Integrating LiDAR Topography Into the Study of

Earthquakes and Faulting

by

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ABSTRACT

Meter-resolution topography gathered by LiDAR (Light Detection and Ranging) has become an indispensable tool for better understanding of many surface processes including those sculpting landscapes that record information about earthquake hazards for example. For this reason, and because of the spectacular representation of the phenomena that these data provide, it is appropriate to integrate these data into Earth science educational materials. I seek to answer the following research question: “will using the LiDAR topography data instead of, or alongside, traditional visualizations and teaching methods enhance a student’s ability to understand geologic concepts such as plate tectonics, the earthquake cycle, strike-slip faults, and geomorphology?”

In order to answer this question, a ten-minute introductory video on LiDAR and its uses for the study of earthquakes entitled “LiDAR: Illuminating Earthquake Hazards” was produced. Additionally, LiDAR topography was integrated into the development of an undergraduate-level educational activity, the San Andreas fault (SAF) earthquake cycle activity, designed to teach introductory Earth science students about the earthquake cycle. Both the LiDAR video and the SAF activity were tested in undergraduate classrooms in order to determine their effectiveness. A pretest and posttest were administered to introductory geology lab students. The results of these tests show a notable increase in

understanding LiDAR topography and its uses for studying earthquakes from pretest to posttest after watching the video on LiDAR, and a notable increase in understanding the earthquake cycle from pretest to posttest using the San Andreas Fault earthquake cycle exercise. These results suggest that the use of LiDAR topography within these educational tools is beneficial for students when learning about the earthquake cycle and earthquake hazards.

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My adviser, Dr. Ramón Arrowsmith introduced me to the wonders of LiDAR topography and its uses for studying earthquakes and faulting. I am truly grateful for his constant motivation, support and intellectual insight, as well as his commitment to the improvement of my education and growth as a student. I could not have done this without his encouragement and supervision.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Overview

The use of Light Detection and Ranging (LiDAR) derived topography in the study of active tectonics has become an indispensable tool for providing insights into geologic phenomena such as earthquake hazards, landslide hazards, and even ice sheet dynamics (Carter et al., 2007; Krishnan et al., 2011). Numerous studies have used LiDAR topography for the study of faulting and earthquakes (e.g., Haugerud, 2003; Cunningham et al., 2006; Chan et al., 2007; Hilley and Arrowsmith, 2008; Arrowsmith and Zielke, 2009; Zielke et al., 2010). For this reason and the spectacular representation of the phenomena the data provide, it is appropriate to integrate these data into Earth science educational materials.

This research looks to answer the following research question: “Will using the LiDAR topography data instead of, or alongside, traditional visualizations and teaching methods enhance a student’s ability to understand the geologic concepts of plate tectonics, the earthquake cycle, strike-slip faults, and geomorphology?”. The purposes of this study are to develop undergraduate introductory earth science resources that use LiDAR topography data, to develop educational resources that use or explain LiDAR topography for teaching earth science topics, and to try to answer the above question by assessing the effectiveness of the educational resources.

In order to answer this question, a short introductory video on LiDAR and how it is used for the study of earthquakes was developed. In addition, an educational activity that implements LiDAR topography to teach undergraduate-level introductory Earth science students about the earthquake cycle was also developed. Both of these educational tools were then tested in classrooms at Arizona State University to evaluate the effectiveness of the tools and to assess the addition of LiDAR topography into Earth science education for teaching about earthquakes.

Review of LiDAR Topography

Depicting features on Earth's surface smaller than a meter is critical for the study of faulting and earthquakes. Unlike other technologies, LiDAR is capable of producing such finely detailed high-resolution models of the earth's surface. These data help scientists to map the locations of active faults, reconstruct fault offsets from past earthquakes, and study landscape evolution by understanding the interaction between faulting and surface processes. LiDAR topography brings a perspective to analyzing Earth's surface that is not possible with simple aerial photography (Carter et al., 2007; Crosby et al., 2011).

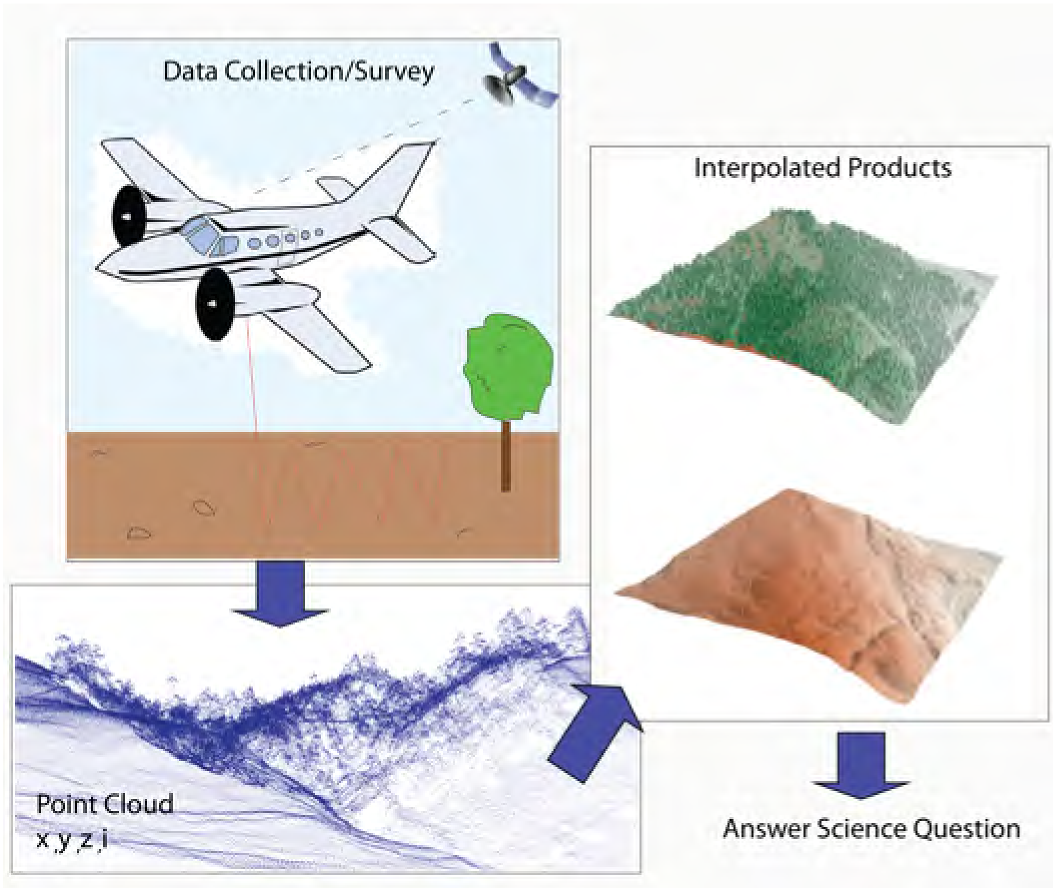

Figure 1. LiDAR topography workflow. Aerial LiDAR data are collected from an aircraft using GPS for positioning. The resulting dataset is referred to as a point cloud, which are points in x,y,z space (calculated from the timing of the laser return and aircraft position and orientation) with return intensity, i. From the point cloud, products for visualization can be produced such as hillshaded DEMS. The "Interpolated Products" box shows how the first returns of the point cloud can be filtered to virtually remove objects such as trees.

LiDAR has many uses within the scientific community and beyond, but specific to the study of earthquakes and faulting it is collected either via aircraft (often referred to as airborne laser swath method or ALSM) or on the ground (known as terrestrial laser scanning or TLS). This study focuses on aerial LiDAR as these datasets often include entire fault zones and many are freely available online via the OpenTopography portal (www.opentopography.org) and other sources.

Aerial LiDAR data collection is both costly and logistically complex. Most geologists and other scientists coordinate with organizations such as the National Center for Airborne Laser Mapping (NCALM) and others to collect and process the data. The LiDAR scanner is typically mounted on an airplane and is used to measure the earth's surface by combining the scanning pulsed laser with corrections for changing aircraft orientation and GPS aircraft positions (Figure 1). A low-flying aircraft scans a laser at pulse rates of tens to hundreds of pulses per second (Carter et al., 2007). Laser returns are collected by the instrument, which catalogs the timing of return, the scanner orientation, and aircraft position using GPS (Carter et al., 2007; Krishnan et al., 2011). This is much more costly and involved than terrestrial LiDAR scanners that allow LiDAR data to be collected for a small area from a ground-based vantage. The raw data collected by the LiDAR scanner is typically referred to as a point cloud.

Although LiDAR data are often known within the scientific community as the processed hillshaded digital elevation model (DEM) images that are produced from the point cloud data, the data have many uses beyond these products. The ability to process the point cloud data and eliminate first returns (for removal of vegetation and other objects) in order to see the underlying surface is advantageous for studying topographic features that may have been hidden by these objects. Often geomorphic evidence of faults is hidden beneath vegetation and is not readily visible via aerial photography or even in the field. LiDAR topography allows for the study of surface features that was previously impossible.

LiDAR topography and visual distracters

In 2010, a preliminary study was conducted at Arizona State University to analyze the effectiveness of LiDAR topography as an aid for teaching geoscience concepts (W. Bohon, unpublished; Figures 2 and 3). This study tested the cognitive ability of students to recognize topographic features that are important for the study of faulting and earthquakes. More complete documentation of the study can be found in Appendix II. The study hypothesis was that LiDAR high-resolution topography when represented as hillshade (as opposed to traditional aerial photography) allows novice learners to focus more directly on the landscape, mainly due to the removal of distracters such as land use and vegetative patterns, allowing them to make more accurate interpretations of geologic features.

Figure 2. San Andreas Fault at Wallace Creek imagery. Google Earth aerial photography (top) and hillshaded LiDAR topography (bottom). For the distracter study, control students were given the aerial photography while experimental students were given the LiDAR topography in order to answer the same set of questions.

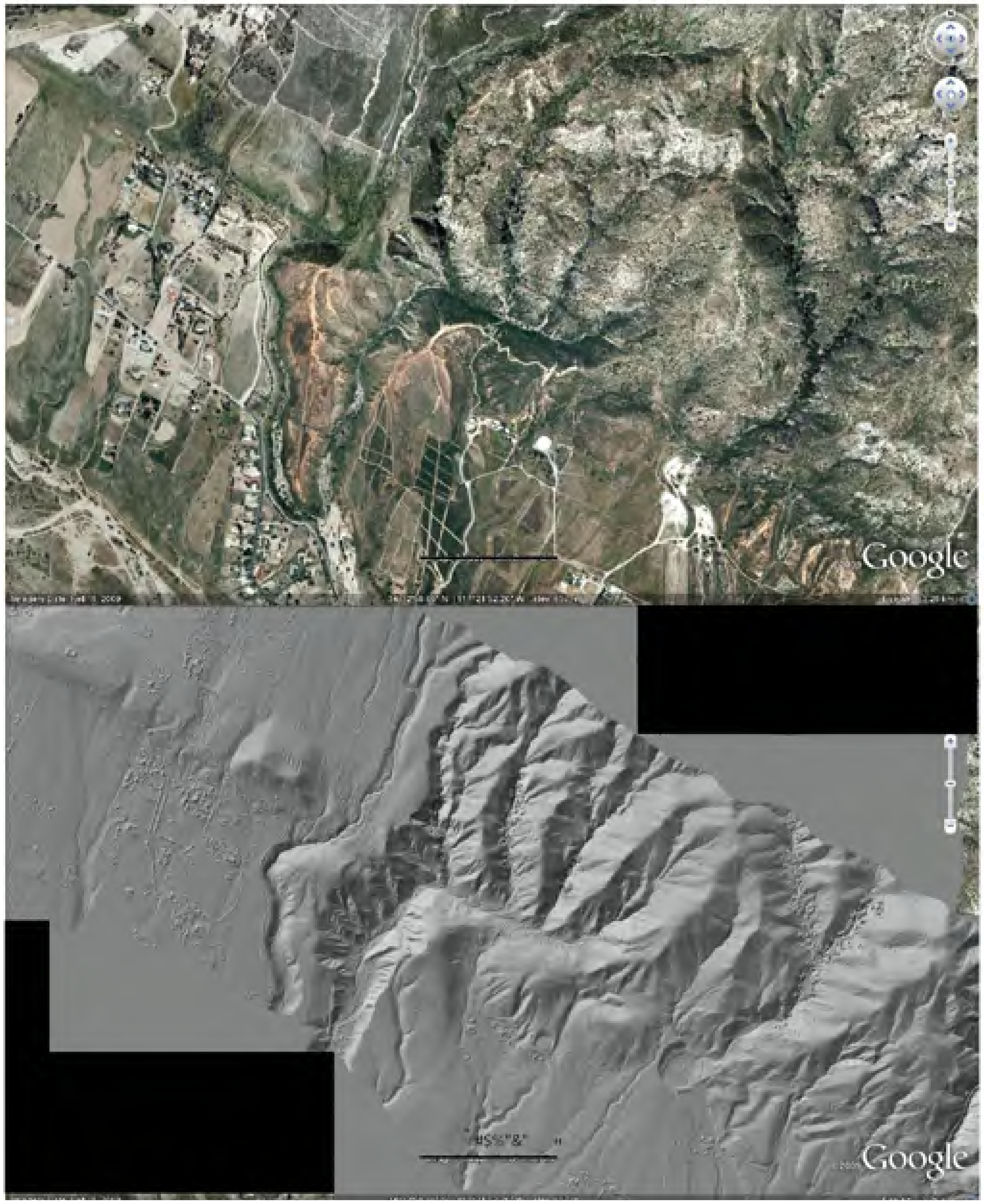

Figure 3. San Andreas Fault near San Bernardino, California Imagery. Google Earth aerial photography (top) and hillshaded LiDAR topography (bottom). For the distracter study, control students were given the aerial photography while experimental students were given the LiDAR topography in order to answer the same set of questions.

For the study, a small group of students (n=46) were tested. 21 undergraduate freshman-level geology students at ASU received LiDAR hillshade imagery and 25 students received Google Earth aerial photography for two areas along the San Andreas Fault in California: Wallace Creek and an area near San Bernardino, California (Figures 2 and 3). Both were then given the same set of questions to answer about the landscape near the fault. At Wallace Creek, the topography shows clear offsets at the fault, and visual distracters are few. The area chosen near the San Bernardino is much more complex visually with numerous visual distracters including vegetation and infrastructure.

Students were asked to describe the landscape near the fault and identify the most prominent feature in the imagery for both locations. They were then asked to identify and draw in the location of the fault. The results from the study indicate a 40-70% increase in the inclusion of the fault in the description of the landscape when students were given LiDAR topography hillshade (Table 1). Results also indicate an increase of up to 38% in correct identification of the fault when given LiDAR topography hillshade (Table 1). The results from the 2010 Bohon study indicate that LiDAR topography can be utilized as a powerful tool when teaching introductory Earth science students about faulting and earthquakes. This initial result motivated the subsequent research and work presented here to implement these data into Earth science teaching tools and the testing of these tools.

Table 1

Bohon distracter study results.

Fault Identification Question					
	Wallace Creek		San Bernardino		Summary
	Google Earth Imagery	LiDAR	Google Earth Imagery	LiDAR	
Marked a valley or ridge	60%	42%	60%	89%	Up to 38% increase in correct identification of the fault
Marked a road	20%	0%	40%	0%	
Correctly marked the fault	20%	58%	0%	11%	

Most Prominent Feature Question					
	Wallace Creek		San Bernardino		Summary
	Google Earth Imagery	LiDAR	Google Earth Imagery	LiDAR	
Land use/vegetation	80%	10%	6%	0%	40-70% increase in description of the landscape as the most prominent feature
Infrastructure	0%	0%	27%	0%	
Landscape	20%	70%	60%	100%	
Fault	0%	20%	0%	0%	
Other	0%	0%	7%	0%	

LiDAR topography and earth science education standards

LiDAR topography brings an advantageous approach to teaching various earth science topics to students. According to the Earth Science Literary Initiative (2009) “Big Ideas”, it is important to introduce Earth as a continuously changing planet, and to show introductory science students that humans are threatened by Earth’s natural hazards. Additionally, the Benchmarks for Science Literacy (AAAS, 1993) stresses that it is important for students to understand that “Earthquakes often occur along the boundaries between colliding plates". The National Science Education Content Standards (NRC, 1996) also points out that the earthquake cycle is an important educational concept for science students by stressing that they should understand that "internal and external processes cause natural hazards" which affect humans. LiDAR topography is able to link these ideas and aid students in their understanding of the earthquake cycle and the ensuing hazards as the high resolution and broad coverage of LiDAR data enable the study of effects of individual as well as multiple earthquakes.

