The Effect of Interactive Computer Animations on Introductory Geology Students' Conceptual Understanding of Mountain Building Processes

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THE EFFECT OF INTERACTIVE COMPUTER ANIMATIONS ON INTRODUCTORY GEOLOGY STUDENTS’ CONCEPTUAL UNDERSTANDING OF MOUNTAIN BUILDING PROCESSES

BY

Michelle Malone

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

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MASTER'S THESIS

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Date: 5/16/18
THE EFFECT OF INTERACTIVE COMPUTER ANIMATIONS ON INTRODUCTORY GEOLOGY STUDENTS' CONCEPTUAL UNDERSTANDING OF MOUNTAIN BUILDING PROCESSES

A Thesis
Presented to
The Faculty of
Western Washington University

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

by
Michelle Malone
July 2005
ABSTRACT

The use of computer animations to help students visualize processes they cannot observe directly is becoming more widespread in geoscience classrooms, but few studies have formally assessed the effectiveness of these technological aids as learning tools. This research project evaluated the effect of interactive computer animations on undergraduate introductory geology students' understanding of mountain building processes. The study focused on introductory geology students' misconceptions about the formation of mountains. With the assistance of Flash programmers, an online interactive web activity was developed. This tool was aimed at reducing misconceptions, and included activities related to plate tectonics, isostasy, erosion and rock exhumation. Although these geologic processes are complex, each was simplified in the learning activity for programming purposes and to be appropriate for introductory geology students. The interactive web activity contained four animation activities in which students could manipulate variables or progress through a series of still or animated images and text. It employed an open-ended navigation style so each student could interact with the animations and text in the way that best suited his or her learning style. A contrast group viewed a static web page containing graphics and text. Outcomes were evaluated with a pre-assessment and two post-assessments to compare students' understanding of the mountain building processes before and after using the static or interactive web activity. The questions and distracters on the assessments were based on misconceptions in the literature and pilot studies. Essay and multiple-choice assessments were given to different subgroups of students within the Static and Interactive groups.

Both groups showed a positive gain on the post-tests. On the multiple-choice assessment, the Static group had significantly higher post-test scores than the Interactive group, and there was no difference between the groups on essay post-tests. Students in both groups displayed a number of common misconceptions in their written responses and selection of multiple-choice distracters. Most of those misconceptions decreased in frequency on the post-tests. The Static
group decreased the percentage of incorrect multiple-choice responses more than the Interactive group, but the Interactive group had the greater reduction in the average number of misconceptions written on essay post-tests.

Self-reported student confidence levels of their understanding about mountain building-related subtopics increased for most subjects, with the Static group's ratings increasing more than the Interactive group's ratings. Student written evaluative comments indicated that the interactive web activity had advantages over the static web activity. Although students in both contrast groups noted problems with the length of the assessments and their lack of motivation to participate, the Static group commented that there was little difference between the static web page and reading a textbook. However, students using the interactive Flash site indicated that they enjoyed the activities where they actively manipulated variables.

The results of this study are not consistent with others that show computer animations to be valuable tools in increasing student understanding. Several factors, including limitations in the design of the multimedia learning object and validity concerns with the assessments, may have affected the results of this study. With refinement, the learning object could be a useful tool to distribute to the geoscience education community in addition to a well-documented collection of student misconceptions about mountain building processes.
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Jimm Myers at University of Wyoming provided the inspiration for this project and invited me to Wyoming to teach me about developing Flash educational objects. Adam Barrus, Shad Malone, and especially Travis Chun and Karl Schoessler provided graphic design and programming expertise that made the development of the interactive web activity possible. My husband, Shad, also deserves thanks for his patience as well as emotional and technical support throughout this research process.
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INTRODUCTION

Introductory geology students often have difficulty learning about concepts and processes that they cannot observe directly (Dove, 1998). This research study was designed to assess the effectiveness of interactive computer animations to increase students' conceptual understanding of the geologic processes that build and shape mountains. Because of the scarcity of Earth Science diagnostic assessments, one of the goals of this project was to develop a rigorous assessment tool that can be used by Earth science instructors to assess their students' understanding of processes related to mountain building. Additional objectives of this thesis were to develop an interactive learning object related to mountain building processes to distribute to the geoscience community and to assess the effectiveness of the interactive web activity in reducing misconceptions about mountain building processes compared to a static web page with text and figures.

