.

Problems: If issues should arise during the conduct of the research, such as unanticipated problems that may increase the risk to the human subjects and change the category of review, notify the Research Compliance Officer promptly. Any complaints from subjects pertaining to the risk and benefits of the research must be reported to the Research Compliance Officer.

If you have any questions, feel free to email me at janai.symons@wwu.edu.
WESTERN WASHINGTON UNIVERSITY
Office of Research and Sponsored Programs

MEMORANDUM

TO: Zachary Schierl, Geology Department
FROM: Janai Symons, Office of Research and Sponsored Programs
DATE: 1/8/2014
SUBJECT: Human Subjects Review – Exemption Research Approval

Thank you for submitting a research protocol regarding your human subject research EX14-044 “Effectiveness of Time-Lapse Videos as a Method to Teach Geologic Rates and Time”, for review by the Human Subjects Review Committee (HSRC).

Approval: The HSRC has reviewed the materials you submitted and found the project described falls into Category #2: research involving survey or interview procedures. Although the research qualifies for exempt status, the investigators still have a responsibility to protect the rights and welfare of their subjects, and are expected to conduct their research in accordance with the ethical principles of Justice, Beneficence, and Respect for Persons, as described in the Belmont Report, as well as with state and local institutional policy. All students and investigators collecting or analyzing data must be qualified and appropriately trained in research methods and responsible conduct of research.

Determination Period: An exempt determination is valid for five years from the date of the determination, as long as the nature of the research activity remains the same. If the involvement of human subjects changes over the course of the study in a way that would increase risks, please submit a revised protocol.

Problems: If issues should arise during the conduct of the research, such as unanticipated problems that may increase the risk to the human subjects and change the category of review, notify the Research Compliance Officer promptly. Any complaints from subjects pertaining to the risk and benefits of the research must be reported to the Research Compliance Officer.

If you have any questions, feel free to email me at janai.symons@wwu.edu.
Appendix C : Informed Consent Documentation

Learning about Geology with Time-Lapse

INFORMED CONSENT FORM

Purpose of research: The goal of this study is to explore the effect of different activities designed to teach geology students about geologic time and the rate at which our planet changes. Results from the study will be published in a Master's Thesis in the Department of Geology.

Benefits and risks: There are no known physical or psychological risks associated with participation in this study nor are there any financial costs associated with participation. By participating, you will be contributing valuable information to our knowledge of the effectiveness of new technology on student learning. The results from this study may be used to improve the content of introductory geology courses here at WWU and at other universities. Upon completion of all assigned tasks, participants will receive a free movie ticket or Woods Coffee gift card as compensation for your participation.

Procedure: By signing this form, you agree to be entered into a pool of possible participants. Depending on the number of volunteers, you may or may not be selected to participate. Should you be selected, you will be sent an email invitation to join a Canvas course created for this project. Upon joining, you will be asked to complete a short questionnaire and quiz via Canvas. Following this, you will be contacted by the researcher to set up a time for you to come to a WWU computer lab to complete participation in the study. While in the computer lab, assigned tasks may include answering assessment questions, viewing time-lapse videos or photos, problem solving, and reading text. Completing the Canvas and computer lab portions of the study should take between 1 and 1 ½ hours of your time.

Confidentiality: All information collected in this study will remain confidential. Data for this project will be gathered both electronically (via Canvas and SurveyMonkey) and on paper. The only document on which your name will appear is this form. All other documents you submit will be anonymous and will be matched to each other using only the last 4 digits of your Western ID number. All documents, whether electronic or hard copy, that contain your name or information will be stored securely and will only be accessible by the researcher and a faculty advisor. Your signed informed consent form will be stored separately from your responses. No names or any information that could be used to identify you will appear in any final research documents.

Contact Information: This research is being conducted by Zachary Schierl, through the Department of Geology at Western Washington University and is being supervised by Dr. Scott Linneman. If you have any questions about the study, please contact Zachary Schierl by phone at (360) 650-4127 or by email at schierz@students.wwu.edu. Scott Linneman may be contacted at (360) 650-7207 or by email at Scott.Linneman@wwu.edu. You may also contact Janai Symons, Research Compliance Officer at WWU at janai.symons@wwu.edu with any questions.