The integration of LiDAR topography data with other data such as GPS velocities allows for comparisons between strain accumulation and release rates. LiDAR topography is an advantageous tool for teaching about the earthquake cycle and plate tectonics as many plate boundaries have freely available datasets online. The entire San Andreas fault system as well as portions of major active faults in the western US has been laser scanned and the data are freely available in various formats included hillshaded DEMs (e.g., www.opentopography.org) (Prentice et al., 2007; Crosby et al., 2011; Krishnan et al., 2011). Tools have been built for their exploration, measurement, and analysis. LiDAR topography is advantageous for teaching about these and other important Earth science topics (See table 2).

Table 2

Earth Science Education Standards and ideas about how LiDAR topography can address them.

Science Topic	Earth Science Literacy Initiative (ESLI, 2009)	Benchmarks for Science Literacy (AAAS, 1993)	National Science Education Content Standards (NRC, 1996)	Content in exemplary introductory geoscience textbooks[1]	How exploration of high resolution topography links to these ideas[2]
Record of repeating earthquakes in the landscape	• Earth is a continuously changing planet (Big Idea 4). •Landscapes result from the dynamic interplay between processes that form and uplift new crust and processes that depress and break it down (Supporting Concept 4.7). •Humans are threatened by Earth's natural hazards (Big Idea 8).	• *4C Processes that Shape the Earth: Earthquakes often occur along the boundaries between colliding plates; Surface layers of these plates may fold, forming [topography] (Grades 9-12).*	• *D, Earth and Space Science:* Lithospheric plates move at rates of centimeters per year; Earthquakes result from these motions; Landforms are the result of a combination of constructive and destructive forces (Grades 5-8). • F, Science in Personal and Social Perspectives: Internal and external processes cause natural hazards; Natural hazards present challenges from incorrectly estimating the rate and scale of change (Grades 5-8); Hazards can be rapid or slow and present the need to assess potential danger and risk (Grades 9-12).	• Tectonic geomorphology of the San Andreas Fault and offset stream channels as evidence of repeated earthquakes. • Fault types (Normal, reverse, strike-slip) explained in terms of effect on landscape.	Fault-system specific acquisitions provide exquisite images and topography of western US active faults some of which cross heavily populated areas. Tectonic and geomorphic signals in topography are often readily apparent.

Science Topic	Earth Science Literacy Initiative (ESLI, 2009)	Benchmarks for Science Literacy (AAAS, 1993)	National Science Education Content Standards (NRC, 1996)	Content in exemplary introductory geoscience textbooks[1]	How exploration of high resolution topography links to these ideas[2]
Earthquake cycle	• Humans are threatened by Earth's natural hazards (Big Idea 8).	• 4C Processes that Shape the Earth: Earthquakes often occur along the boundaries between colliding plates (Grades 9-12)	•F, Science in Personal and Social Perspectives: Internal and external processes cause natural hazards; natural hazards present challenges from incorrectly estimating the rate and scale of change (Grades 5-8); hazards can be rapid or slow; hazards present the need to assess potential danger and risk (Grades 9-12)	•Tectonic geomorphology of the San Andreas Fault and offset stream channels as evidence of repeated earthquakes and long term slip rates. • Importance of knowledge of earth science for mitigation of hazards.	High resolution and broad coverage enable study of effects of individual as well as multiple earthquakes. Integration with other data such as GPS velocities allows for comparisons between strain accumulation and release rates.

Science Topic	Earth Science Literacy Initiative (ESLI, 2009)	Benchmarks for Science Literacy (AAAS, 1993)	National Science Education Content Standards (NRC, 1996)	Content in exemplary introductory geoscience textbooks[1]	How exploration of high resolution topography links to these ideas[2]
Manifestation of plate tectonics along faults at and near plate boundaries	•Earth is a continuously changing planet (*Big Idea 4*). •Many active and energetic geologic processes occur at plate boundaries (*Supporting Concept 4.5*).	•4C *Processes that Shape the Earth: Plates ride on a deformable layer (Grades 9-12).* •*10E Moving the Continents: The theory of plate tectonics provides an explanation for diverse phenomena (Grades 9-12)*	•D, *Earth and Space Science:* Lithospheric plates move at rates of centimeters per year; Major geological events result (Grades 5-8); Heat transfer and resulting convection propel the plates (Grades 9-12)	•The San Andreas fault as an on-land example of a transform fault. •Other faults as part of a larger system of deformation.	The entire San Andreas fault system as well as portions of major active faults in the western US has been laser scanned and the data are freely available. Tools have been built for their exploration, measurement, and analysis.

Science Topic	Earth Science Literacy Initiative (ESLI, 2009)	Benchmarks for Science Literacy (AAAS, 1993)	National Science Education Content Standards (NRC, 1996)	Content in exemplary introductory geoscience textbooks[1]	How exploration of high resolution topography links to these ideas[2]
Geometry and processes of fluvial systems and hillslopes	•Earth is the water planet (*Big Idea 5*). •Water shapes landscapes (*Supporting Concept 5.6*).	•4C Processes that Shape the Earth: [Surface processes] shape and reshape the earth's land surface (Grades 3-5); Surface changes can be abrupt or slow; The surface is shaped by the motion of water and wind (Grades 6-8).	•D, *Earth and Space Science:* Landforms are the result of a combination of constructive and destructive forces; Water circulates through crust, oceans, and atmosphere; Water is a solvent (Grades 5-8).	•Various levels of description and process discussion for terrestrial landforms illustrated via cartoons and actual examples from maps, imagery, and photography.	2D, map-based, representations are the entry to description, but the processes are driven and resisted by slopes and various scale roughnesses. These parameters can be measured from high resolution data because the data are at the appropriate fine scale at which processes are active (i.e., channel cross-sections; hillslope steepness, landslide roughness).

Science Topic	Earth Science Literacy Initiative (ESLI, 2009)	Benchmarks for Science Literacy (AAAS, 1993)	National Science Education Content Standards (NRC, 1996)	Content in exemplary introductory geoscience textbooks[1]	How exploration of high resolution topography links to these ideas[2]
Earth as a system of which humans are a significant part	•Humans have become a significant agent of change on Earth (*Big Idea 9*). •Humans are the most significant agents of change in surficial Earth processes (*Supporting Concept 9.3*).	•4C Processes that Shape the Earth: Human activities have changed the Earth's [surface] (Grades 6-8).	•D, *Earth and Space Science*: Living organisms have played many roles in the Earth system (Grades 5-8). •F, *Science in Personal and Social Perspectives*: Human activities can induce hazards; Hazards present the need to assess potential danger and risk; Risk analysis estimates [who] might suffer consequences (Grades 9-12).	•Appreciation of effects of alteration of surface processes by humans; Importance of knowledge of earth science for sustainability.	LiDAR data are recently gathered and will continue to be so. This data type measures topography, vegetation, and anthropogenic structures equally well and provides detailed and synoptic perspective. Data integration via digital globes and GIS enables students to spatially relate natural and human systems and assess effects and hazards.

[1]For example. Marshak. 2008: Revnolds. et al.. 2008: Chernicoff and Whitnev. 2007: Abbott. 2009: and Keller. 2008.

[2]In addition to the basic power of active learning enabled by these data and the associated tools. Students can go anywhere where the data are available and find features of interest.

METHODS

LiDAR Topography Content Generation

For this study, two main educational tools were developed. The first is a ten-minute introductory video on LiDAR and its uses for studying earthquakes and faulting. The second is a classroom lab activity that implements LiDAR topography into the Google Earth environment and has students evaluate GPS velocities across and along the San Andreas Fault in order to teach about the earthquake cycle. Both of these tools were tested in undergraduate geology classrooms at Arizona State University to assess the effectiveness of the tools for teaching about earthquakes using LiDAR topography.

"LiDAR: Illuminating Earthquake Hazards" video. Concisely and accurately defining LiDAR topography and its uses in the geosciences drove the development of the video "*LiDAR: Illuminating Earthquake Hazards*" (This video is available for free viewing online at http://www.youtube.com/watch?v=dwGT9B4s6Iw; 4,201 views up to August 1, 2011). The primary goal of producing this video was to create a freely available video that introduced airborne LiDAR and its applications to the geosciences and specifically to the study of faulting and earthquakes.

The video was produced in order to accomplish the following goals:

- Create a video that defines and shows what LiDAR is

- Create a video that explains why LiDAR is important for the study of earthquakes
- Show the advances of LiDAR over other visualizations
- Show how LiDAR data are freely available via the OpenTopography portal
- Show current scientific research on faulting and earthquakes and how LiDAR is being used in these studies
- Demonstrate all the above in less than ten minutes

The development of the video involved a team of geologists and scientists for writing and editing the script to ensure the accuracy of the narration content. The script is supplemented by interviews with experts on LiDAR topography such as Chris Crosby from the OpenTopography team, and scientists who actively use LiDAR topography in their research and work on faults and earthquakes (Ken Hudnut, Sally McGill, Tom Hanks, and others). Using a combination of videography and computer animation, the film was filmed, edited, and completed in the summer of 2010 at the Southern California Earthquake Center (SCEC) at the University of Southern California (USC).

The "*LiDAR: Illuminating Earthquake Hazards*" video is comprised of four main parts. The first part is an introduction earthquake science and the motivation for studying faulting and active tectonics. This section introduces the need for using the most up-to-date technology for studying earthquakes because of the hazard that earthquakes pose to human life and infrastructure.

The second part of the video is an introduction to LiDAR technology and LiDAR data collection. In this section of the video, animations show how aerial LiDAR data are collected. Chris Crosby of the OpenTopography portal explains LiDAR concepts and terminology. The point cloud is defined and shown, along with digital elevation models created from point clouds. DEMs created from older technology are compared with those created from LiDAR point clouds (Figure 4). The ability to filter LiDAR data is also demonstrated showing the “virtual deforestation” of an area that reveals the evidence of faulting underneath the first returns.

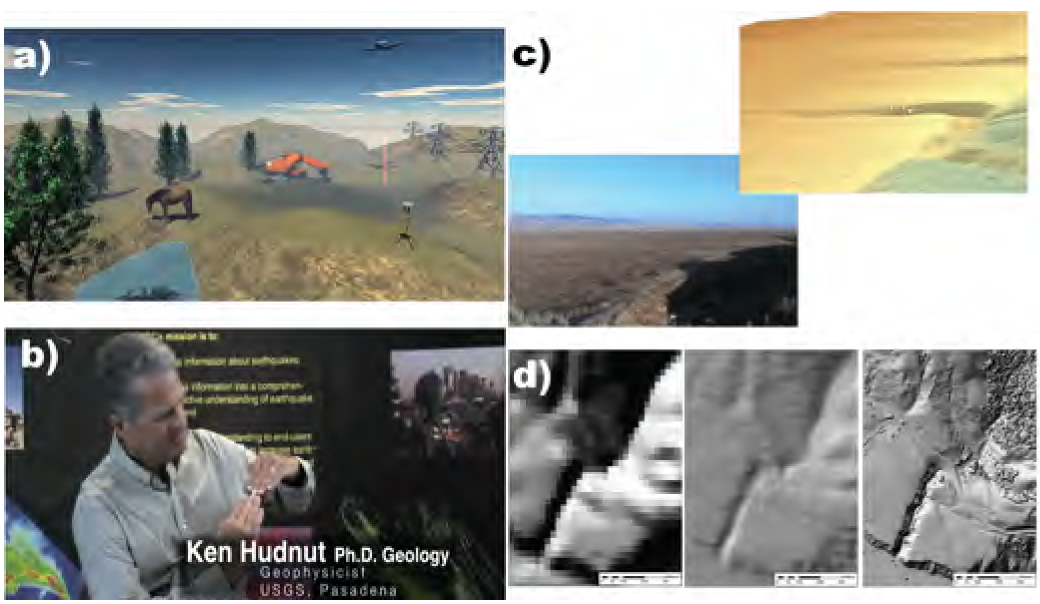

Figure 4. Examples of LiDAR video content. a) Animation of aerial LiDAR data collection. B) Dr. Ken Hudnut discusses how LiDAR topography has revealed small offset channels at the San Andreas Fault that were previously overlooked and unstudied. c) LiDAR topography is compared

with videography of the same location at Wallace Creek. d) Comparison of DEM hillshades derived from older technology with LiDAR hillshades (from left to right, 30 m USGS DEM, 10 m USGS DEM, 2 m LiDAR-derived DEM).

The third part of the video includes an explanation of the OpenTopography portal and community access of LiDAR topography. This section describes in greater detail the logistics of storing LiDAR data and the volume of data that LiDAR collection produces. The goal of OpenTopography to allow free access to LiDAR data via a web portal is discussed (e.g., Crosby, et al., 2011; Krishnan, et al. 2011).

The final part of the video shows how LiDAR topography is currently being used for the study of earthquakes. An explanation of Zielke, et al 2010 is described by Ken Hudnut (USGS): the LiDAR topography was used to virtually back-slip the San Andreas fault at the Carrizo Plain to find best-fit alignments of offset channels. Previous study had attributed the 9 meters of offset to the 1857 earthquake for this section of the San Andreas (Sieh and Jahns, 1984). Using LiDAR topography, numerous channels showed a best-fit alignment of 5 meters when they were virtually backslipped. If a smaller amount of offset can be attributed to the 1857 earthquake (5 meters as opposed to the previous 9 meters), then the time interval between ground-rupturing earthquakes on the fault must be less than was thought previously. These smaller offsets which were previously unstudied and unnoticed without the LiDAR topography shed new light on the behavior of this section of the San Andreas fault.

This part of the video is followed by field interviews at the San Jacinto fault where a team of geoscientists used LiDAR topography to locate their paleoseismic trenching site near Mystic Lake in California. The video concludes with a closing statement from Ken Hudnut on the future of LiDAR topography and the potential for improvement as technology improves.

San Andreas Fault Earthquake Cycle activity. The educational motivation for developing the San Andreas Fault Earthquake Cycle activity is multifaceted. There is a need for an undergraduate-level geology classroom activity that teaches the earthquake cycle and elastic rebound theory accurately. There is also a need to use LiDAR topography as a tool in this activity as these data display the landscape at an appropriate scale and resolution for studying faults and earthquakes. The San Andreas Fault Earthquake Cycle activity incorporates LiDAR topography into a hands-on exercise that teaches students about the earthquake cycle, strain accumulation and release, and earthquake recurrence intervals (Appendix III).

The earthquake cycle is the geologic concept involving interseismic strain accumulation and coseismic strain release (Figure 5). Between earthquakes, strain accumulates from steady far-field plate tectonic motion and causes deformation within the fault zone as the rocks on one side of the fault move in the opposite direction of the rocks on the other side of the fault. This deformation stresses the fault surface. In the case of the right-lateral San Andreas Fault, the Pacific Plate moves to the northwest relative to the North American Plate and deformation accumulates on the scale of meters between ground-rupturing earthquakes (Bolt, 1999). This straining cannot continue indefinitely, and eventually strength along the fault surface is exceeded and the fault slips generating an earthquake (coseismic phase). The interseismic phase of steadily loading continues until the fault breaks again and the cycle persists. This elastic rebound concept was first elucidated by Reid, 1911.

Figure 5 shows the concept of elastic rebound for horizontal displacement along a strike-slip fault. U_x represents fault parallel displacement. x is the fault parallel direction and y is the fault perpendicular direction. Δu is the coseismic offset, or U_x (slip rate) * ΔT (time between earthquakes). The length scales are on the scale of tens of kilometers, and for the San Andreas fault Δu is between 2 and 10 meters. The slip rate for this segment of the San Andreas fault is about 35 mm/yr so ΔT would be 57 to 285 yrs.