Geoscience education research is discipline-based research, meaning that the researcher is knowledgeable about educational research methods and the science of the discipline. In order for claims we make about effective teaching methods to be valid, we must conduct scientific evaluation of those methods by controlling variables and statistically analyzing data. Physics educators have been improving curricula and students' understanding of physics concepts via discipline-based research for 30 years (McDermott and Redish, 1999). The community of discipline-based researchers in the geosciences is a small, but it is a growing field of increasing importance. Scientifically evaluating our teaching methods is beneficial to our students, who learn most effectively from meaningful, research-based curricula. Publishing the results from our research is useful to the entire education community, allowing educators to examine rigorous studies rather than anecdotal evidence of "what seems to work" in classrooms (Libarkin, 2001).

Getting beyond "what seems to work" seems especially important when evaluating the effectiveness of instructional technology. Increasing quantities of money and resources are being
spent on educational technology, but it is rarely evaluated for effectiveness. The advances in graphics, for example, are driven more by technology's ability to make them more attractive rather than research about their utility (Tversky et al., 2002). The same seems to be true for educational animations. It is rare to find an introductory Geology textbook being marketed today without a packaged CD-ROM or web site containing computer animations. Is the money and time spent producing and distributing these animations to students and instructors worth it in terms of increasing conceptual understanding?

Mountain building processes, like many processes that are taught in science, are difficult for students to visualize. In biology and chemistry, many processes occur on a microscopic or atomic scale. Some laws and processes taught in physics are so abstract and complicated that they are often presented with simplifying assumptions such as a frictionless universe. Earth science contains many concepts, such as plate motion and mountain building, which occur over millions of years or in places deep within Earth. As we learn through our senses and experiences, we develop and organize tangible concepts such as "cat" or "house", but concepts such as compounds or electrons or plate motions cannot be understood in the same sensory way (Johnstone, 1991).

Traditionally, introductory science courses at the college level have been taught using presentations of facts and theories and through problem solving. Equations are solved to develop "understanding" of physical and chemical processes or chemical equations are balanced to show reactions. Studies show that students can solve algorithmic or symbolic problems without successfully answering conceptual questions of the processes involved (e.g. Nurrenbern and Pickering, 1987; Sawrey, 1990; Gabel and Bunce, 1991; Burke et al., 1998). Laboratory experiments and lecture demonstrations are designed to help students understand concepts and processes, but students' observations often do not meet the level of conceptual understanding intended by the instructor. Students can observe changes without understanding why or how they
are occurring (Johnstone, 1991). This may be because very little inductive thinking is involved with the way introductory college-level science courses are commonly taught. Instructors tend to introduce fully-formed generalizations to students rather than actively involving students in the process of abstraction and generalization (McDermott, 1993). Moreover, the perceptions of students in introductory science classes, very few of whom will major in the sciences, may be very different than those of the instructor (McDermott, 1993).

Because of the abstract nature of many Earth science concepts, students often develop misconceptions, also referred to as alternate frameworks or alternate conceptions, which are different than the scientifically accepted explanation for the way those processes operate. A great deal of research, to be summarized in subsequent sections, has been conducted over the last three decades on misconceptions in the sciences. Common misconceptions identified in the literature can be a useful starting place for teachers to help their students overcome their own alternative conceptions (Schoon, 1995).