Consent to participate: If you agree to participate in this study, please read all instructions carefully and give your thoughtful and honest responses to all questions. Your effort and thoughtful participation is vital in obtaining reliable and useable data. Your participation in this study is entirely voluntary, and you are free to withdraw at any time without penalty to your course grade.

Please sign below if you are 18 years of age or older, have read the above information, and agree to participate in this study. (If you are not yet 18, please do not sign before as participating in this study would require parental permission.)
Appendix D: Treatment Website Screenshots

Figure D.1 - Example of directions page and navigation header provided to students at the beginning of treatment activities (example from Group 2).
Columbia Glacier, Alaska (Overhead camera)

The Columbia Glacier is a 50 kilometer long glacier in southern Alaska. It is a tidewater glacier, meaning that it flows from the mountains all the way down to the ocean, in this case Prince William Sound, an inlet of the Pacific Ocean. At the terminus of the glacier, large chunks of ice break off forming icebergs, a process known as "calving". In the background are the Chugach Mountains where heavy snowfall accumulates and gives birth to the Columbia Glacier.

The scene in this photograph is about 4 kilometers (~2.5 miles) wide. The ice cliff formed where the glacier meets the sea is approximately 50 meters high, or about as high as a 15 story building. The tallest mountains visible in the photo rise to about 4000 feet above sea level.

Figure D.2-Example of background information provided to student about each landscape. This example taken from Group 2, although background information was identical for each group.
Figure D.3-Examples of before/after photo pairs of the Elwha River used by Group 1 during treatment activities (navigation bar and background information not shown in screenshot, but would appear at top of page).
Figure D.4-Examples of time-lapse videos of the Elwah River used by Group 2 during treatment activities (navigation bar and background information not shown in screenshot, but would appear at top of page).
Appendix E: Directions and Conceptual Questions Provided to Students During Treatment

Directions (Group 1):
1. Log into the project Canvas page and click on “Group 1”. When prompted, enter the following password: group1_659878
2. Click on the link to the time-lapse page and follow the on-screen directions.

Questions to consider:

- What is changing in this landscape? How quickly are the changes occurring? Use the date(s) stamped on the photos and the scale to help you determine this.
- Do all aspects of the landscape change at the same rate? Are there any parts of the landscape that are NOT changing?
- Does the rate of change in the landscapes appear constant? Or is the rate of change dependent on the season, time of day, or other factors?
- Do changes occur continuously or intermittently?
- Do any of the changes you observe have the potential to affect human society? Are any of the changes you observe the result of human activity?
- Are changes generally constructive (making things larger, depositing material) or destructive (wearing things down, eroding material)?
- What might these places look like 10, 100, or 1000 years into the future?
Appendix F: Demographic Questionnaire

**Predictions Quiz (Group 1)**

*This questionnaire is intended only for participants in the "Learning about Geology with Time-Lapse" research project. If you have not yet signed an informed consent form, please exit this quiz now and contact Zach Schierl at schierz@students.wwu.edu*

1. Please indicate which form of compensation you would prefer to receive after participation in this project is complete:
   - [ ] $10 Woods Coffee gift card
   - [ ] 1 free movie ticket at Bankley Cinema

2. Please enter the last 4 digits of your Western ID number (*Note: this information will not be used to identify you, only to match your responses*):

   [ ]
# Predictions Quiz (Group 1)

The purpose of this first page of questions is to collect some basic demographic information about you. Collecting this information is necessary in order to interpret the results of this study. **The following information will not be linked to your name and will only be viewed by the researcher and faculty advisor.**

1. What is your gender?
   - Female
   - Male

2. What is your age?
   - Age: ___________

3. What is your hometown (city and state)?
   - __________________________

4. What is your GPA?
   - 3.0 - 4.0
   - 3.0 - 3.5
   - 2.6 - 3.0
   - 2.1 - 2.5
   - 2.0 or below

5. What is your major? (if no declared major, please indicate an interest)
   - __________________________

6. Approximately how many college credits have you completed?
   - __________________________

7. Prior to enrolling in GEOL 101/211, had you taken any other geology or geoscience courses at the college level?
   -  Yes
   -  No