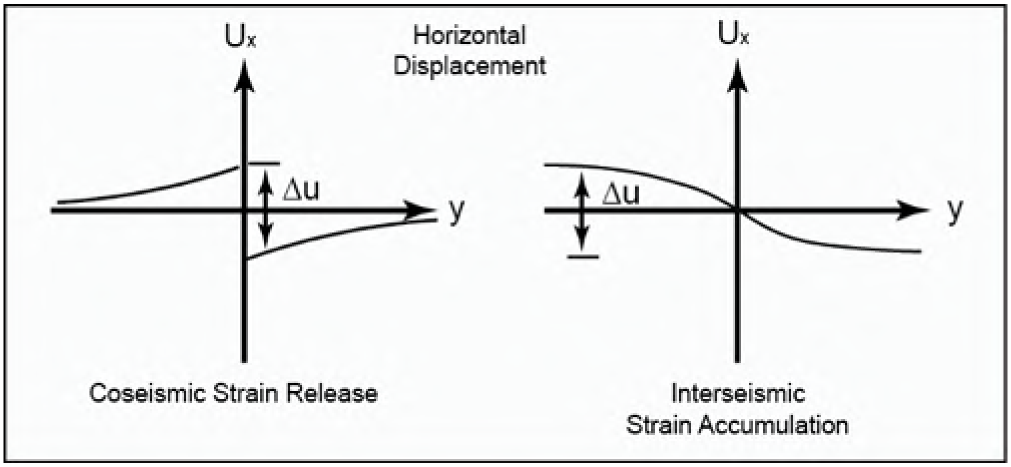

Figure 5. Elastic rebound for horizontal displacement along a strike-slip fault. See text for explanation. Modified from Thatcher, 1990.

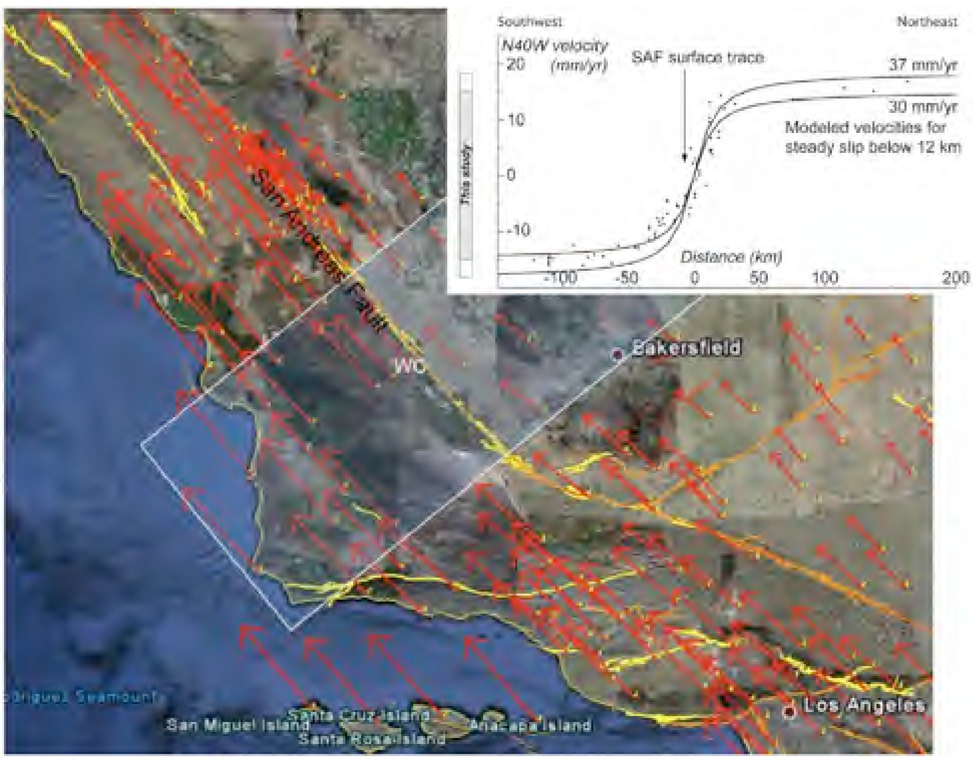

Figure 6. GPS velocity vectors near Wallace Creek. The tails of the arrows show the location of the corresponding GPS station, and length of the arrows corresponds to velocity (the longer the arrow, the higher the velocity). The box shows the area where students measure velocity arrows to calculate strain on the SAF. The inset fault parallel velocity profile computed from the arrows in the box is a more detailed version of

the expected result from the GPS portion of the student exercise. GPS data courtesty the Plate Boundary Observatory (PBO) at UNAVCO.

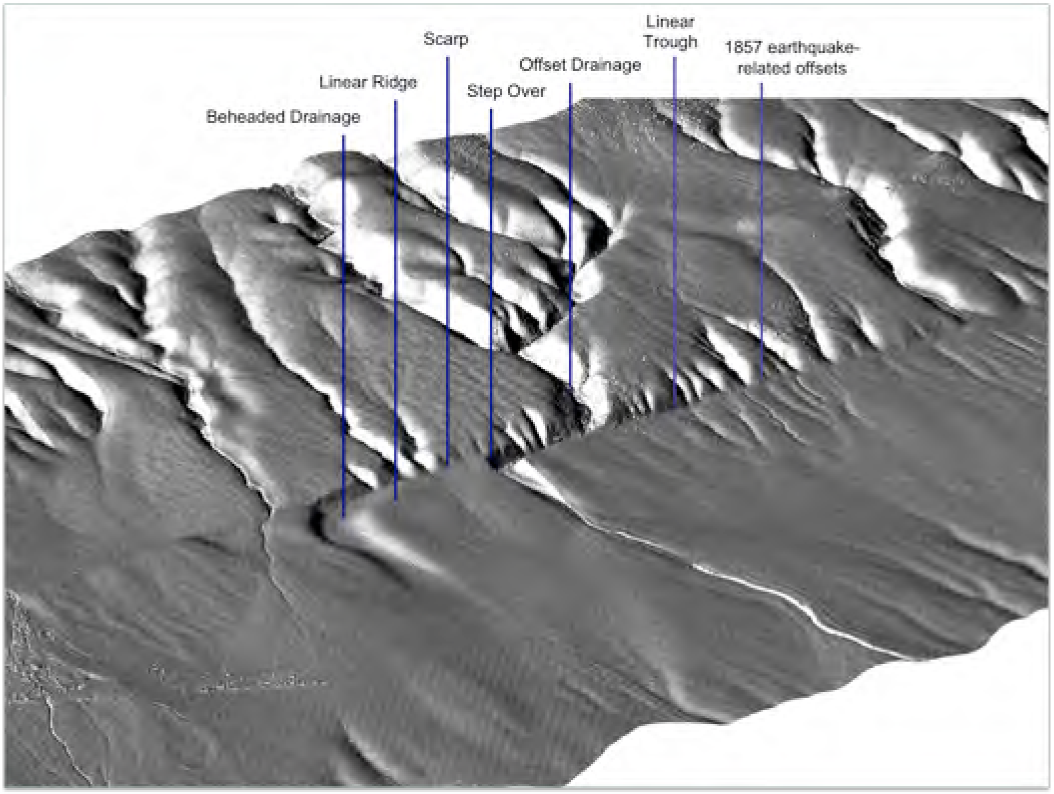

Figure 7. The geomorphology of Wallace Creek as exemplary strike-slip fault zone tectonic landforms. Annotations show the various features indicating a fault. The 1857 earthquake-related offsets are difficult to see without LiDAR topography.

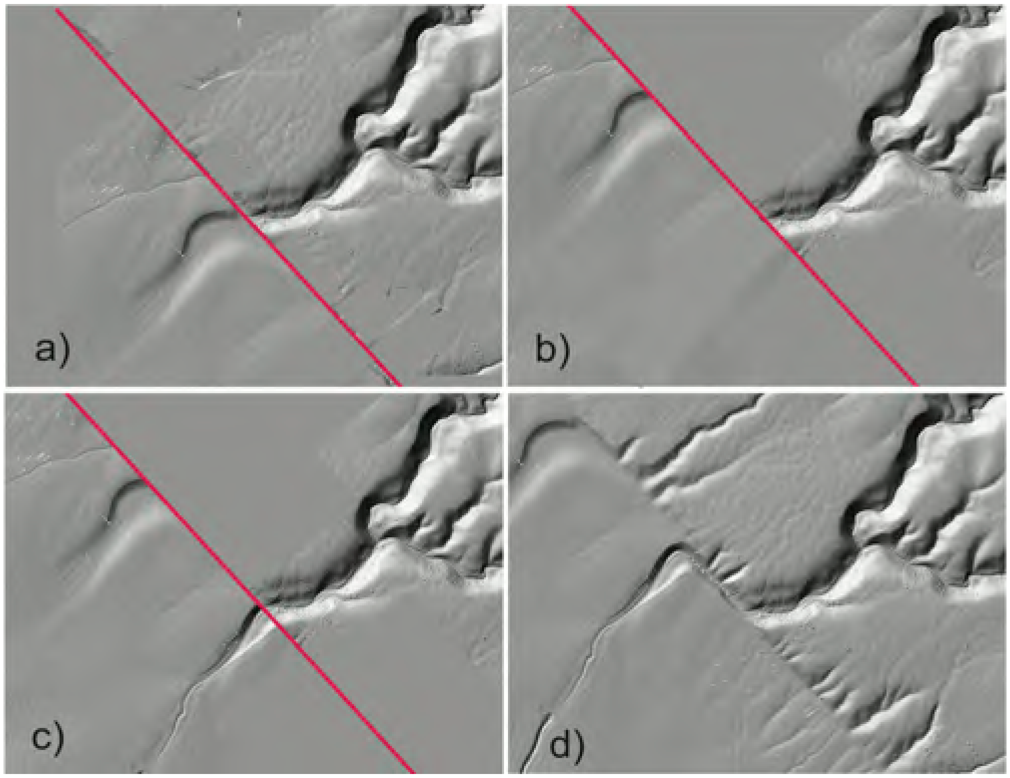

Figure 8. Wallace Creek Evolution (after Sieh and Jahns, 1984). The San Andreas fault is shown in red. a) A new channel is cut across the fault at about 10,000 years ago. b) The channel at Wallace Creek is offset by repeated ground-rupturing earthquakes but a new channel has not yet incised at about 3,700 years ago. c) A new channel incises straight across the fault at around 3,700 years ago. d) Approximately 130 meters of offset has accumulated at Wallace Creek between 3,700 years ago and the present. Continued offset and aggradation of the channel will lead to its abandonment and the incision of a new channel in the future cutting straight across the fault.

The concept of elastic rebound is often difficult to teach to introductory students because the scale at which elastic rebound occurs is difficult to convey with most simple elastic rebound illustrations and animations. Simple illustrations often cause the misconception that deformation and elastic rebound occurs within a few meters of the fault at most when in reality, deformation is on the scale of tens to hundreds of kilometers (the length scale of the displacement gradients in both phases of the earthquake cycle is controlled by the 10-20 km locking depth of the fault; e.g., Thatcher, 1990). This can be seen at the San Andreas fault in California by observing Earth's movement using stationary GPS velocity stations (Figure 6). These stations record Earth's movement relative to stable North America and allows for the measurement of interseismic strain accumulation. This strain is released during ground-rupturing earthquakes along the narrow fault zone that is the San Andreas fault where offset accumulates (the best example of which is Wallace Creek). Using both LiDAR topography and GPS station data within the SAF Earthquake Cycle activity helps students to see the geographic scale at which strain accumulation occurs relative to the scale of displacement on the fault as well as how the two balance roughly along a plate boundary.

The activity itself is divided into two parts. The first part uses Google Earth as a platform to allow students to view B4 LiDAR-derived hillshaded digital elevation models of the San Andreas fault in California at Wallace Creek [The 'B4 Project' (www.earthsciences.osu.edu/b4) collected LiDAR point cloud data along the southern San Andreas and San Jacinto Faults. Data acquisition and processing were performed by the National Center for Airborne Laser Mapping (NCALM). The project was led by Ohio State University and USGS with funding from the Division of Earth Sciences Geophysics program at the NSF. Optech International contributed the ALTM3100 laser scanner. UNAVCO and Southern

California Integrated GPS Network assisted in GPS ground control. Numerous volunteers and landowners made the project possible.]. The dramatic offsets at Wallace Creek make it an appropriate location for the study of faulting and earthquakes (Figure 7).

Wallace Creek has a fairly simple development history. Within this alluvial environment, the main channel incised across the San Andreas fault and was then offset repeatedly by ground-rupturing earthquakes (Wallace, 1968; Sieh and Jahns, 1984; Figure 7). The active channel has accumulated approximately 130 meters of accumulated offset over a period of 3700 years, and Wallace Creek has been dated using carbon from correlating sediments within the channel (Sieh and Jahns, 1984). The most recent earthquake on this segment of the San Andreas fault was in 1857 (Wallace, 1968; Sieh, 1978). This rupture was a M_w7.9 earthquake rupturing 360 kilometers of the fault (Agnew and Sieh, 1978; Sieh, 1978).

Students use tools within Google Earth to measure the main offset at Wallace Creek, along with smaller offsets south of the main creek that would be difficult to see without LiDAR topography (Figures 2 and 7). Google Earth has an environment that has a universal appeal for viewing the earth’s topography by zooming in and out until objects of interest are visible. A keyhole markup language (kml) zipped file (or kmz) was created and put online for students to access the B4 LiDAR imagery and other virtual features at Wallace Creek (http://cordillera.la.asu.edu/wc/wc1.kmz). The Google Earth environment allows for students to view the LiDAR hillshades, Google Earth aerial imagery and on-site photos. Within the kmz there is also a 3D panorama view of Wallace Creek (Courtesty of Ron Schott). The versatility of Google Earth is ideal for students to fully investigate the landscape and its features while getting an appropriate understanding of scale and geographic location. Students can use tools within the Google Earth program to do things like measure features and digitally draw lines representing the fault location. Another benefit to using Google Earth is that there is a freely available version, and every function required for completion of the San Andreas Fault Earthquake Cycle activity is available within this free version.

The students are first asked to describe the landscape using the LiDAR topography as well as the aerial photography, on-site photos, and the 3D panorama. The lab states that the main offset at Wallace Creek is the result of repeated earthquake offsets and students are asked to calculate the long-term slip rate on the fault given the age of the creek and using the amount of offset they measured within Google Earth. Students calculate the slip rate using the formula: slip rate = [offset]/[age of channel]. If a student measures the amount of offset to be ~130 meters, they will calculate slip rate as: slip rate = [130 meters]/[3700 years]. Once the student calculates the slip rate (~ 35 mm/yr), they are asked to try and find the smallest offset channel they can see and measure it. Assuming that the local smallest offset is attributed to the most recent ground-rupturing event (as is told to them within the lab; e.g., Sieh, 1978; Zielke, et al., 2010), the students are informed that their answer should be their interpretation of the amount of offset one would attribute to the 1857 earthquake. Students are expected to get varying answers to this question (Usually somewhere between 3 and 10 meters) as it is somewhat open to interpretation which assumed offsets are actually from one original offset channel that has been displaced in a single ground-rupturing event.

Students then use their chosen measurement for the smallest local offset along with the slip rate they calculated earlier to determine how long it would take to accumulate their measure of offset (offset divided by slip rate = ΔT). By this the students begin to understand the basic concept of elastic rebound that the long-term motion along the fault (e.g., Wallace Creek) is released episodically in a ground-rupturing earthquake (smallest offset). The point of this first part of the exercise is for students to get an understanding of fault displacement, the earthquake cycle, and long-term slip rate.