Diagnostic assessments have been developed by several authors to assess student understanding and identify misconceptions related to several science subjects, including the nature of science (Lederman et al, 2002), mechanics (Hestenes et al, 1992), diffusion and osmosis (Odom and Barrow, 1995), covalent bonding (Peterson et al., 1986), photosynthesis and respiration (Haslam and Treagust, 1987) and natural selection (Anderson et al., 2002). Several of these diagnostic assessments are two-tiered multiple choice tests based on an assessment method developed by Treagust (1988). It is important to note that formal assessment of key concepts have been developed in the life and physical sciences, but a review of the literature revealed no published examples of assessments designed to diagnose key Earth science concepts. The Geoscience Concept Inventory (GCI), consisting of diagnostic items related to plate tectonics, geologic time and Earth’s interior developed and validated by Libarkin and Anderson (2005) is currently in press.
Teaching Mountain Building Processes

This study focuses on students’ conceptual understanding of mountain building and related processes for several reasons. Mountain building, erosion, and geologic time have been identified by the National Research Council (NRC) and American Association for the Advancement of Sciences (AAAS) as concepts important for students and adults to understand in order to be scientifically literate. These concepts are also consistent with the WWU geology faculty’s goals and philosophies for Geology 101. The geographic setting of Western Washington University lies between two mountain belts, so the processes of mountain formation and differentiation between volcanic peaks and other mountain ranges are especially locally relevant. While the relationships between mountain formation and erosion processes are important for understanding how the Earth changes over time, they can be difficult concepts for students to grasp. Because of the slow rate (millimeters per year) of mountain formation processes, they are generally unobservable in a human lifetime, making them abstract concepts for students to understand. Misconceptions about these processes have been documented in the literature (Table 1) and are prevalent in our own introductory geology students at WWU.

National Standards

One way to ensure that animations are addressing meaningful learning goals is to align the lesson objectives with national standards and benchmarks. Concepts related to mountain building have been included as important science learning goals in the National Science Education Standards (NRC, 1996), and the Benchmarks for Science Literacy (AAAS, 1993). These documents outline benchmarks for given grade levels in K-12 education with the ultimate goal of achieving science literacy for all children and adults. Until the standards are achieved in K-12 grade levels, they are also appropriate learning goals for post-secondary education. According to the NRC (1996), science literacy is a necessity in our society so that all people can make informed decisions and develop creative thinking, reasoning, and decision-making skills.
that are important in today’s job market and society. Our future depends on the wisdom with which we use science and technology, which in turn, depends on the education we receive (AAAS, 1993). An understanding of the forces that shape the Earth is just one of the many concepts people should understand to attain scientific literacy.

The standards which formed the basis for the learning goals for this project address the relationship between plate tectonics and mountain building processes, the geologic time scale over which change occurs, and interrelationships in the Earth System. Some of these specific benchmarks and standards for grades 6-8 and 9-12 include:

Lithospheric plates on the scales of continents and oceans constantly move at rates of centimeters per year in response to movements in the mantle. Major geological events, such as earthquakes, volcanic eruptions, and mountain building, result from these plate motions (NRC, 1996).

Landforms are the result of a combination of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruption, and deposition of sediment, while destructive forces include weathering and erosion (NRC, 1996).

Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years (NRC, 1996).

Where the crustal plates collide, they may scrape sideways, or compress the land into folds and eventually become mountain ranges (such as the Rocky Mountains and the Himalayas); or one plate may slide under the other and sink deeper into the earth. Along the boundaries between colliding plates, earthquakes shake and break the surface, and volcanic eruptions release molten rock from below, also building up mountains (Rutherford and Ahlgren, 1990).