   If you answered "YES", please list them here:
   - __________________________

8. Did you take geology or a similar class in high school?
   -  Yes
   -  No

   If you answered "YES", please list them here:
   - __________________________
### Predictions Quiz (Group 1)

**9. Please rate your level of interest in the following topics:**

<table>
<thead>
<tr>
<th></th>
<th>Extremely interested</th>
<th>Very interested</th>
<th>Moderately interested</th>
<th>Slightly interested</th>
<th>Not at all interested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology and the earth sciences:</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td>○</td>
</tr>
</tbody>
</table>

**10. Please rate your level of knowledge regarding the following subjects:**

<table>
<thead>
<tr>
<th></th>
<th>Extremely knowledgeable</th>
<th>Very knowledgeable</th>
<th>Somewhat knowledgeable</th>
<th>Not very knowledgeable</th>
<th>Not at all knowledgeable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geology and geologic processes:</td>
<td>○</td>
<td></td>
<td></td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>How the Earth changes over time:</td>
<td>○</td>
<td></td>
<td></td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

**11. Please rate the following:**

<table>
<thead>
<tr>
<th></th>
<th>Extremely confident</th>
<th>Very confident</th>
<th>Somewhat confident</th>
<th>Not very confident</th>
<th>Not at all confident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your confidence regarding your overall ability in science classes:</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Your confidence using computers and the internet:</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Your confidence using new and unfamiliar forms of technology:</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td>○</td>
</tr>
</tbody>
</table>

**12. My GEOL 101/211 lecture professor is:**

- ○ Colin Amos
- ○ Thomas Evans
- ○ Julie Gross
- ○ Thor Hansen
- ○ Dave Hirsch
- ○ Paul Thomas
- ○ Robert Mitchell
### Predictions Quiz (Group 1)

13. My GEOL 101 or 211 lab T.A. is:

- Adrian Bender
- Randall Conger-Best
- Cass Dimitroff
- Sarah Gregory
- Chelsea Mack
- Ryan Murphy
- Zach Schierl
- Chad Stellern
- Brett Tobin
- Kirsten Weiner
- Hal Warshow
- Anton Ypma
Appendix G: Pre- and Post-Assessments

Note: Pre-test is shown here; post-test is identical with the exception of the directions page shown at the end of Appendix G. Test for Group 1 is shown here, tests for Group 2 and Group 3 are identical except the word “photos” is replaced with “videos” where appropriate to reflect the different treatment activities.

### Predictions Quiz (Group 1)

**Directions:**

The purpose of this study is to examine how students learn about the rate of geological processes. A “geological process” is any geological event or occurrence that acts to change the physical nature of the Earth. Geological processes are responsible for changing the landscape of the Earth over time. The term “landscape” refers to the physical and geologic features visible in a place. For example, in Bellingham the landscape includes things like the coastline, Sehome Hill, the Chuckanut Mountains, Lake Whatcom, and the cone of Mt. Baker visible in the distance.

The following questions will ask you to make predictions about how the landscape of the Earth changes over time. The quiz is not graded and many of the questions do not have a “right answer”. Your responses are anonymous, confidential, and will not affect your grade in any class. However, in the interest of obtaining reliable data, I ask that you please answer ALL of the questions independently, honestly, and to the best of your ability.

Clicking on words with hyperlinks will take you to a glossary that may help with any unfamiliar terms. Note that you will need to be logged into the project Canvas page for these links to work.