The second part of the activity involves the measurement of GPS velocities that are mapped as vectors on a map of California (e.g., Figures 6 and 11). Students measure velocity vectors within the box seen in Figure 6 and the actual vectors shown in Figure 11 that is approximately drawn across the location of Wallace Creek. Students then plot the vectors with distance perpendicular to the SAF to measure the changes in motion parallel to the SAF. This part of the activity allows for students to see that the greatest gradient of motion is across the fault. The students then quantify the difference in velocities between the two plates (North American Plate and Pacific Plate). This gives the student a value for the current rate of strain accumulation on the San Andreas fault. The value students determine should be 35 mm/yr, which is the same rate calculated using the LiDAR topography at Wallace Creek for long-term slip rate. Students compute the time it takes to accumulate the amount of slip released in the last earthquake (another ΔT) and compare that to the time since 1857, the last great earthquake. The exercise closes with having students write a short answer explaining what the significance of discovering that the current strain accumulation rate is equal to the long-term slip rate. This allows for students to grasp the entire concept of the earthquake cycle and the scale at which both strain accumulation occurs and the scale at which coseismic strain release occurs.

Educational Assessment

Overview. This study was considered exempt after review by the Institutional Review Board (IRB) under Federal Regulations 45CFR46.101(b) on 2/16/2011 and approved for testing with human subjects (Appendix I). The IRB protocol number is 1102006008. The purpose of the study is to test the effectiveness of the educational tools (both the video and the lab activity) and to determine the effectiveness of using LiDAR topography to teach about earthquakes and faulting.

In addition to a pilot test, the main testing involved a pretest, two consecutive weeks of testing, and a posttest. Students were split into two groups: a control group consisting of 45 students and an experimental group consisting of 88 students. For the pretest, both the control group and the experimental group were administered the LiDAR Video assessment and the SAF EQ Cycle assessment as a pretest (without having watched the “LiDAR: Illuminating Earthquake Hazards” video and without completing the SAF EQ cycle activity). The following week, control group students were administered the same two assessments. Experimental group students, however, were shown the “LiDAR: Illuminating Earthquakes” video before taking the LiDAR video assessment. Experimental groups also completed the SAF EQ cycle activity in groups of 3-4 students before taking the SAF EQ Cycle assessment.

Pilot testing. A total of 71 undergraduate students at Arizona State University were tested in February of 2011 to refine the assessment materials and the educational tools themselves. All students were freshman-level introductory geology students enrolled in the class “GLG110 Geologic Disasters and the Environment”. No prerequisites were required for taking the class. All students were shown the “LiDAR: Illuminating Earthquake Hazards” video first and then were given a short multiple-choice assessment. After completion of the assessment they were given the San Andreas Fault Earthquake Cycle activity to complete. They were given another multiple-choice assessment following completion of the lab activity. No pre-test was given and there was no control group.

Results from the study indicated that much refinement was needed to the assessment tools before results could be analyzed in much detail. The original testing materials had distracters in the multiple-choice assessment questions that often either gave away the correct choice or were so close to the correct answer that they could have been considered correct as well. The assessment questions were re-evaluated using the methodology and reasoning of Fuhrman (1996) and rewritten for the main testing that took place in April 2011.

Testing methods. In April 2011, freshman-level introductory geology students were tested. Testing was administered over a two-week period in lab sections that meet once a week. The control group consisted of 3 sections of an introductory geology lab (GLG 103) under the same lab Teaching Assistant (TA). The experimental group consisted of 4 sections of the same introductory geology lab (GLG 103) but under a different lab TA. Although the lab TAs were different, the lab manual and methodology for each lab are exactly the same. This helps in maximizing the reliability of results.

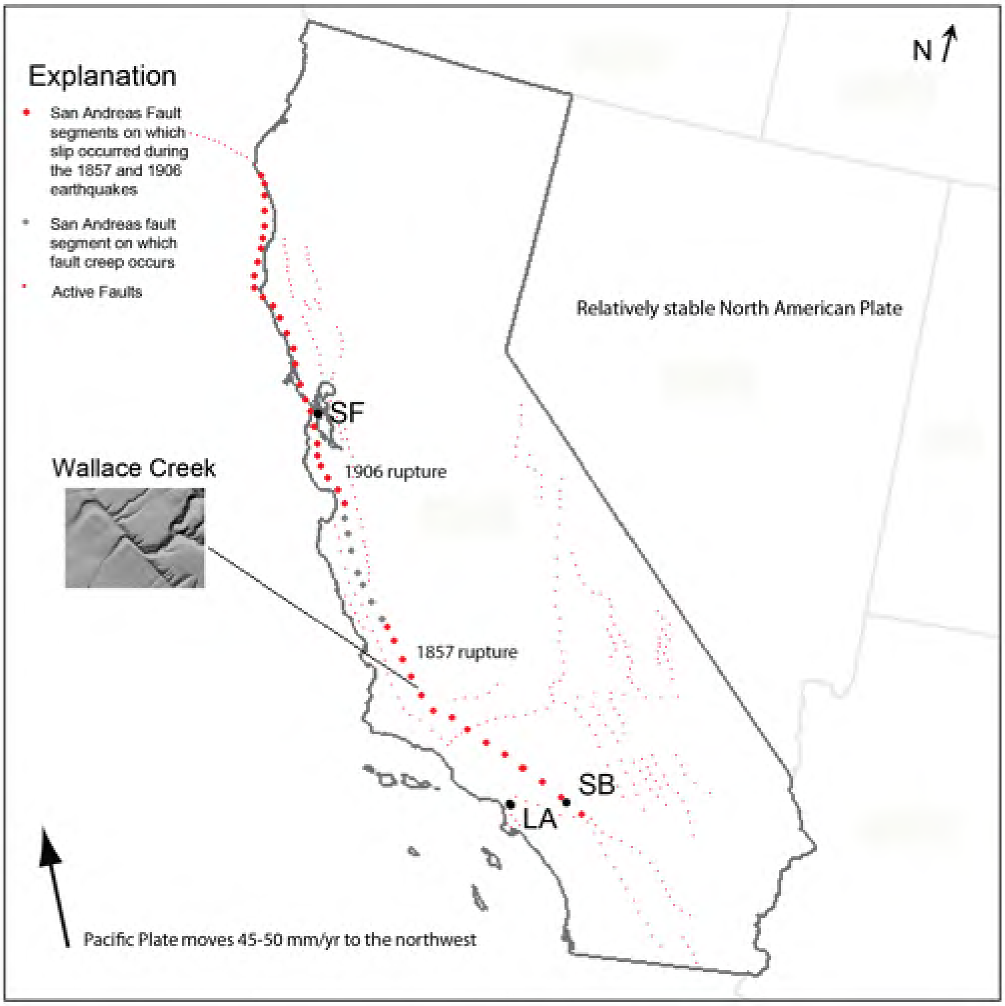

Figure 9. Map of California. The location of the San Andreas fault and other active faults is shown as red and gray colored dotted lines (red for locked and gray for creeping). SF is San Francisco, SB is San Bernardino, and LA is Los Angeles.

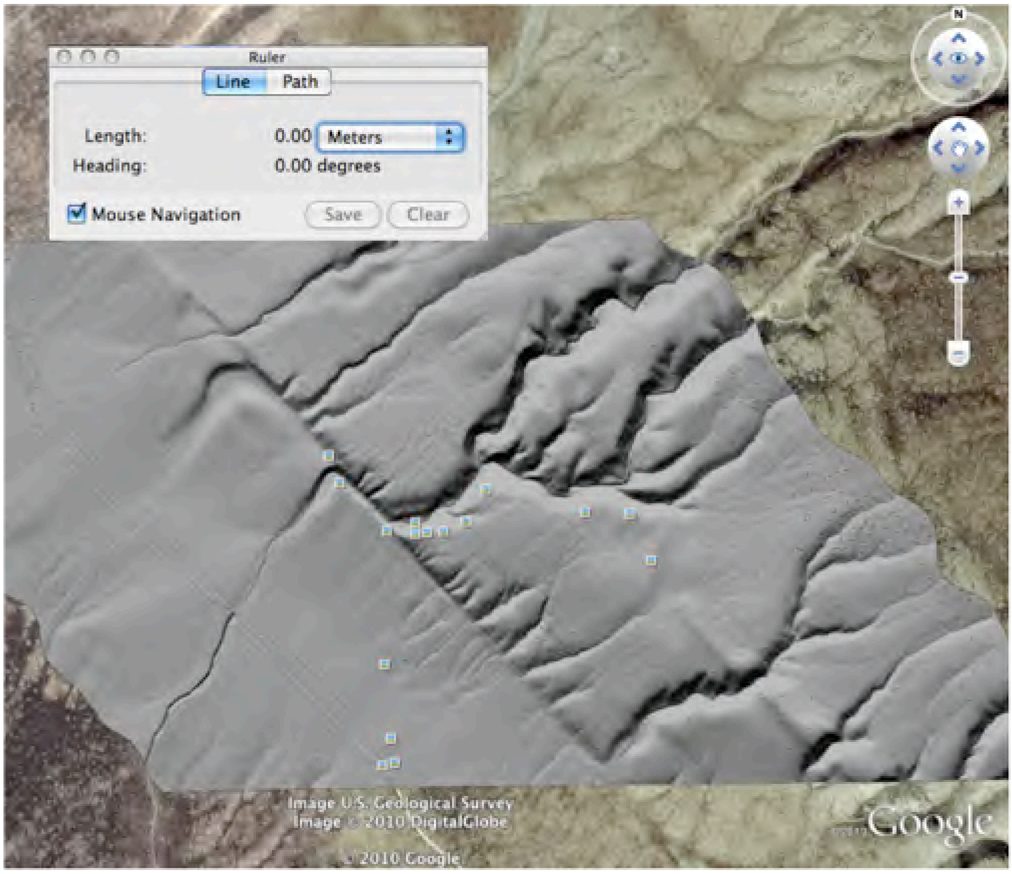

Figure 10. LiDAR Topography of Wallace Creek within Google Earth. Students use the “Ruler” tool within Google Earth in order to measure offset at Wallace Creek (both the main offset at the active channel and the smaller offsets to the southeast).

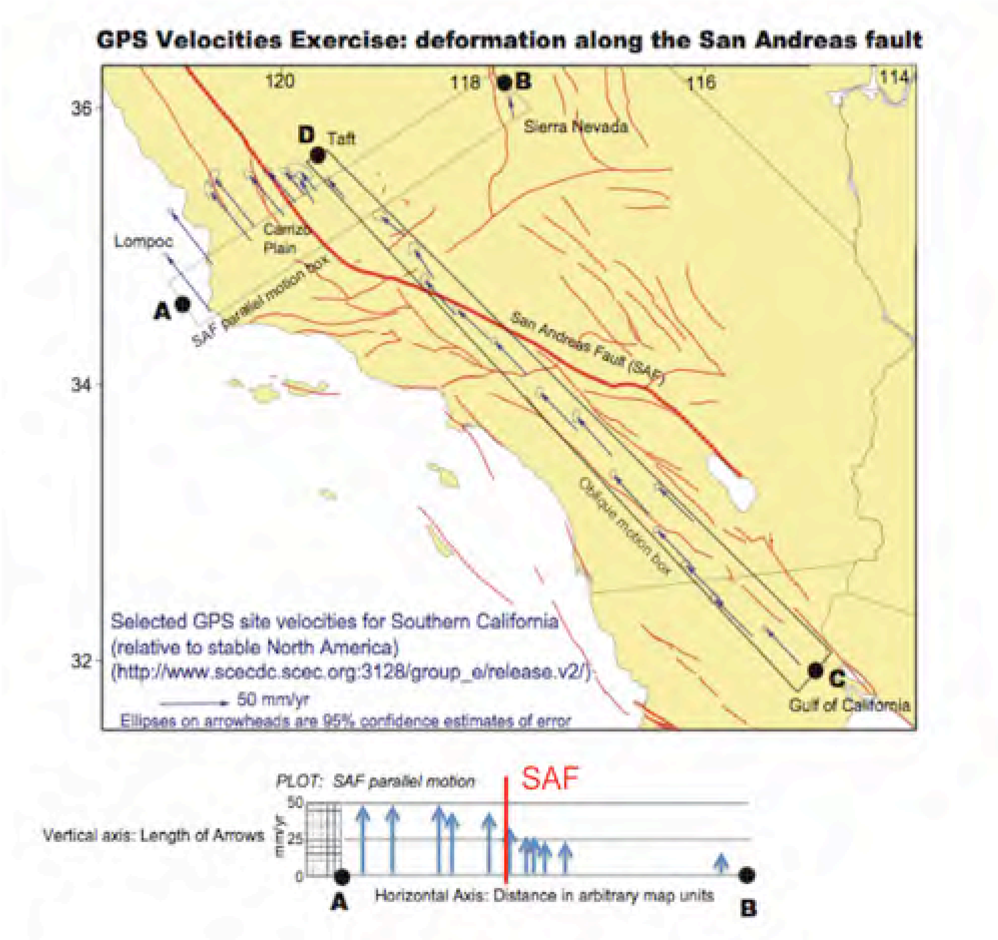

Figure 11. GPS Velocities Exercise. Students measure the length of the vectors on the map from length A to B and plot them on the SAF parallel motion plot below the map. The blue arrows and red fault line within the SAF parallel motion plot show how a student might fill in their answers.

RESULTS

A complete table of all student responses to assessments can be found in Appendix V. All results are multiple choice assessment responses to the San Andreas Fault Earthquake Cycle Exercise assessment and the "LiDAR: Illuminating Earthquake Hazards" Video assessment. All student responses for each of the assessments fall in one of four categories: control group pretest, control group posttest, experimental group pretest, and experimental group posttest.

Table 3

Summary of assessment results. SAF 1,2, etc. correspond to each question on the San Andreas Fault Earthquake Cycle Exercise Assessment. LV 1,2 etc. correspond to each question on the LiDAR: Illuminating Earthquake Hazards Video Assessment.

	SAF 1	SAF 2	SAF 3	SAF 4	SAF 5	SAF 6
Control Group Pretest						
n response	45	45	45	45	45	45
correct response	15	10	24	2	25	5
percent correct	33.3	22.2	53.3	4.4	55.6	11.1
Control Group Posttest						
n response	45	45	45	45	45	45
correct response	18	6	17	4	17	5
percent correct	40	13.3	37.8	8.9	37.8	11.1
Experimental Group Pretest						
n response	88	88	88	88	88	88
correct response	33	30	46	13	55	14
percent correct	37.5	34.1	52.3	14.8	62.5	15.9
Experimental Group Posttest						
n response	88	88	88	88	88	88
correct response	32	63	41	6	53	9
percent correct	36.4	71.6	46.6	6.8	60.2	10.2
Control Group Percent Increase	6.7	-8.9	-15.6	4.4	-17.8	0.0
Experimental Group Percent Increase	-1.1	37.5	-5.7	-8.0	-2.3	-5.7

	LV 1	LV 2	LV 3	LV 4	LV 5	LV 6	LV 7	LV 8a	LV 8b	LV 8c
Control Group Pretest										
n response	45	45	45	45	45	45	45	45	45	45
correct response	5	7	7	6	16	10	7	31	32	27
percent correct	11.1	15.6	15.6	13.3	35.6	22.2	15.6	68.9	71.1	60.0
Control Group Posttest										
n response	45	45	45	45	45	45	45	45	45	45
correct response	9	9	8	2	15	11	12	31	32	19
percent correct	20.0	20.0	17.8	4.4	33.3	24.4	26.7	68.9	71.1	42.2
Experimental Group Pretest										
n response	88	88	88	88	88	88	88	88	88	88
correct response	17	19	16	5	39	18	14	65	53	48
percent correct	19.3	21.6	18.2	5.7	44.3	20.5	15.9	73.9	60.2	54.5
Experimental Group Posttest										
n response	88	88	88	88	88	88	88	88	88	88
correct response	50	25	57	44	66	57	39	75	63	66
percent correct	56.8	28.4	64.8	50.0	75.0	64.8	44.3	85.2	71.6	75.0
Control Group Percent Increase	8.9	4.4	2.2	-8.9	-2.2	2.2	11.1	0.0	0.0	-17.8
Experimental Group Percent Increase	37.5	6.8	46.6	44.3	30.7	44.3	28.4	11.4	11.4	20.5

LiDAR: Illuminating Earthquake Hazards Video Assessment Results

A summary of the results for the LiDAR Video assessment is displayed in Table 3. This table shows the overall number of correct responses for each individual question for both control and experimental groups who took the LiDAR video assessment. Detailed assessment results can be found in Appendix V. An overview of the results can be seen in Figure 12. The only group that received scores of 8 or higher is the experimental group post-testers. Less than 10 out of the 88 total experimental group post-testers scored 3 correct or less. The raw score gains from pre-test to post-test are in Figure 13 alongside results from the SAF earthquake cycle activity results. The control group has a gain of 0 from pretest to posttest and the experimental group has a raw gain of 2.8 (out of a possible 10) (Figure 13). A complete table of the gains data can be found in Appendix V.