Current Teaching Practice at WWU

To gain a more local perspective, six WWU Geology 101 professors were interviewed about their goals for the course and their coverage of mountain building processes. At WWU, Geology 101 serves as a general university science course that has enrollment of approximately 1400 students per year, primarily non-science majors. The course includes three hours of lecture and two hours of a laboratory section each week. The goals expressed by the faculty for Geology
101 students closely mirrored the criteria for science literacy outlined in the national standards and benchmarks documents discussed above. Their goals are that students understand how Earth and its subsystems work, including the relationships between chemical and physical processes, and also that students be able to recognize and appreciate Earth materials and processes. In addition, the faculty stated that concepts taught in introductory geology should be made relevant to students' lives. Students should gain an appreciation for science, learn how science is conducted, and build enough knowledge to become practical homebuyers and educated voters. The faculty members use a variety of approaches to teaching about mountain building processes. Some devote an entire lecture specifically to the topic, while others spread related concepts among many lectures throughout the quarter with or without addressing mountain building specifically.

**Orogenic Processes**

The following section has been included to explain current research and scientific understanding of orogenic processes that deform Earth's crust and change the surface landscape during the formation of mountains. Much of the information herein is beyond the scope of a typical introductory geology curriculum, but was used as background to make decisions such as erosion and uplift rates and how to represent isostatic and exhumation processes in the animated learning object. A complete conceptual understanding of mountain building requires an understanding of all the interconnected processes in the Earth system. The animations and assessments in this thesis are not intended to address all of these interactions, but rather to introduce the idea of interactions in the Earth system and concentrate on key concepts related to tectonics, isostasy, erosion, exhumation and changes over time.

A complex relationship exists between tectonic processes, climate, relief, erosion rates and uplift of mountain ranges. As the study of mountain building has progressed, it has been
recognized that the role of tectonic processes such as horizontal shortening and vertical thickening of continental crust is only part of the elaborate feedback cycles that create mountains (Keller and Pinter, 2002) (Fig. 1). Climate influences precipitation, mass wasting, surface runoff and glaciation, all of which are important erosive agents. Increased precipitation or glaciation will increase erosion rates, which in turn will increase uplift rates (Willett et al., 2001). Isostatic uplift increases the elevation of mountain ranges, which affect climate locally and perhaps globally creating a feedback mechanism (Pinter and Brandon, 1997).

Previous misconceptions research revealed naïve ideas about how mountains form such as building up from a pile of wind-blown dirt and rocks or the idea that mountains have always existed in the locations where they are seen today. A few of the introductory geology students at WWU that were surveyed before the main study had these ideas as well, but most were aware that plate tectonics were involved (Tables 2 and 3). Therefore the discussion of orogenic processes begins with the influence of tectonic processes rather than historical beliefs that predate the theory of plate tectonics. This section concentrates on the roles of tectonic processes, isostasy and erosion on mountain building and rock exhumation, as those are main learning objectives in the mountain building web activities.

**Tectonic Processes**

Since the development of the theory of plate tectonics, mountain building has been primarily attributed to the tectonic processes associated with plate movement. Mountains form at convergent plate boundaries where two continental plates collide or where oceanic crust and continental crust interact, causing deformation, thickening and uplift of the overriding continental crust. Denser oceanic crust subducts under more buoyant continental crust or younger oceanic crust as plates converge, forming a subduction zone. Volcanic island arcs form at oceanic-oceanic subduction zones (Fig. 2A), which can later collide into continental margins and form mountains (Fig. 2B). Subduction of oceanic crust beneath continental crust, which may include
accreted terranes such as island arcs, results in orogeny in which volcanism and crustal shortening build mountains along the continental margin (Fig. 2C). As the continents continue to converge, they will eventually collide resulting in collisional mountain ranges such as the Himalayan range (Fig. 2E). Over millions of years, the mountain range erodes down to form a tectonically stable craton (Fig. 2E).

Four mechanisms for mountain building at oceanic-continental subduction margins have been proposed. First, tectonic shortening due to compressive stress of converging plates causes horizontal shortening and vertical thickening of the crust. Fold and thrust belts form near the surface while weaker rocks at depth undergo ductile deformation. Tectonic shortening is the primary mechanism for building mountains at collisional boundaries such as the Himalaya and the European Alps, and also plays a role in orogeny at subduction margins.