Thank you for your participation. Let’s begin!
1. In a sentence or two, describe in your own words what the word “rate” means in the following sentence:

“The purpose of this study is to examine how students learn about the rate of geological processes.”
**Predictions Quiz (Group 1)**

1. Which of the following is the mathematical definition of "rate":
   - ( ) distance/time
   - ( ) time/distance
   - ( ) speed/time
   - ( ) velocity/distance

2. Please indicate how much you agree or disagree with the following statements about how the Earth's landscapes change over time. **Note: for this purposes of this question, changes in vegetation and falling/melting snow are not considered landscape changes.**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catastrophic events are more important in sculpting the Earth than slow, gradual processes that occur every day:</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Landscapes change at a constant rate through time:</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Apart from human activity, Earth's landscape looks similar today as it did a few million years ago:</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Humans can alter the rate at which landscapes change:</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>The landscape around us is constantly changing:</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Landscapes can change significantly over the course of an average human lifetime:</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Water only changes the surface of the Earth during rare events, such as large floods or tsunamis:</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Moving water (such as rivers or waves) can only change the surface of the Earth over long periods of time (i.e. more than one year):</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
<tr>
<td>Geologic time is measured in millions of years because that is how long it takes landscapes to change significantly:</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
<td>( )</td>
</tr>
</tbody>
</table>

3. What are the slowest and fastest geological processes you can think of that can change the surface of the Earth?

   **Slowest:**
   
   **Fastest:**
<table>
<thead>
<tr>
<th>Predictions Quiz (Group 1)</th>
</tr>
</thead>
</table>

The remaining questions will ask you to look at photographs of three different landscapes and make predictions about how the landscapes might change over time.

Don’t worry if you don’t know all of the answers! When you come to the computer lab to participate in the study, you will view a series of photos and/or videos of the same landscapes which will allow you to investigate the answers to these questions.
Predictions Quiz (Group 1)

Landscape #1: Columbia Glacier, Alaska

This is a photograph of the Columbia Glacier in Alaska. The Columbia Glacier is a “tidewater glacier”, meaning that it flows from the mountains all the way down to the ocean. This photograph focuses on the area where the glacier meets the ocean, where large chunks of ice are breaking off the terminus of the glacier forming icebergs. In the background are the Chugach [pronounced CHEW-gatch] Mountains where heavy snowfall accumulates and gives birth to the Columbia Glacier. The mountains visible in the photo rise to about 4000 feet above sea level.

1. Which of the following statements do you think best describes how ice within the Columbia Glacier moves over time:

- The ice will occasionally flow backwards as it retreats due to global warming
- The ice will always flow toward the ocean but its speed will vary with time
- The ice will always flow toward the ocean at a constant rate
- The ice is frozen to the ground so it will not move
Predictions Quiz (Group 1)

2. Approximately how long do you think it would take ice within the Columbia Glacier to move 10 meters (approximately the length of a city bus)?
   - 1 hour
   - 1 day
   - 1 month
   - 1 year

3. What do you think the Columbia Glacier will look like from this location 100 years from now?
   - The glacier will appear visibly larger
   - The glacier will appear visibly smaller
   - The glacier will have disappeared completely
   - The glacier will appear more or less the same

Please briefly explain why you chose the answer that you did:


4. What do you think the Chugach Mountains will look like from this location 100 years from now?
   - The mountains will appear smaller or shorter
   - The mountains will have disappeared completely
   - The mountains will appear more or less the same
   - The mountains will appear larger or taller

Please briefly explain why you chose the answer that you did:


5. What do you think the Chugach Mountains will look like from this location 100,000 years from now?
   - The mountains will appear larger or taller
   - The mountains will have disappeared completely
   - The mountains will appear more or less the same
   - The mountains will appear smaller or shorter

Please briefly explain why you chose the answer that you did:


Predictions Quiz (Group 1)

6. There are several geologic processes occurring in this image:

- Movement of the Columbia Glacier
- Pieces of ice breaking off the terminus of the glacier, forming icebergs (calving)
- The tide going in and out
- Weathering and erosion of the Chugach Mountains

Using your mouse, drag the following events into order based on how long you think they would generally take to occur. Put the fastest event at the TOP and the slowest event at the BOTTOM:

- [ ] The Columbia Glacier moves 10 meters
- [ ] The tide goes in and out once
- [ ] Weathering and erosion reduces height of Chugach Mountains by 1 meter
- [ ] A large piece of ice breaks off of the glacier, forming an iceberg