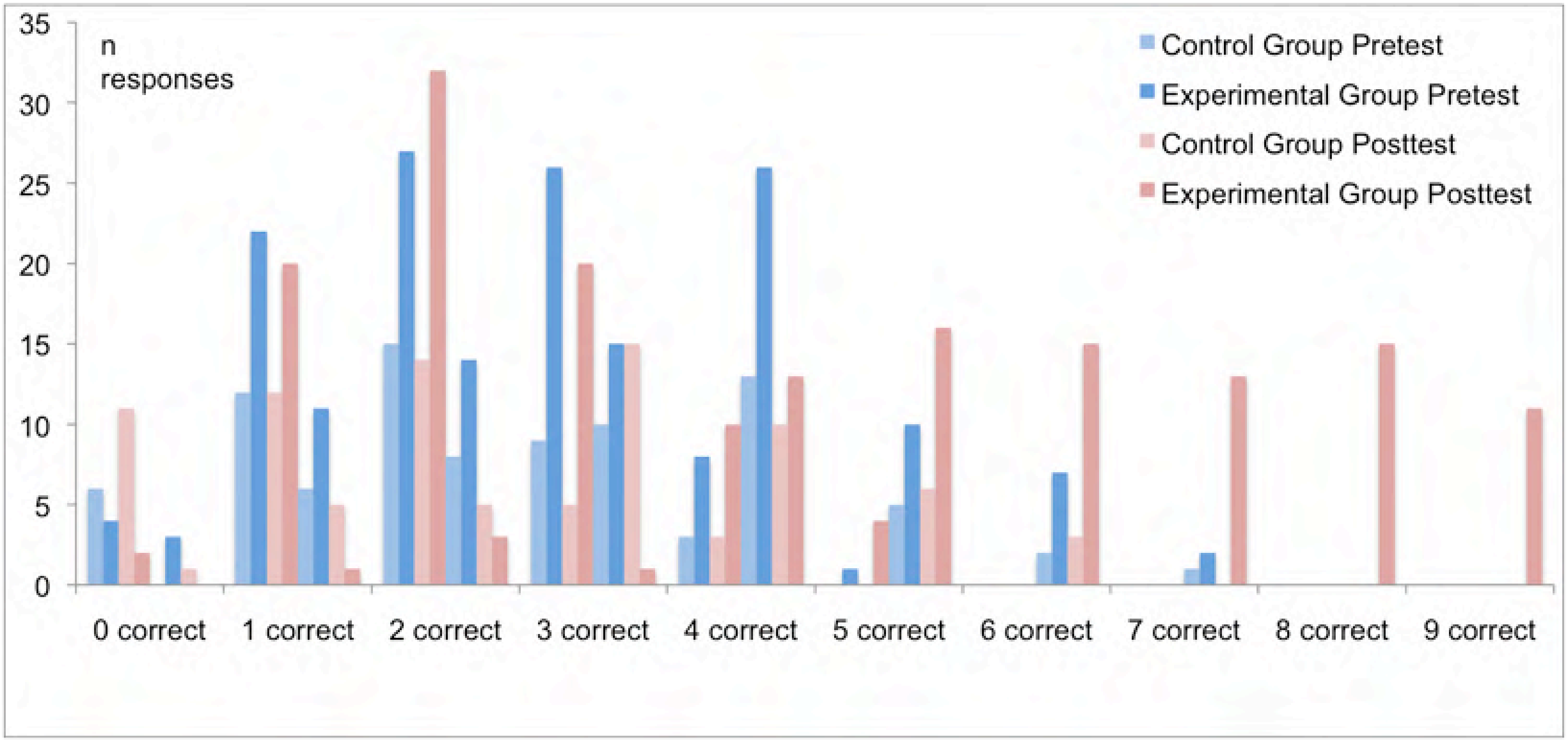

Figure 12. "LiDAR: Illuminating Earthquake Hazards" video assessment results overview. Plotted by the number of students (n) that received a score of 1 through 9 correct out of 10 possible correct. No students received a perfect score. The number of control group students total is 45 and the number of experimental group students

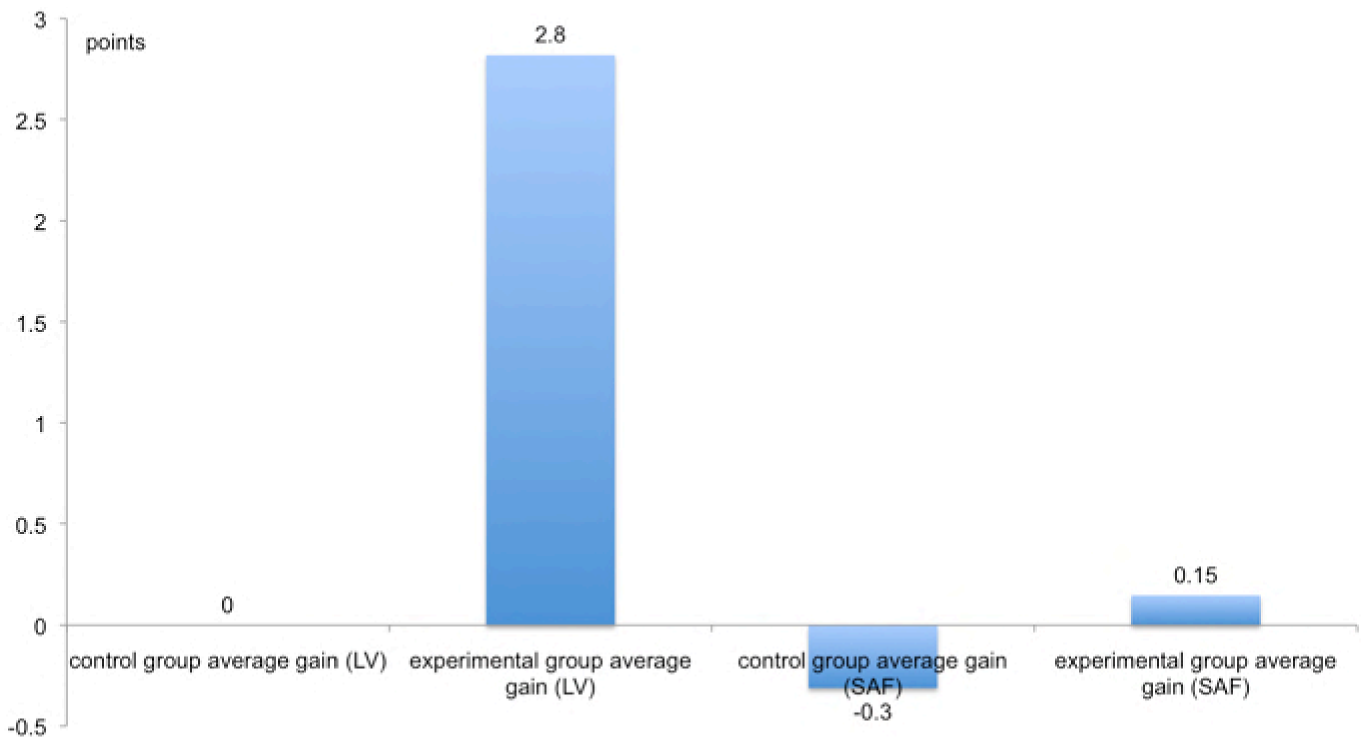

Figure 13. Overall average raw score gain from pretest to posttest. Shows the raw gain in scores from pretest to posttest for both control and experimental groups where LV is LiDAR video assessment results and SAF is San Andreas fault exercise assessment results. The LiDAR video assessment is out of a possible 6 questions and the SAF exercise assessment is out of 10.

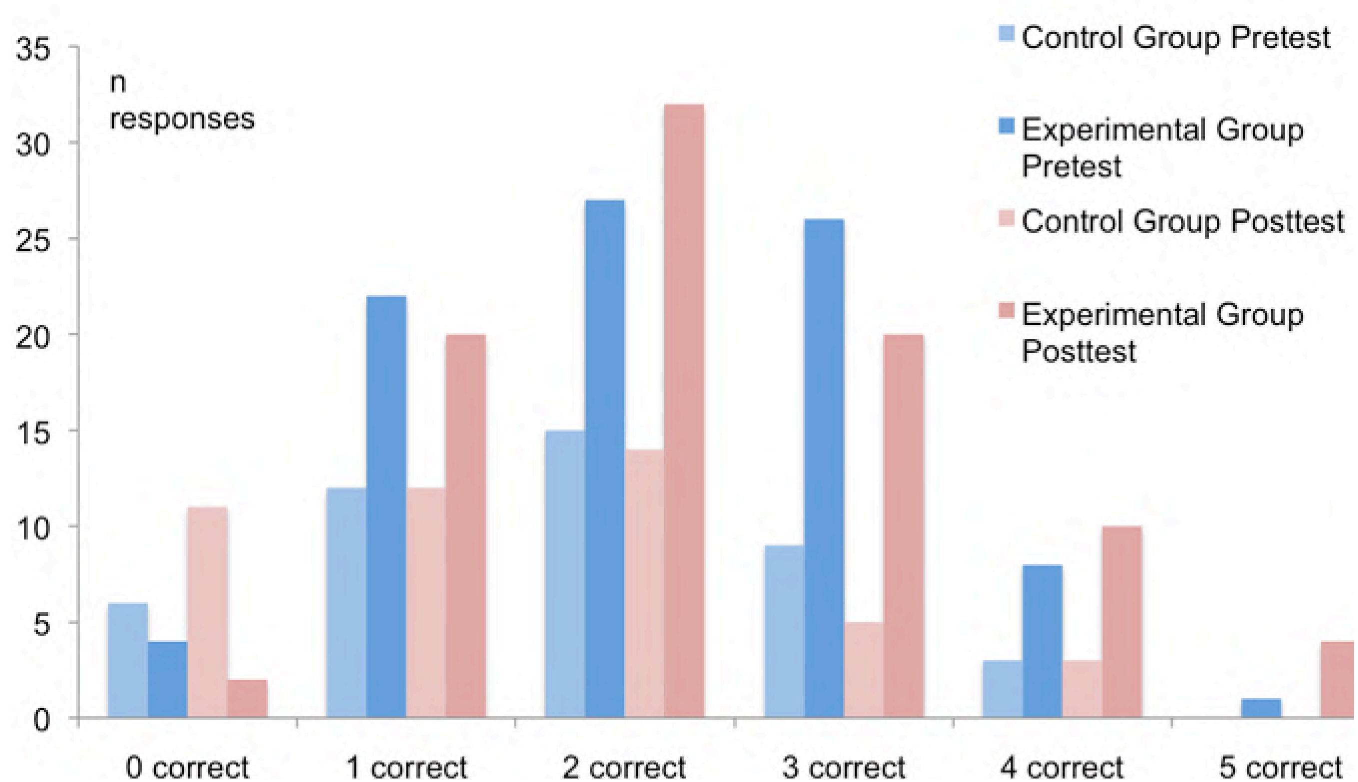

Figure 14. San Andreas fault earthquake cycle activity assessment results overview. Plotted by the number of students (n) that received a score of 1 through 5 correct out of 6 possible correct. No students received a perfect score. The number of control group students total is 45 and the number of experimental group students is 88.

San Andreas Fault Earthquake Cycle Exercise Assessment Results

A summary for the SAF earthquake cycle exercise assessment results is presented in Table 3. This table shows the overall number of correct responses for each individual question for both control and experimental groups who took the SAF earthquake cycle assessment. The results are in Figure 13

A summary of the raw gains results can be seen alongside the LiDAR Video assessment results in Figure 13. The control group shows a raw gain of -0.3. The experimental group shows a gain of 0.15. These results are out of a possible gain of 6 (going from 0 correct responses to 6).

DISCUSSION

The purpose of this study was to determine whether using the LiDAR topography data instead of, or alongside, traditional visualizations and teaching methods would enhance a student's ability to understand the geologic concepts of plate tectonics, the earthquake cycle, strike-slip faults, and geomorphology. The results of the educational assessments that were administered indicate that students are reaching the expected learning goals from both the video and the lab. Although the SAF EQ assessment results do not show a great increase in scores from pretest to posttest, looking at the lab short-answer responses can help to triangulate whether students learned what was expected.

LiDAR Video Discussion

For the LiDAR video, students were asked ten questions to assess what they had learned (Appendix IV). Looking at the assessment results as a whole, students overall improved in the experimental group from pretest to posttest (Figure 11) with an overall average gain of 2.8 points out of a possible 10 points. This is with each assessment question being weighted at 1 point. The control group had a zero gain from pretest to posttest, which is ideal as the control group was not shown the LiDAR video or given any material in-class to cause an increase in their understanding of LiDAR and its applications to earthquake science. These results indicate that overall the LiDAR video is effective in increasing the viewers understanding of LiDAR and the role of LiDAR for studying earthquake hazards. When looking at the questions individually, it can be more fully dissected whether students learned what they were intended to in this study.

Some of the questions on the LiDAR assessment are those of terminology. For example, question 1 requires the student to answer what LiDAR stands for. Question 3 asks for the best definition of a point cloud. These questions show a significant increase in the correct response from pretest to posttest in the experimental group.

One of the key questions asked in the LiDAR video assessment is question 6: Which of the following is the **BEST** reason to use LiDAR for the study of earthquakes?

a. The data can be used to image the earth's surface at a resolution of a meter or smaller
b. The data can create 3D models of the earth's surface in real color with hillshading
c. The data can create 3D models of the earth's surface with exaggerated topography
d. The data can be used to image the earth's surface at a resolution of millimeters or smaller

The correct response to the question is response a. This response implies that the student understands the appropriate scale for studying faulting and earthquakes. Although distracter d might seem a more suitable selection, aerial LiDAR topography is not capable of these fine resolutions, and this capability would not significantly increase the study of faults and earthquakes as most features relevant to these studies are on the scale of a meter or less. The results from this question from the experimental group show an increase from 18 correct responses to 57 correct responses out of 88 students from pretest to posttest, or a 45 percent increase in the correct response. These results indicate that students understand one of the more important reasons LiDAR topography is used for the study of earthquakes, and that they understand both the scale at which aerial LiDAR is collected and the correct scale to study earthquakes and faulting.

SAF Earthquake Cycle Activity Discussion

For the San Andreas Fault Earthquake Cycle activity, students were asked 6 questions on the assessment in order to assess what they had learned. The raw gains results can be seen in Figure 12 for overall test scores. The control group actually did slightly worse from pretest to posttest, which is not expected. Although it is small, it could indicate that something confused the students in the curriculum from week 1 to week 2. The experimental group had a slight increase in score from pretest to posttest.

The results of this assessment do not show as much of an improvement on the test as was hoped for in order to show the effectiveness of the activity. However, the lack of a great increase in score could be a problem with the assessment itself. Some of the wording of the questions may not be the most concise and appropriate for testing a student's understanding of the earthquake cycle after the completion of the San Andreas Fault Earthquake Cycle activity. For example, question 3 asks the student about landscape evolution, which is a term never used in the SAF EQ cycle activity. Students actually did worse on this question from pretest to posttest in both the control and the experimental group. In fact, the only question that the students show any improvement on for the SAF EQ cycle activity assessment is question 2: How was the landscape at Wallace Creek formed?

a. It is a creek that formed by flooding events. It has a significant and strange bend in it that geologists have studied and continue to not understand.
b. It is a creek that formed after an earthquake on the San Andreas Fault. The creek was deflected by the crack in the ground from the fault.
c. It is a creek that formed before a large earthquake on the San Andreas Fault. This earthquake offset the creek in one major ground-rupturing event.
d. It is a creek that formed and has been repeatedly offset by numerous earthquakes on the San Andreas Fault.