The second mechanism contributing to mountain building is magmatic addition via pluton emplacement and surface volcanism. Magmatic addition was once assumed to be the primary mechanism for mountain building in subduction margins. Recent research has shown a significant contribution to crustal thickening by tectonic shortening in the Andes (Sheffels, 1990; Haschke and Günther, 2003) (Fig. 3). Combining detailed mapping of magmatic rocks in the Chilean Andes with rare earth element analyses, balanced structural across-arc cross-sections and kinematic models, Haschke and Günther (2003) estimated that the ratio of crustal thickening by tectonic shortening compared to magmatic addition was 2:1. Underplating, the offscraping and underthrusting of material from the subducting oceanic plate beneath the orogenic wedge, and surface volcanism had relatively small contributions according to their models.

The third and fourth mechanisms for mountain formation, frontal accretion and underplating, are not emphasized in the web activities, but may have been discussed in lectures and influenced student responses on the assessments. Frontal accretion of marine sediments scraped from the subducting plate onto the overriding continental crust forms an accretionary...
wedge. Material is added to the outboard edge of the continent while shortening and thickening the accretionary wedge, which can grow large enough to form mountains such as the Olympic Mountains and Coast Ranges (Pazzaglia and Brandon, 2001, Willett et al., 2001) (Fig. 4A). Underplating elevates continental crust as new material from the subducting oceanic crust is added to the base of the accretionary wedge on the continent. Underplating causes vertical movement of overlying rocks as new material is added below and has no horizontal shortening component (Willett et al. 2001) (Fig. 4B). Underplating is assumed to work in combination with other orogenic processes to form mountain ranges (Willett et al. 2001; Haschke and Günther, 2003).

Regardless of the relative contribution of each of these mechanisms, tectonic processes as a whole are very important in deforming continental crust at collisional and subduction margins. However, the relative importance of tectonic processes in building mountains may be small compared to erosion and isostatic response (Pinter and Brandon, 1997).

Isostasy and the Structural Support of Mountains

Isostasy is the primary mechanism of mountain range support; the weight of Earth’s crust is supported by the fluid-like properties of the mantle (Keller and Pinter, 2002). The elevation of the crust is controlled by the balance of gravitational and buoyancy forces acting on the crust, and is thus affected by the overall thickness of the crust and the relative density of the crust and the mantle. Continental crust is 80-85% as dense as the mantle beneath it, allowing it to “float” buoyantly on the mantle much as the tip of an iceberg floats above the level of the water (glacial ice has approximately 90% the density of water).

Two models were proposed in 1855 to explain isostatic support of mountains. According to the Airy isostasy model, mountain ranges are supported by a buoyant crustal “root” beneath the range that penetrates into the mantle beyond the average thickness of the continental crust (Pinter and Brandon, 1997) (Fig. 5A). Although we cannot see thickened crustal roots below Earth’s
surface, geophysical evidence such as gravity anomalies and seismic reflection studies indicate the presence of low-density material below mountain ranges. The Pratt model proposes that high mountains are supported by lower density material below as opposed to a thicker root of the same average crustal density (Fig. 5B). Heating the crust causes its density to decrease which can cause regional uplift, consistent with Pratt’s isostasy hypothesis (Keller and Pinter, 2002).

Isostasy does not act alone in supporting uplifted topography; the additional mass of mountain ranges is also supported by flexural support of the rigid lithosphere beneath the thickened crust (Keller and Pinter, 2002) (Fig. 5C). For example, if Airy isostasy were acting alone to support the Himalaya, the crustal root below it would need to be 80 kilometers thick to support the weight of the range. The root is only 55 km thick, so some of the height of the Himalayan range can be attributed to the rigidity of the subducted Indian plate below the mountain range (Molnar, 1986). Tomographic images of the mantle beneath the Himalaya and Tibet show seismic wave anomalies interpreted as remnants of the subducted Indian plate (Van der Voo et al., 1999).