7. What are some factors that might control how quickly the Columbia Glacier moves? Enter up to three factors, one in each box. Place the factor you think is MOST IMPORTANT in box #1:

Factor #1

Factor #2

Factor #3
Predictions Quiz (Group 1)

Landscape #2: Elwha River, Olympic Peninsula, Washington:

This is a photo of the Elwha River, a 45-mile long river on the Olympic Peninsula of Washington. It flows from the Olympic Mountains to the Strait of Juan de Fuca, an arm of the Pacific Ocean. In the early 1900s, two large concrete dams were built along the lower part of the river. Water filled the river valleys behind the dams creating two reservoirs which trapped sediment and halted fish migration upstream for nearly a century. Beginning in 2011, the dams were removed and the reservoirs were drained. This photo shows the former site of one of the reservoirs, Lake Aldwell. The water in the reservoir was once as high as the dashed black line on the photo below, but the river is now returning to its natural, free-flowing state.

For scale, the main river channel in the center of the photo is about 20 meters across, the river valley is about 450 meters (~0.25 miles) across, and the small dark specks on the valley bottom are tree stumps.
Predictions Quiz (Group 1)

1. Which of the following statements do you think best describes the rate of erosion along rivers in the Pacific Northwest (including the Elwah River)?
   - The rate of erosion remains constant throughout the year.
   - Erosion occurs all year, but occurs faster in the winter than in the summer.
   - Erosion occurs all year, but occurs faster in the summer than in the winter.
   - Erosion occurs only during the summer.
   - Erosion occurs only during the winter.

   Please briefly explain why you chose the answer that you did:

2. If you were to return to this same location and take another photograph 50 years from now, which of the following is most likely to be true:
   - The river will follow a different path across the valley floor.
   - Floods will have deposited sediment and the river valley will be shallower than it is today.
   - The river will follow the same path, but will have carved a deeper channel.
   - The river, valley, and channel will look nearly the same as it does today.

3. Which of the following statements do you think best describes the rate of erosion in this photograph?
   - The rate of erosion is greatest along the banks (sides) of the river channel.
   - Erosion is occurring everywhere in the photograph at the same rate.
   - The rate of erosion is the same everywhere on the valley bottom.
   - The rate of erosion is greatest along the base (bottom) of the river channel.

4. If you were to stand and watch this landscape for an extended period of time, which of the following is most likely to be true:
   - I would be likely to observe growth in the vegetation before I observed any changes in the river channel.
   - I would be likely to observe changes in the river channel before I observed any growth in the vegetation.
   - I would likely observe changes in the river channel and growth in the vegetation after approximately the same amount of time.

5. What are some factors that might control the rate of erosion along the Elwah River? Enter up to three factors, one in each box. Place the factor you think is MOST IMPORTANT in box #1:

   Factor #1
   Factor #2
   Factor #3
Predictions Quiz (Group 1)

Landscape #3: Swift Creek landslide, Whatcom County, Washington

This is a photo of the Swift Creek landslide located on Sumas Mountain, about 1 hour northeast of Bellingham. It is a large mass of rocks, soil, trees, and other materials that are moving downhill under the influence of gravity. The landslide encompasses the entire un-vegetated area, although some of the vegetation is also involved in the slide. The landslide is nearly 1 km (0.6 mile) long but this photo shows only the lowermost portion of the landslide, known as the "toe".

1. Which of the following statements do you think best describes the movement of the Swift Creek Landslide:

- [ ] Landslide movement is continuous, but the rate of movement varies with time
- [ ] Landslides only move once during a quick burst and then remain stationary
- [ ] Landslide movement starts and stops repeatedly over time
- [ ] Landslide movement is continuous, and has a constant rate

Please briefly explain why you chose the answer that you did:
Predictions Quiz (Group 1)

The next three questions refer to the annotated image of the Swift Creek landslide above.