The correct answer to this question is response d. Students showed a 37.5% increase from pretest to posttest in the experimental group and an 8.9% decrease in the control group for this question (see Table 3). This shows that students who completed the activity understand how Wallace Creek formed by earthquakes repeatedly offsetting the channel over a period of time.

Looking at the answers to the short answer questions within the lab itself showed students had a satisfactory understanding of the concepts. For example, one student writes the answer the question 6.3 within the lab, “Difference [in velocity between the two tectonic plates] is 35 mm/year which is what we calculated in question 4.2 [for slip rate]. This makes sense because the plates are moving at the same rate over time.” This key concept about comparing long-term slip rate to current strain accumulation rate is not addressed in the assessment.

Students also showed within the lab their understanding of being aware of earthquake hazards. Students were able to connect conceptually that their calculations of slip rate and measurement of small local offsets relate to the potential risk of an earthquake on the San Andreas fault today. Most students measured either ~5m or ~9m offsets southeast of the main channel, which they attributed to the 1857 earthquake. One group of students measured an 8.16 m offset and attributed it to the most recent earthquake. These students then calculated that it would take 228 years to accumulate this offset, which means they expect an earthquake in the year 2085. These same students answered question 5.4 within the lab (a question that asks if the student should be worried about earthquake preparedness based on their earthquake “forecast” date): “We should be slightly worried, but we don't need to take urgent measures now". Another group of students measured a 5.82 m offset and attributed it to the most recent earthquake and assumed an earthquake "forecast" date to be the year 2023. These students answered question 5.4 within the lab: "We should be worried because it [the next big earthquake] is in the near future". Both of these groups drew the correct conclusion based on their calculations depending on which offset channel they interpreted to be the smallest.

After re-evaluation of the assessment, it can be concluded that the assessment itself has some poor questions for assessing the student's understanding of the concepts taught in the SAF EQ cycle activity. The activity itself appears to be helping students reach the learning goals, but the results of the assessment to not completely reflect that.

CONCLUSION

The results of this study indicate that the tools developed for this study involving LiDAR topography are effective and useful tools. The video introduces LiDAR as a tool for the study of earthquakes in an effective way where students understand what LiDAR is and the importance of LiDAR for understanding earthquake hazards. The addition of LiDAR topography to the SAF earthquake cycle activity helps reduce the visual distracters to a student when viewing the topography while also increasing their ability to see more subtle features within the topography that are important for interpreting the geologic, geomorphologic, and tectonic history. Additional revisions to the SAF earthquake cycle activity and the SAF earthquake cycle assessment may make it a more effective tool for understanding the earthquake cycle and relating concepts such as elastic rebound and earthquake recurrence. This study has shown the importance of LiDAR topography for the study of earthquakes and faulting and the importance of implementing these data into Earth science educational tools.

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APPENDIX I

INSTITUTIONAL REVIEW BOARD (IRB) MATERIALS

ASU Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Ramon Arrowsmith PSF
From:	Mark Roosa, Chair Soc Beh IRB
Date:	02/16/2011
Committee Action:	**Exemption Granted**
IRB Action Date:	02/16/2011
IRB Protocol #:	1102006008
Study Title:	LiDAR Educational Materials Testing

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1) (2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

Arizona State University
Office of Research
Integrity and Assurance
660 S. Mill Avenue Suite 315
Arizona State University
Tempe AZ 85287-6111
(Mail Code 6111)
Phone: 480-965-6788
Fax: (480) 965-7772

For Office Use Only:
Date Received:
HS Number:

ARIZONA STATE UNIVERSITY
APPLICATION FOR EXEMPT RESEARCH

PROTOCOL TITLE: LiDAR Educational Materials Testing		**DATE OF REQUEST:** February 3, 2011
PRINCIPAL INVESTIGATOR: **Ramon Arrowsmith**	**DEPARTMENT/CENTER:** **School of Earth and Space Exploration**	**UNIVERSITY AFFILIATION:** ☒ Professor ☐ Associate Professor ☐ Assistant Professor ☐ Instructor ☐ Other: **Please specify**. ("Other" categories may require prior approval. Students **can not** serve as the Principal Investigator)
CAMPUS ADDRESS: (include campus mail code) **School of Earth and Space Exploration, Arizona State University, 1404**	**PHONE:** **480-236-9226** **E-MAIL:** **Ramon.arrowsmith@asu.edu**	
List all co-investigators. (Attach an extra sheet, if necessary.) A co-investigator is anyone who has responsibility for the project's design, implementation, data collection, data analysis, or who has contact with study participants.		
CO-INVESTIGATOR: **Sarah Robinson**	**DEPARTMENT/CENTER:** **School of Earth and Space Exploration**	**UNIVERSITY AFFILIATION:** ☐ Professor ☐ Associate Professor ☐ Assistant Professor ☐ Instructor ☒ Other: **Please specify**. **Graduate Research Assistant**
CAMPUS ADDRESS: (include campus mail code) **School of Earth and Space Exploration, Arizona State University, 1404**	**PHONE:** **480-965-4053** **EMAIL:** **serobins@asu.edu**	

STUDY OVERVIEW

1. Provide a **brief** description of the **background, purpose, and design** of your research. Avoid using technical terms and jargon. Be sure to list all of the **means you will use to collect data** (e.g. tests, surveys, interviews, observations, existing data). Provide a short description of the tests, instruments, or measures and **attach copies of all instruments and cover letters for review.** *If you need more than a few paragraphs, please attach additional sheets.* **FOR ALL OF THE QUESTIONS, WRITE YOUR ANSWERS ON THE APPLICATION RATHER THAN JUST SAYING SEE ATTACHED.**

Background

The use of high-resolution topography derived from Light Detection and Ranging (LiDAR) in the study of active tectonics is widespread and has become an indispensable tool to better understand earthquake hazards. For this reason and the spectacular representation of the phenomena the data provide, it is appropriate to integrate these data into the Earth science education curriculum. An educational video on LiDAR and an undergraduate-level introductory earth sciences lab that uses LiDAR data have been developed at Arizona State University in order to teach about earthquakes and faulting to undergraduate geology students using LiDAR.

Purpose

To ensure that the designed educational materials involving LiDAR help students reach the intended learning goals.

Design

The students will be given two hours to complete the following activities:

- Watch a 10-minute video called "*LiDAR: Illuminating Earthquake Hazards*". (www.youtube.com/watch?v=dwGT9B4s6Iw)
- Complete an 8-question multiple-choice quiz on the video's content.
- Complete a virtual field trip to the San Andreas Fault at Wallace Creek within Google Earth. Work in groups to answer questions about the fault and learn about earthquakes.
- Complete a 6-question multiple-choice quiz on the lab's content.

RECRUITMENT

2. Describe how you will recruit participants (attach a copy of recruitment materials). Flyers and notification will be given to students in freshman-level geoscience labs (GLG 103 and GLG 111). The students will complete the activities as an extra-credit assignment.

PROJECT FUNDING

3. How is the research project funded? (A copy of the grant application(s) must be provided prior to IRB approval. For funded projects, researchers also need to submit a copy of their human subjects training certification: http://researchintegrity.asu.edu/irb/training/)

☒ Research is **not funded** (Go to question 4)
☐ Funding decision is pending
☐ Research is **funded**

a) What is the source of funding or potential funding? (Check all that apply)

☐ Federal	☐ Private Foundation	☐ Department Funds
☐ Subcontract	☐ Fellowship	☐ Other

b) Please list the name(s) of the sponsor(s):

c) What is the Project grant number and title (for example NIH grant number)?

d) What is the ASU account number/project number?

e) Identify the institution(s) administering the grant(s):

STUDY POPULATION- If you are doing data analysis only, please write DA.

4.Indicate the **total number of participants** that you plan to include or enroll in your study. 90		Indicate the **age range** of the participants that you plan to enroll in your study	>18 (College Students)

SUPPLEMENTAL MATERIALS

5. Attach a copy of the following items as applicable to your study (Please check the ones that are attached):

- ☒ Research Methods (Research design, Data Source, Sampling strategy, etc)
- ☒ Any Letters (cover letters or information letters), Recruitment Materials, Questionnaires, etc. which will be distributed to participants
- ☐ If the research is conducted off-site, provide a permission letter where applicable

☐ If the research is part of a proposal submitted for external funding, submit a copy of the FULL proposal

Note: The information should be in sufficient detail so IRB can determine if the study can be classified as EXEMPT under Federal Regulations 45CFR46.101(b).

DATA USE

6. How will the data be used? (Check all that apply)

☐ Dissertation	☒ Publication/journal article
☒ Thesis	☐ Undergraduate honors project
☐ Results released to participants/parents	☐ Results released to employer or school
☐ Results released to agency or organization	☒ Conferences/presentations
☐Other *(please describe):*	

EXEMPT STATUS

7. Identify which of the 6 federal exemption categories below applies to your research proposal and explain

why the proposed research meets the category. Federal law 45 CFR 46.101(b) identifies the following EXEMPT categories. Check all that apply to your research and provide comments as to how your research falls into the category.

SPECIAL NOTE: The exemptions at 45 CFR 46.101(b) do not apply to research involving prisoners. The exemption at 45 CFR 46.101(b)(2), for research involving survey or interview procedures or observation of public behavior, does not apply to research with children, except for research involving observations of public behavior when the investigator(s) do not participate in the activities being observed.

☒ (7.1) Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Please provide an explanation as to how your research falls into this category: **All of the research will be conducted within a classroom setting. The only special educational instructional strategy change will be the addition of higher resolution digital elevation model imagery for teaching earthquakes than has typically been used in earth science curriculum. All quiz questions are based on science curricula content.**

☐ (7.2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; AND (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation. **Please provide an explanation as to how your research falls into this category:**
☐ (7.3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) The human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter. **Please provide an explanation as to how your research falls into this category:**
☐ (7.4) Research, involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. **Note-Please review the OHRP Guidance on Research Involving Coded Private Information or Biological Specimens: http://www.hhs.gov/ohrp/humansubjects/guidance/cdebiol.pdf** **Please provide an explanation as to how your research falls into this category:**
☐ (7.5) Research and demonstration projects which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) Public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those

programs. **(Generally does not apply to the university setting)**

☐ (7.6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.
Please provide an explanation as to how your research falls into this category:

TRAINING

8. The research team must document completion of human subjects training within the last 3 years. (Attach a copy of the human subjects training for the PI and all Co-Investigators: http://researchintegrity.asu.edu/humans.)

Please provide the date that the PI and co-investigators completed the training.
Arrowsmith--January 17, 2011; Robinson---January 25, 2011

PRINCIPAL INVESTIGATOR

In making this application, I certify that I have read and understand the ASU Procedures for the Review of Human Subjects Research and that I intend to comply with the letter and spirit of the University Policy. I may begin research when the Institutional Review Board gives notice of its approval. I must inform the IRB of ANY changes in method or procedure that may conceivably alter the exempt status of the project. **I also agree and understand that records of the participants will be kept for at least three (3) years after the completion of the research**
Name (first, middle initial, last):

Signature: Date:

FOR OFFICE USE:	This application has been reviewed by the Arizona State University IRB: ☐ Exempt Category/Categories: ☐ Approved ☐ Deferred to other review ☐ Recommended that investigator submit for expedited or Full Board review.
	Authorizing Signature: Date: **X**

COVER LETTER

LiDAR Educational Materials Testing

Date

Dear Participant:

I am a graduate student under the direction of Ramon Arrowsmith in the School of Earth and Space Exploration at Arizona State University.

I am conducting a research study to understand the effectiveness of adding high resolution topography LiDAR (Light Detection and Ranging) imagery to traditional undergraduate geoscience curriculum. I am inviting your participation, which will involve a maximum or 2 hours of your time to watch a 10-minute video on LiDAR, complete a lab that teaches about earthquakes within the computer program Google Earth, and take two short multiple-choice quizzes.

Your participation in this study is voluntary. You can skip questions if you wish. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. It will not affect your grade. You will receive extra credit for your participation in this study. You must be 18 years of age or older to participate.

The responses to the multiple-choice quizzes will aid in the development of earth science curriculum in using appropriate new imagery for visual learning. There are no foreseeable risks or discomforts to your participation.

All results will be kept confidential, and responses will be tied to an identifier rather than to a name. Each participant will be assigned a three-digit number. Your responses will be anonymous. The results of this study may be used in reports, presentations, or publications but your name will not be known.

If you have any questions concerning the research study, please contact Sarah Robinson via email at serobins@asu.edu. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

Return of the questionnaire will be considered your consent to participate.
Sincerely,

Sarah Robinson

APPENDIX II

BOHON DISTRACTER MATERIALS

Summary of Eye Distracter Study (Wendy Bohon)

Hypothesis

•LiDAR high resolution topographic data (as opposed to traditional aerial photography) allows novice learners to focus more directly on the landscape, mainly due to the removal of distractors such as land use and vegetative patterns, which allows them to make more accurate interpretations of geologic features.

Methods for Pilot Study

•Administered to 2 different Glg 103 lab classes

–7:30 AM classes (Tues 02/09/10; Wed. 02/10/10)

–Alka Tripathy as lab instructor

–same amount of background (plate tectonics, but no faulting; 2 lab class on landforms and reading topographic maps)

•1 class looked at LiDAR images, 1 class looked at Google Earth images.

•Each class divided into 2 sections

–1 section looked at Wallace Creek

–1 section looked at San Bernardino

•Each student was given an image to look at (in plastic sheeting), an image on which to annotate, and a question sheet

•10 minutes in which to answer 5 questions

•*They were given no information about the image type or location. They were given no information about faults or how to recognize them in a landscape.*

Questions

•1. To what are your eyes first drawn?

•2. What things in the image do you recognize? List them here and label them on the image.

•3. What geologic features do you see? List them here and label them on the image.

•4. What features might indicate a fault? Draw arrows to them on the image (if you see any).

•5. How much experience do you have with maps or aerial photographs?

•6. Additional Observations or comments

Conclusions

•LiDAR images allow novice learners to focus on the landscape

–40-70% increase in description of the landscape as the most prominent feature when compared with Google Earth

–20% of the WC LiDAR students said the fault was the most prominent feature!!

•Google Earth images have distractors which keep the students from focusing on the appropriate parts of the landscape

–30-40% increase in discussion of none landscape related features when using Google Earth as opposed to LiDAR

•LiDAR images increase correct identification of specific geologic features

–Up to 38% increase in correct identification of the fault when using LiDAR.

Therefore, LiDAR imagery is more appropriate for teaching novice learners because it allows students to focus directly on the topography which increases *the probability of correct landscape feature identification. This will aid in geologic interpretation and overall understanding of the landscape.*

Distracter study quiz given to both the control and the experimental group students.

Name ___________________________________

Date___________________

Please answer the questions as completely as you can. In some cases you need to write answers on both this sheet and on the image. Write your name on this sheet and on the image.

1. To what are your eyes first drawn?

2. What things in the image do you recognize? List them here and label them on the image.

3. What geologic features do you see? List them here and label them on the image.

4. What features might indicate a fault? Draw arrows to them on the image (if you see any).

5. How much experience do you have with maps? With aerial photographs?

6. Additional observations or comments…

	WC Google Earth		*WC LiDAR*		*SB Google Earth*		*SB LiDAR*
Total participants	**10**		**12**		**15**		**9**
First noticed		**First noticed**		**First noticed**		**First noticed**	
landscape	2	landscape	7	landscape	9	landscape	6
infrastructure	0	infrastructure	0	infrastructure	4	infrastructure	0
land use/vegetation	8	land use/vegetation	1	land use/vegetation	1	land use/vegetation	0
other	0	other	0	other	1	other	0
Fault	0	Fault	2	Fault	0	Fault	0
Students who recognized		*Students who recognized*		*Students who recognized*		*Students who recognized*	
Landscape features		**Landscape features**		**Landscape features**		**Landscape features**	
Mountains /ridges	3	Mountains /ridges	7	Mountains /ridges	15	Mountains /ridges	8
valleys	4	valleys	9	valleys	8	valleys	7
structures	0	structures	0	structures	11	structures	2
roads	3	roads	0	roads	10	roads	0
Fault		**Fault**		**Fault**		**Fault**	
marked the fault	2	marked the fault	7	marked the fault	0	marked the fault	1
marked a road	2	marked a road	0	marked a road	2	marked a road	0
marked a valley or ridge	6	marked a valley or ridge	5	marked a valley or ridge	3	marked a valley or ridge	8
Previous map experience		**Previous map experience**		**Previous map experience**		**Previous map experience**	
lots	0	lots	0	lots	0	lots	0
some	2	some	3	some	5	some	4
none	7	none	8	none	8	none	4

Table shows the raw data collected for the eye distracter study.