Isostatic compensation of the growing orogenic belt affects the cross-sectional shape of the mountain range. As plates converge, a balance of horizontal compressional forces and vertical forces from the strength and buoyancy of the lithosphere act on the crust, affecting its shape and position within the mantle. The undeformed crust on either side of the mountain range flexes downward forming a foreland basin which may be enhanced by the negative buoyancy of the subducted lithosphere (Willett et al., 1993) (Fig. 6A). As the crustal root forms, the changing shape of the base of the range affects the surface slopes. The increased temperature resulting from continued crustal thickening over time weakens and allows viscous flow in the lower crust forming a low-angle plateau (Willett et al., 1993) (Fig. 6B). Isostasy and thermal evolution of the lower crust also play a role in gravitational collapse of the orogen, which causes extensional
normal faulting at high elevations and thrust faulting at lower elevations as the mountain range spreads laterally (Fig. 6C).

Isostasy provides an important link between the internal tectonic processes and the external surficial processes that affect the height and shape of a mountain range.

**Erosion**

Erosion is a general term which refers to processes of weathering (physical and chemical processes which break down bedrock at or near Earth’s surface) and mass transport by wind, water or ice, or due to gravity. Denudation, which describes all processes that wear away land over time including weathering, fluvial and glacial transport, and mass wasting, is wider in scope than erosion but the terms are often used synonymously. Several factors influence average erosion rates of a region, including vegetation, soil or rock type, topography and climate.

Erosive agents such as water, wind, glacial ice and mass wasting shape the topography of the mountain range, at the same time removing mass from the mountains as sediment is transported away. As this mass is removed, the mountain range responds isostatically to replace approximately 80% of the mass that was lost due to erosion (Pinter and Brandon, 1997). If erosion is concentrated at the bottom of river valleys, the peaks of the mountains can actually be lifted higher than they were before because isostasy responds to changes in average elevation (England and Molnar, 1990; Montgomery, 1994; Burbank and Anderson, 2001) (Fig. 7). Using mathematical modeling, Montgomery (1994) estimated that isostatic compensation for deep valley incision could account for 5-10% of the present elevation of the peaks in the Sierra Nevada and Tibetan Plateau and up to 20-30% of the Himalayan peaks.

Relief is the difference in elevation between the highest and lowest point in a region. Greater relief is associated with steeper hillslopes and greater gravitational potential energy, both of which contribute to higher erosion rates since water can move at a higher velocity and driving forces on hillslopes increase while resisting forces decrease. Recent studies have reported
evidence for decoupling of average erosion rates and slope morphology on steep slopes prone to landslides. In these situations, hills decrease in elevation at a similar pace to river incision (Montgomery and Brandon, 2002).

Various methods have been used to estimate denudation rates by different agents of erosion. Suspended sediment load is commonly used to measure erosion rates in fluvial systems, though this should be considered a minimum estimate since up to 50% of sediment could travel as bedload in mountain catchments (Burbank, 2002). Landslide erosion rates have been estimated by Hovius and others (1997) using comparisons of sets of aerial photos over a known period of time. The photos are used to determine areal extent of the landslide scarp features, from which a volumetric estimate can be calculated. Glacial erosion rates are difficult to determine because much of the load in glacial streams moves as bedload. Glacial sediment load is estimated through coring of proglacial lakes or marine deltas, or by measuring ice flux at the equilibrium line, which may indicate sediment flux (Anderson and McGregor, 1998).