2. Which of the following statements do you think best describes the rate at which different parts of the Swift Creek landslide move:
   - All parts of the landslide move at approximately the same rate
   - Region A moves faster than Region B
   - Region B moves faster than Region A
   - Neither region moves fast enough for humans to detect

3. Which of the following is closest to the amount of time it would take a piece of rock in Region B of the Swift Creek landslide to move downhill a distance of 10 meters (approximately the length of a city bus)?
   - 6 seconds
   - 6 minutes
   - 6 days
   - 6 months
   - 6 years
Predictions Quiz (Group 1)

4. Assume that the yearly rate of movement on the landslide remains constant. About how long do you think it would take the patch of ground labeled “X” in the photo to reach the bottom of the landslide at lower left? Please type your answer in the box below (include units!):

5. What are some factors that might control the rate at which the Swift Creek landslide moves? Enter up to three factors, one in each box. Place the factor you think is MOST IMPORTANT in box #1:

<table>
<thead>
<tr>
<th>Factor #1</th>
<th>Factor #2</th>
<th>Factor #3</th>
</tr>
</thead>
</table>


### Predictions Quiz (Group 1)

1. Finally, consider all of the landscapes you just looked at. How long do you think it would take, on average, for each of the following geologic events to occur? Use the drop down menus to select an approximate answer for each event:

<table>
<thead>
<tr>
<th>Event</th>
<th>Select an answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A river channel changing its course.</td>
<td></td>
</tr>
<tr>
<td>Uplift of a large mountain range from a flat plain.</td>
<td></td>
</tr>
<tr>
<td>Complete wearing down of a mountain range by weathering and erosion.</td>
<td></td>
</tr>
<tr>
<td>Soil, boulders, and trees moving downhill in a landslide.</td>
<td></td>
</tr>
<tr>
<td>A large piece of ice breaks off a tidewater glacier, forming an iceberg.</td>
<td></td>
</tr>
<tr>
<td>The formation of a volcanic lava dome.</td>
<td></td>
</tr>
<tr>
<td>The tide going in and out once.</td>
<td></td>
</tr>
<tr>
<td>A tidewater glacier moves 10 meters.</td>
<td></td>
</tr>
</tbody>
</table>
Differences in Post-Test:

<table>
<thead>
<tr>
<th>Learning about Geology with Time-Lapse</th>
</tr>
</thead>
</table>

**Directions:**

Once again, the following questions will ask you to make predictions about how the landscape of the Earth changes over time. Use your observations from looking at the time-lapse photos to inform your answers. Please remember that the quiz is not graded; your responses are anonymous, confidential, and will not affect your grade in any class. **However, in the interest of obtaining reliable data, I ask that you please answer ALL of the questions independently, honestly, and to the best of your ability.**

Clicking on words with hyperlinks will take you to a [glossary](#) that may help with any unfamiliar terms. Note that you will need to be logged into the project Canvas page for these links to work.

Please click next to begin:
Appendix H: Post-Test Questionnaire

### Learning about Geology with Time-Lapse<br>

Finally, please answer a few questions about your impressions of this study. Remember that all of your answers are anonymous; please try to give your honest opinion!

1. Approximately how long did you spend looking at the time-lapse photos?
   - [ ] Less than 10 minutes
   - [ ] 10-20 minutes
   - [ ] 20-30 minutes
   - [ ] 30-40 minutes
   - [ ] 40-50 minutes
   - [ ] 50-60 minutes
   - [ ] More than 60 minutes

2. Please indicate how much you agree or disagree with the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The directions provided were clear and concise:</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>I felt comfortable using the computer-based portion of this activity:</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>I found this activity confusing and/or frustrating:</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>I felt that the time-lapse photos were a good way to learn about how quickly landscapes change:</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>This activity increased my understanding of how quickly landscapes change:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I enjoyed completing this activity:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I took this activity seriously and answered all questions to the best of my ability:</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

3. What did you find most useful about this activity?

4. Did you learn anything during this activity that you found particularly surprising or interesting?
<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Were there any parts of this activity that you found especially confusing or unclear?</td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>6. What could be added to or changed about this activity to make it better?</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>7. What was your primary motivation for agreeing to participate in this study?</td>
<td></td>
</tr>
</tbody>
</table>