APPENDIX III

SAN ANDREAS FAULT EARTHQUAKE CYCLE EXERCISE

Identifier: ___________________________
Lab Section: _____________________
Date: ____________________________

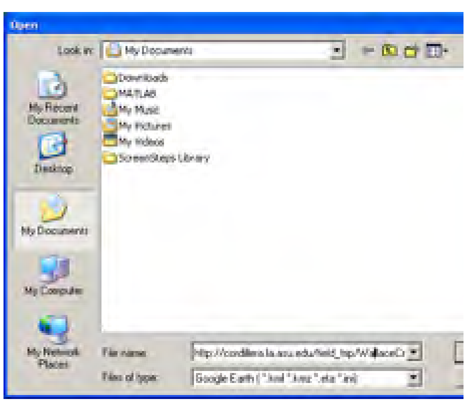
Wallace Creek Field Trip Student Guide

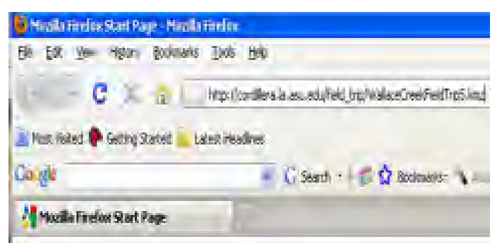
Introduction

The goal of this exercise is to give a better understanding to students about the earthquake cycle, strike-slip faulting, plate boundaries, and plate motion using Wallace Creek on the San Andreas Fault in California as an example. At the end of this exercise, students will be able to identify geomorphologic features which infer the location of a fault. They will be able to measure offset features and calculate slip rate given sediment ages. They will be able to connect their understandings about faults and earthquakes with the greater concepts of the earthquake cycle, plate boundaries, and plate motion.

Part 1: Measuring Offsets

Step 1. Open the file http://cordillera.la.asu.edu/wc/wc1.kmz in Google Earth. You can do this by either opening Google Earth and clicking File->open and copying and pasting the path above into "File Name", or you can copy and paste the path into an internet browser. You must be connected to the internet.





Option 1: In Google Earth under File -> open, Copy and paste path into File Name box and

Option 2: Copy and paste path into a browser such as Firefox.

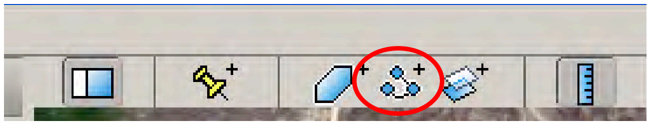
Step 2.You should automatically be zoomed in to Wallace Creek. The landscape at this site has been altered because of movement on the San Andreas Fault. Wallace Creek crosses the San Andreas Fault here. The San Andreas is a right-lateral strike-slip fault. This means if you are standing on one side of the fault trace and looking across the fault at the other side, everything on the other side of the fault is moving to your right. Click on the blue squares in order to view photos of the landscape at this site. Use the slider bar on the left to compare the LiDAR to the Google Earth imagery by changing the transparency of the LiDAR.

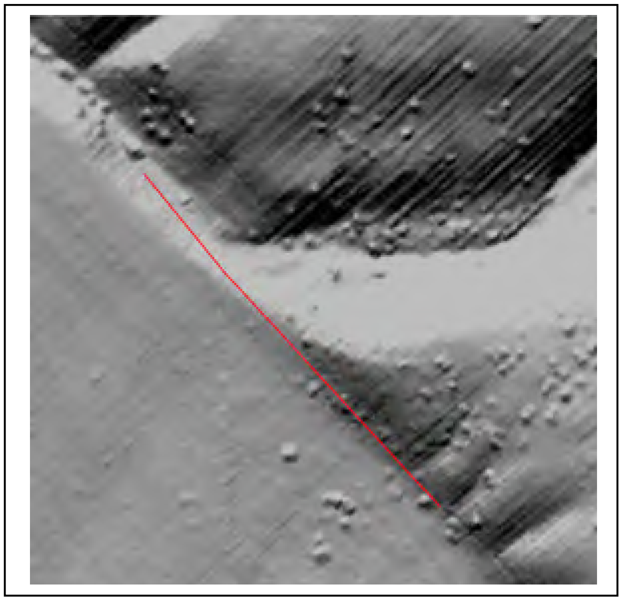
2.1 Describe the landscape here. Use the LiDAR hillshade, the satellite photography in Google Earth, and the ground photography to do this. What kind of environment is this? Describe any unusual features that you see.

2.2 How do you know that there is a fault here? Give at least two lines of evidence.

Step 3. Click on the Add Path button. In the window that pops up, put the word "Fault". Then click out a line where you think the fault is. When you are finished, press ok.

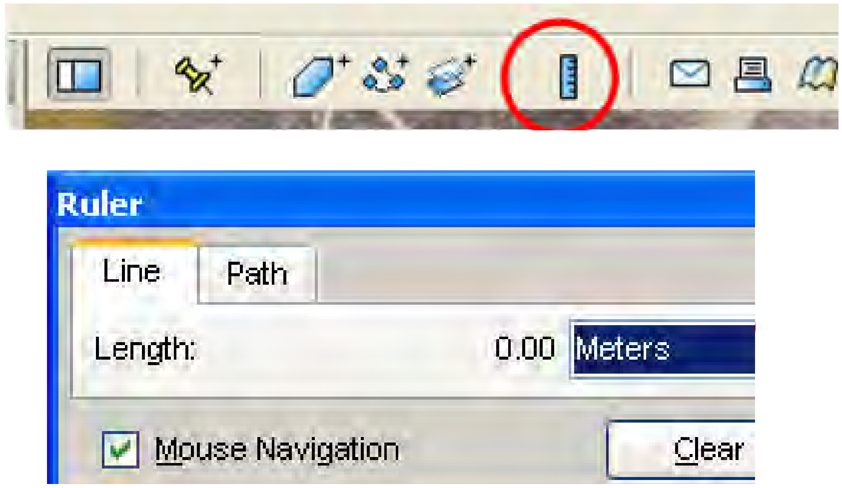
Add Path





3.1 Turn in your interpretation of where the fault is. One way to do this is to save a snapshot of the Google Earth window. Click on the Google Earth window, and press ctrl -> alt -> print screen. Then paste into Word (ctrl -> v).

Step 4. Using the measuring tool in Google Earth, Measure the horizontal offset of Wallace Creek. Make sure you are measuring in meters. A critical part of this task is to think about how the offset markers project to the fault line you have mapped. Were they straight across and perpendicular when they formed but before offset? Or was there some natural variation in their mapped shape? Measure the offset a few times in different ways (middle to middle, bank to bank, etc...).



4.1 Record five measurements of displacement here, along with the average of your measurements.

Offset amount in meters	Short description of the feature that was offset. Is this a high or low confidence measurement?

4.2 Researchers have determined via carbon dating that Wallace Creek channel is 3700 years old. What is the average rate of motion (slip rate) defined by the offset at Wallace Creek? (slip rate = displacement/time). Use the average of your displacement measurements from 4.1.

Step 5: Look elsewhere along the fault for other offset channels (especially south of the main offset at Wallace Creek).

5.1 What is the smallest offset you encounter? Remember that the local smallest offset is attributed to the last ground-rupturing earthquake. Therefore, your answer should be how much offset you would attribute to the 1857 event.

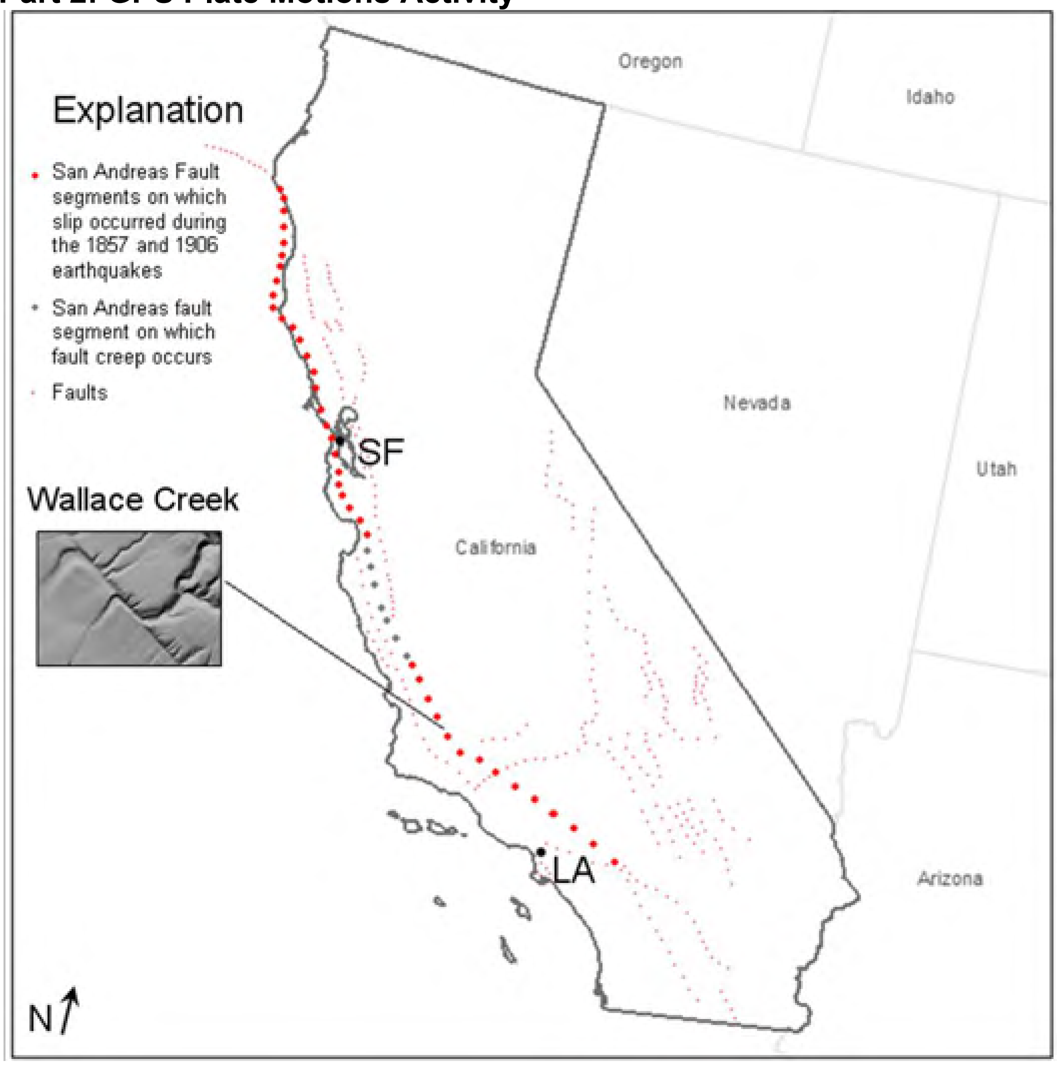
5.2 How long will it take to build up the offset that occurred in 1857 based on the average rate of motion you calculated earlier?

5.3 Based on your calculation of how long it takes to build up the offset that occurred in 1857, when would you expect the next earthquake?

5.4 Based on your earthquake "forecast" date, should we be worried about earthquake preparedness? How does your answer compare to

the answer of others? Compare your results with the results of others, and explain why you think your answer makes the most sense.

Part 2: GPS Plate Motions Activity



Wallace Creek Channel is just one of many offset features along the San Andreas Fault system in California. The San Andreas Fault is the most important part of the plate boundary where the Pacific Plate and North

American Plate meet. Certain parts of the plate boundary are always moving (creeping) at the earth's surface with the rest of the plate. Other areas are stuck, such as the section of the San Andreas Fault where Wallace Creek is found. These sections only "break" once in a while, causing an earthquake.

You just figured out how fast the two plates are moving relative to each other at a specific location along the plate boundary. The long-term slip rate is what you calculated using the geomorphology and paleoseismology at Wallace Creek. The current movement of plates can be determined by using Global Positioning System measurements of the movement of benchmarks, which tells us how much stress is building up along the San Andreas Fault waiting to be released in the next big ground-rupturing earthquake. The current strain rate on the San Andreas Fault can be calculated if we know how fast the plates are moving today relative to each other. Let us now calculate the rate of motion using GPS and compare it to the value you calculated in question 4.2 (Comparing the long-term slip rate with the current strain rate).

For GPS velocities exercise:

6.1 For the parallel motion plot: Where is steepest gradient of motion? Why do you think it is there?

6.2 For the oblique motion plot: Where is the steepest gradient of motion? What kind of faults and earthquakes do you expect here?

6.3 Looking at the parallel motion plot, what is the velocity difference between the Sierra Nevadas and Lompoc? Compare this value with the value you obtained in question 4.2. If the answers are different, explain why they are different. If they are the same, explain why they

are the same. What are these values telling us about the San Andreas Fault and about the relative motion of the Pacific and North American Plates? You can think of the strain buildup that is released in an earthquake as you snap your fingers: you hold them together and slowly load them up and then all the sudden snap.

About this Activity:
Authors: Sarah Robinson (Arizona State University)
Ramon Arrowsmith (Arizona State University)
Christopher Crosby (OpenTopography)
Robert DeGroot (Southern California Earthquake Center)

ASU ARIZONA STATE UNIVERSITY

OpenTopography

SCEC an NSF+USGS center

APPENDIX IV

EDUCATIONAL ASSESSMENT MATERIALS

Identifier: ____

Lab Section: __________________________________

Date: ____

LiDAR: Illuminating Earthquakes Assessment
http://www.youtube.com/watch?v=dwGT9B4s6Iw

1. What does LiDAR stand for?
   a. Light Detection and Radar
   b. Light Detailing and Radar
   c. Light Detection and Ranging
   d. Light Detailing and Ranging

2. What is LiDAR as it is used for the study of earthquakes?
   a. high-resolution aerial photography that produces very detailed topographic maps.
   b. a remote-sensing technology that produces very detailed topographic maps.
   c. a remote-sensing technology that uses both satellites and radar.
   d. high-resolution aerial photography that uses both satellites and radar.

3. What is the **BEST** definition of a point cloud?
   a. The collection of individual bounces of the laser during collection via aircraft
   b. The collection of data that shows topography with artificial sun shading
   c. The collection of data that shows satellite imagery and topography
   d. The collection of photographs at high resolution which represents topography in 3D

4. How is LiDAR data collected for the study of earthquakes?
   a. High-resolution photographs are taken via aircraft and GPS is used for positioning.
   b. High-resolution photographs are taken via satellite and GPS is used for positioning.
   c. Laser technology collects laser bounce returns via aircraft.
   d. Laser technology collects laser bounce returns via satellite.