In a review of field data on glacial erosion rates, Hallet and others (1996) summarized findings of dozens of studies in which erosion rates varied by orders of magnitude depending on the relief, substrate, and climate of the region (Fig. 8). The erosion rates ranged from 0.01 mm/yr for polar glaciers to 10-100 mm/yr for fast-moving temperate valley glaciers in Alaska. While warm-based glaciers can erode quickly, cold-based glaciers are frozen to the substrate, do not erode and can protect against erosion by other means (Burbank, 2002). Comparisons of erosion rates in glaciated and non-glaciated basins of comparable size in Norway and British Columbia, Canada revealed glacial erosion rates are one to two orders of magnitude higher than fluvial rates in those basins (Hallet et al., 1996). In the Olympic Mountains, glaciated valleys had two to four times greater cumulative rock volume removed than fluvial valleys of similar width, relief and cross-sectional areas (Montgomery, 2002).
Studies of fluvial erosion in Taiwan yielded erosion rates of 4-6 mm/yr, estimated with apatite and zircon fission track ages in combination with thermochronometry data (Willett et al., 2003). This range falls within the 2.2-8.3 mm/yr range estimated for Taiwan mountain basins from suspended sediment records (Fuller et al., 2003). Studies of river incision studies in the Indus River and Himalayan foreland using cosmogenic isotopes and dated deformed river terraces yielded erosion rates of 5-10 mm/yr (Burbank et al., 1996; Lavé and Avouac, 2000).

**Rock Exhumation**

Exhumation, or movement of deep crustal rock bodies up to shallower levels, is facilitated by the feedbacks and interactions of denudation and uplift processes. As material is stripped from the top of a mountain range by erosion or extensional faulting, isostatic and tectonic uplift move rock bodies in the crust upward. General quantitative relationships for denudation rates and uplift rates versus mean elevation have been calculated based on data from mid-latitude temperate mountains (Yoshiskawa, 1985; Pinet and Souriau, 1988).

Exhumation rates are measured by radiometric dating methods based on the closure temperature of isotopic systems such as K-Ar, Ar-Ar, Rb-Sr or U-Pb. Fission track dating of zircon or apatite is based on the annealing temperature of fission tracks within the mineral. In combination with established thermobarometers and thermochronometers, the P-T path describing the pressure and temperature changes a rock body undergoes as it is formed at depth and exhumed can be established and exhumation rate calculated.

Low temperature thermochronometry has facilitated study of relatively recent stages of exhumation because the low closure temperatures of 70-180°C allows determination of when rocks passed through shallow depths. Using (U/Th)/He and fission track ages of bedrock on the west flank of the Washington Cascade range, Reiners and others (2002) calculated an exhumation rate of 0.5-1.0 km/My during a rapid pulse of exhumation in the late Miocene (8-12 Ma).

Geologic evidence such as the upwarping of 17-15.5 Ma Columbia River Basalts supports the
rapid late Miocene uplift hypothesis (Mitchell et al., 2001). Brandon and others (1998) used fission track ages from sandstones in the Olympic subduction complex and overlying Coast Range Terrane to calculate exhumation rates in the Olympic Mountains. They determined that exhumation began approximately 18 million years ago and has maintained a relatively constant rate of about 0.75 km/My in the central undeformed massif and about 0.28 km/My for the entire Olympic Peninsula over the last 14 million years. The constant exhumation rates since 14 Ma suggest that the Olympic Mountains have steady-state topography.

**Steady-State Topography**

Tectonic processes, erosion, isostatic uplift, and rock exhumation occur gradually over the course of millions of years. Catastrophic events such as earthquakes or massive erosion due to flooding or landslides can make observable changes to mountain topography, but the overall process of forming or degrading a mountain range occurs at rates of millimeters per year. The rate at which mountains grow taller or degrade depends on the relative rates of uplift and erosion. One model, which builds on W. M. Davis’ 1883 Geographical Cycle model and the 1960s plate tectonics revolution, proposes that mountain ranges evolve through three major stages (Yoshiskawa, 1985; Pinter and Brandon, 1997). The first stage, while tectonic collision or subduction is occurring, involves uplift rates that far exceed erosion causing the mountain range to grow. During the second stage, the range is relatively stable in steady-state equilibrium as isostatic rebound compensates for erosion and both rates are approximately equal. In the third stage, the buoyant root and the mountain range will grow smaller as erosion rates exceed the uplift rate until little trace of the mountain range remains. Steady-state topography is most likely to occur in orogenic belts with moderate rates of surface uplift and crustal accretion and high rates of erosion. The Olympic Mountains, Taiwan and New Zealand are hypothesized to have such conditions (Willett et al., 2001).
As discussed earlier, it is not realistic or appropriate for introductory geology students to understand the intricate connections between the processes described in this section. Current learning theory research was used to determine an appropriate instructional level for the subjects of this study and appropriate methods for developing conceptual understanding.