5. How is LiDAR different from photography?
   a. the data use GPS which can recreate a 3D environment
   b. the data are individual points which can recreate a 3D environment

c. the data are shaded artificially by the sun which can recreate a 3D environment
d. the data are photographs taken in stereo which can recreate a 3D environment

6. Which of the following is the **BEST** reason to use LiDAR for the study of earthquakes?

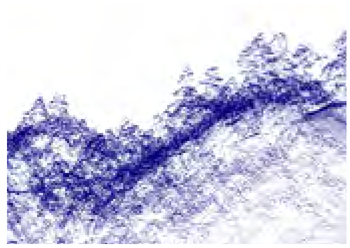
e. The data can be used to image the earth's surface at a resolution of a meter or smaller
f. The data can create 3D models of the earth's surface in real color with hillshading
g. The data can create 3D models of the earth's surface with exaggerated topography
h. The data can be used to image the earth's surface at a resolution of millimeters or smaller

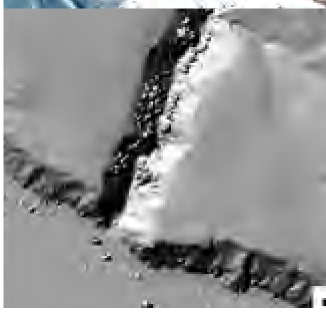
7. Which of the following is **NOT** true about LiDAR topography data?

a. LiDAR can be used to virtually remove trees and other objects.
b. LiDAR can represent the earth's surface in 3D at a high resolution
c. LiDAR can represent the earth's surface as a photograph in color
d. LiDAR can be used to virtually back-slip faults to see how the landscape looked before an earthquake
e. LiDAR can be used to virtually forward-slip faults to see how the landscape could look after an earthquake

8. Match the images below with the appropriate letter. Write your choice underneath the image. Not all choices will be used.

a. hillshaded digital elevation model (DEM)
b. photograph
c. point cloud
d. geologic map
e. topographic contour map





Identifier: ____

Lab Section: __________________________________

Date: ____

San Andreas fault earthquake cycle Activity Assessment

1. What is a fault?
    a. A lithospheric plate which moves with respect to any other tectonic plate
    b. A displaced topographic feature along a plate boundary
    c. A crack, fracture, or hole in the earth's crust
    d. The point on the surface of the earth directly above where an earthquake originates
    e. The break in a rock along which one side of the rock has moved with respect to the other side

2. How was the landscape at Wallace Creek formed?
    a. It is a creek that formed by flooding events. It has a significant and strange bend in it that geologists have studied and continue to not understand.
    b. It is a creek that formed after an earthquake on the San Andreas Fault. The creek was deflected by the crack in the ground from the fault.
    c. It is a creek that formed before a large earthquake on the San Andreas Fault. This earthquake offset the creek in one major ground-rupturing event.
    d. It is a creek that formed and has been repeatedly offset by numerous earthquakes on the San Andreas Fault.

3. Choose the **BEST** statement describing landscape evolution:
    a. The landscape changes by magmatic fluctuations and radioactivity
    b. The landscape changes by erosion via water and air which breaks it down
    c. The landscape changes by tectonic processes which uplift and form new crust
    d. a and b
    e. b and c
    f. a and c
    g. a, b, and c

4. What does a GPS station record?
    a. The movement of the earth at the station's location
    b. Earthquakes at the station's location
    c. Long-term slip rate on faults over many years
    d. a and b
    e. b and c
    f. a and c
    g. a, b, and c

5. Which statement is **NOT** true about the San Andreas fault and how it relates to plate boundaries?

a. The San Andreas is a fault that is related to plate motion
b. The San Andreas is a fault that has resulted from stress and movement at the Pacific Plate and North American Plate boundary.
c. The San Andreas is part of the plate boundary between the Pacific and North American plates
d. The San Andreas fault is moving at the surface at the current strain accumulation rate
e. The San Andreas fault is located in California

6. The earthquake cycle is

a. steady strain accumulation due to plate tectonics and episodic strain release in the earthquake
b. repeating earthquakes
c. the offset of stream channels along faults by earthquakes
d. the offset of geomorphologic features along faults by earthquakes
e. a and b
f. a, b, and c
g. a, b, and d
h. a, b, c, and d

APPENDIX V

DETAILED ASSESSMENT RESULTS

Table shows number of correct responses for the SAF EQ Cycle Assessment, out of a possible 6 correct responses.

Number of Correct Responses for SAF EQ Cycle Assessment

Control Group Identifier	Control Group Pretest	Control Group Posttest	Experimental Group Identifier	Experimental Group Pretest	Experimental Group Posttest
603	2	3	201	2	4
604	0	2	202	3	4
605	1	1	203	2	4
607	1	2	204	1	3
609	1	2	205	0	1
610	1	1	206	2	3
611	3	2	207	1	2
612	0	0	208	1	2
613	3	4	209	3	2
614	3	3	210	1	2
615	2	2	211	0	3
616	2	2	212	0	1
617	2	1	213	5	3
620	3	3	214	1	2
621	2	4	215	4	2
702	2	0	217	1	2
704	1	2	218	2	2
709	1	0	219	4	2
711	2	1	301	2	2
712	2	1	302	3	2
713	0	3	303	1	1
714	1	0	304	3	5
715	1	1	305	1	1
716	2	1	306	1	1
717	3	0	307	2	1
718	1	1	308	2	1
720	2	0	310	2	2
721	3	2	311	2	1
723	1	0	312	1	3
724	4	2	314	3	4
725	2	4	315	2	1

901	3	3
902	2	0
903	4	2
905	2	0
907	2	2
909	4	0
910	0	1
911	0	1
915	1	2
916	1	0
917	3	1
919	3	2
920	0	1
923	2	2

316	2	2
317	2	3
318	2	3
320	3	3
321	2	2
323	2	1
324	1	2
326	2	3
327	3	4
328	3	3
329	3	3
401	0	1
402	1	3
403	3	1
404	2	0
407	3	3
409	1	2
410	3	1
412	2	3
413	4	1
414	3	4
415	3	4
416	4	4
417	3	2
418	2	1
420	4	2
422	2	3
424	2	5
425	1	4
430	1	2
432	4	2
501	3	3
502	3	5
503	4	3
504	3	3
506	3	2
507	2	2
508	1	2
510	3	1
511	2	2
512	1	1
513	3	4
514	3	2
515	2	2

			516	1	2
			518	1	2
			519	3	3
			521	3	5
			522	2	2
			523	4	1
			524	1	2
			525	3	2
			526	2	1
			527	2	1
			528	1	0
			529	3	2
			530	1	3

Table shows number of correct responses for the LiDAR Video assessment based on control and experimental group identifier numbers given each individual student. Correct responses are out of a possible 10 correct.

Number of Correct Responses for "LiDAR: Illuminating Earthquake Hazards" Video Assessment

Control Group Identifier	Control Group Pretest	Control Group Posttest	Experimental Group Identifier	Experimental Group Pretest	Experimental Group Posttest
603	4	3	201	4	9
604	2	1	202	2	6
605	3	3	203	3	6
607	4	4	204	4	5
609	2	3	205	3	6
610	2	1	206	4	8
611	3	3	207	3	4
612	2	3	208	6	7
613	4	4	209	2	5
614	3	4	210	1	6
615	1	3	211	1	5
616	2	2	212	1	5
617	1	3	213	2	6
620	1	5	214	4	4
621	3	3	215	1	1
702	2	3	217	3	8
704	4	5	218	1	2
709	1	0	219	3	9
711	6	3	301	4	4
712	5	3	302	6	6
713	4	4	303	4	7
714	4	5	304	4	5

715	3	5	305	1	4
716	2	1	306	1	4
717	3	2	307	3	2
718	3	3	308	5	5
720	4	3	310	4	9
721	1	3	311	6	8
723	4	2	312	4	4
724	4	4	314	4	8
725	3	4	315	5	5
901	6	1	316	5	9
902	1	6	317	2	5
903	3	5	318	4	6
905	4	6	320	4	8
907	2	2	321	1	9
909	4	4	323	3	3
910	5	6	324	5	6
911	7	3	326	3	8
915	3	4	327	4	4
916	4	2	328	2	7
917	5	5	329	2	7
919	4	4	401	5	6
920	5	1	402	3	7
923	5	4	403	2	8
			404	7	5
			407	0	5
			409	4	5
			410	6	6
			412	6	7
			413	2	5
			414	1	8
			415	5	8
			416	2	6
			417	2	5
			418	0	9
			420	4	9
			422	6	4
			424	4	7
			425	3	5

430	5	9
432	2	4
501	2	8
502	3	7
503	4	7
504	4	5
506	1	8
507	3	6
508	5	8
510	6	7
511	3	4
512	4	5
513	7	9
514	4	8
515	4	6
516	4	9
518	4	4
519	1	8
521	4	9
522	4	7
523	4	7
524	0	2
525	2	4
526	5	7
527	3	8
528	5	6
529	2	6
530	3	4

Table shows dates of experimentation and teaching assistant/lab sections for testing.

IDs	Lab Section	Date of Pretest	Date of Posttest	Experimental or Control	TA
200	Monday 7:30a	3/28/11	4/4/11	E	Scott Robinson
300	Monday 4:10p	3/28/11	4/4/11	E	Scott Robinson
400	Tuesday 10:30a	3/29/11	4/5/11	E	Scott Robinson
500	Tuesday 4:30p	3/28/11	4/5/11	E	Scott Robinson
600	Wednesday 9:40a	3/30/11	4/6/11	C	Danny Foley
700	Wednesday 11:50a	3/30/11	4/6/11	C	Danny Foley
800	Thursday	3/31/11	N/A	C	Danny Foley
900	Friday	4/1/11	4/8/11	C	Danny Foley

Table shows gain summary. The raw gains for each individual subject is shown for pretest and posttest of both of the given assessments.

Subject (ID)	Group	Pretest (LV)	Posttest (LV)	Gain (LV)	Pretest (SAF)	Posttest (SAF)	Gain (SAF)
603	Control	4	3	-1	2	3	1
604	Control	2	1	-1	0	2	2
605	Control	3	3	0	1	1	0
607	Control	4	4	0	1	2	1
609	Control	2	3	1	1	2	1
610	Control	2	1	-1	1	1	0
611	Control	3	3	0	3	2	-1
612	Control	2	3	1	0	0	0
613	Control	4	4	0	3	4	1
614	Control	3	4	1	3	3	0
615	Control	1	3	2	2	2	0
616	Control	2	2	0	2	2	0
617	Control	1	3	2	2	1	-1
620	Control	1	5	4	3	3	0
621	Control	3	3	0	2	4	2
702	Control	2	3	1	2	0	-2
704	Control	4	5	1	1	2	1
709	Control	1	0	-1	1	0	-1
711	Control	6	3	-3	2	1	-1
712	Control	5	3	-2	2	1	-1
713	Control	4	4	0	0	3	3
714	Control	4	5	1	1	0	-1
715	Control	3	5	2	1	1	0
716	Control	2	1	-1	2	1	-1
717	Control	3	2	-1	3	0	-3
718	Control	3	3	0	1	1	0
720	Control	4	3	-1	2	0	-2
721	Control	1	3	2	3	2	-1
723	Control	4	2	-2	1	0	-1
724	Control	4	4	0	4	2	-2
725	Control	3	4	1	2	4	2
901	Control	6	1	-5	3	3	0
902	Control	1	6	5	2	0	-2
903	Control	3	5	2	4	2	-2
905	Control	4	6	2	2	0	-2
907	Control	2	2	0	2	2	0
909	Control	4	4	0	4	0	-4
910	Control	5	6	1	0	1	1
911	Control	7	3	-4	0	1	1
915	Control	3	4	1	1	2	1
916	Control	4	2	-2	1	0	-1

917	Control	5	5	0	3	1	-2
919	Control	4	4	0	3	2	-1
920	Control	5	1	-4	0	1	1
923	Control	5	4	-1	2	2	0
201	Experimental	4	9	5	2	4	2
202	Experimental	2	6	4	3	4	1
203	Experimental	3	6	3	2	4	2
204	Experimental	4	5	1	1	3	2
205	Experimental	3	6	3	0	1	1
206	Experimental	4	8	4	2	3	1
207	Experimental	3	4	1	1	2	1
208	Experimental	6	7	1	1	2	1
209	Experimental	2	5	3	3	2	-1
210	Experimental	1	6	5	1	2	1
211	Experimental	1	5	4	0	3	3
212	Experimental	1	5	4	0	1	1
213	Experimental	2	6	4	5	3	-2
214	Experimental	4	4	0	1	2	1
215	Experimental	1	1	0	4	2	-2
217	Experimental	3	8	5	1	2	1
218	Experimental	1	2	1	2	2	0
219	Experimental	3	9	6	4	2	-2
301	Experimental	4	4	0	2	2	0
302	Experimental	6	6	0	3	2	-1
303	Experimental	4	7	3	1	1	0
304	Experimental	4	5	1	3	5	2
305	Experimental	1	4	3	1	1	0
306	Experimental	1	4	3	1	1	0
307	Experimental	3	2	-1	2	1	-1
308	Experimental	5	5	0	2	1	-1
310	Experimental	4	9	5	2	2	0
311	Experimental	6	8	2	2	1	-1
312	Experimental	4	4	0	1	3	2
314	Experimental	4	8	4	3	4	1
315	Experimental	5	5	0	2	1	-1
316	Experimental	5	9	4	2	2	0
317	Experimental	2	5	3	2	3	1
318	Experimental	4	6	2	2	3	1
320	Experimental	4	8	4	3	3	0
321	Experimental	1	9	8	2	2	0
323	Experimental	3	3	0	2	1	-1
324	Experimental	5	6	1	1	2	1
326	Experimental	3	8	5	2	3	1
327	Experimental	4	4	0	3	4	1

328	Experimental	2	7	5	3	3	0
329	Experimental	2	7	5	3	3	0
401	Experimental	5	6	1	0	1	1
402	Experimental	3	7	4	1	3	2
403	Experimental	2	8	6	3	1	-2
404	Experimental	7	5	-2	2	0	-2
407	Experimental	0	5	5	3	3	0
409	Experimental	4	5	1	1	2	1
410	Experimental	6	6	0	3	1	-2
412	Experimental	6	7	1	2	3	1
413	Experimental	2	5	3	4	1	-3
414	Experimental	1	8	7	3	4	1
415	Experimental	5	8	3	3	4	1
416	Experimental	2	6	4	4	4	0
417	Experimental	2	5	3	3	2	-1
418	Experimental	0	9	9	2	1	-1
420	Experimental	4	9	5	4	2	-2
422	Experimental	6	4	-2	2	3	1
424	Experimental	4	7	3	2	5	3
425	Experimental	3	5	2	1	4	3
430	Experimental	5	9	4	1	2	1
432	Experimental	2	4	2	4	2	-2
501	Experimental	2	8	6	3	3	0
502	Experimental	3	7	4	3	5	2
503	Experimental	4	7	3	4	3	-1
504	Experimental	4	5	1	3	3	0
506	Experimental	1	8	7	3	2	-1
507	Experimental	3	6	3	2	2	0
508	Experimental	5	8	3	1	2	1
510	Experimental	6	7	1	3	1	-2
511	Experimental	3	4	1	2	2	0
512	Experimental	4	5	1	1	1	0
513	Experimental	7	9	2	3	4	1
514	Experimental	4	8	4	3	2	-1
515	Experimental	4	6	2	2	2	0
516	Experimental	4	9	5	1	2	1
518	Experimental	4	4	0	1	2	1
519	Experimental	1	8	7	3	3	0
521	Experimental	4	9	5	3	5	2
522	Experimental	4	7	3	2	2	0
523	Experimental	4	7	3	4	1	-3
524	Experimental	0	2	2	1	2	1
525	Experimental	2	4	2	3	2	-1
526	Experimental	5	7	2	2	1	-1
527	Experimental	3	8	5	2	1	-1
528	Experimental	5	6	1	1	0	-1
529	Experimental	2	6	4	3	2	-1
530	Experimental	3	4	1	1	3	2

Table shows raw average gains

control group average gain (LV)	0
experimental group average gain (LV)	2.8
control group average gain (SAF)	-0.3
experimental group average gain (SAF)	0.15

Table shows number of students that received x number of correct responses for the San Andreas Fault Earthquake Cycle activity assessment and the LiDAR Video assessment.

SAF EQ Assessment correct response	**Control Group Pretest**	**Control Group Posttest**	**Experimental Group Pretest**	**Experimental Group Posttest**
0 correct	6	11	4	2
1 correct	12	12	22	20
2 correct	15	14	27	32
3 correct	9	5	26	20
4 correct	3	3	8	10
5 correct	0	0	1	4
6 correct	0	0	0	0

LiDAR Video Assessment correct response	**Control Group Pretest**	**Control Group Posttest**	**Experimental Group Pretest**	**Experimental Group Posttest**
0 correct	0	1	3	0
1 correct	6	5	11	1
2 correct	8	5	14	3
3 correct	10	15	15	1
4 correct	13	10	26	13
5 correct	5	6	10	16
6 correct	2	3	7	15
7 correct	1	0	2	13
8 correct	0	0	0	15
9 correct	0	0	0	11
10	0	0	0	0