**Learning Theory: How People Learn**

In 1999, the Committee on Developments in the Science of Learning and the Committee on Learning Research and Educational Practice, both of the National Research Council (NRC), concluded a study of the research on the science of learning and how to incorporate learning theory research into instructional practice (Bransford et al., 2000). Three key findings were chosen by the group based on their extensive research base and implications on teaching practice:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.

2. To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.

3. A “metacognitive” approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

This section addresses the NRC research (Bransford et al., 2000) that supports these key findings as well as studies from a literature review on several aspects of learning theory and misconceptions of science concepts.
Misconceptions and Conceptual Change Research

In the early 1970s, science education researchers began to observe, interview and assess children and older students to investigate the way those students conceptualized a range of scientific concepts. Many of the students’ ideas uncovered by these studies reflected “a compelling reasonableness” (Driver, 1989), but were not consistent with explanations agreed upon in the scientific community. These beliefs have been dubbed preconceptions, misconceptions, alternative conceptions, naïve theories, alternative frameworks, and alternate conceptions, among other terms, by various authors. In this paper, the term ‘misconception’ will be used to refer to explanations of scientific concepts that differ from the accepted scientific way of thinking, despite the negative connotation perceived by some authors (e.g. Dove, 1997). The term ‘misconception’ is the most familiar to the teaching community and general public (Roth, 1990). It should be noted, however, that the student ideas referred to as misconceptions here are not usually completely inconsistent with scientific thinking. The conceptual schemes constructed by each individual student may have some basis in scientifically accepted theory, but also contain incorrect ideas (Roth, 1990). It is the incorrect ideas, rather than an incomplete concept attained at a low level of understanding and use, that distinguishes a misconception from partial understanding of a concept (Klausmeier, 1990).

Early studies of student misconceptions focused on the physical sciences including mechanics, light, electricity, and the structure of matter, along with a few studies of subjects in the biological sciences (Driver, 1989). More recently, a number of authors have researched pre-college students’, pre-service teachers’ and K-12 teachers’ misconceptions related to Earth structure, plate tectonics and mountain building (Happs, 1982; Philips, 1991; Muthukrishna et al., 1993; Schoon, 1995; Marques and Thompson, 1997; Chang and Barufaldi, 1999; King, 2000). Utilizing surveys, interviews, or Earth Science standardized achievement tests, the researchers uncovered key misconceptions related to mountain building, including the beliefs
that mountains are rapidly formed, mountains are formed by piles of earth or dirt piling up, mountains are formed by earthquakes and volcanoes, mountains are formed when sea level falls, and that mountains have always existed (see Table 1 for a more complete list).

In an extensive review of misconceptions in science, Wandersee and others (1993) composed eight major claims based on their findings. The first claim, that learners bring a diverse set of misconceptions about natural objects and events to formal science instruction, was later echoed by the key findings of the NRC (Bransford et al, 2000) and is the subject of the bulk of misconceptions research. The second claim that the misconceptions students bring to formal instruction cut across age, ability, gender and cultural boundaries became a more recent focus of misconceptions research (Roth, 1990). Happs' (1982) study of 11-17 year old students' concepts and misconceptions of how mountains formed in New Zealand revealed similar beliefs, expressed in interview statements, across age groups. Students at all age levels, for example, stated that they believed that the mountains 'had always been there'. A comparison of "gifted" students with a mean IQ of 146 and "non-gifted" high school physics students with a mean IQ of 116 revealed common misconception about moving objects in both groups (Placek, 1987).

Misconceptions are persistent and very difficult to change by conventional teaching strategies (Hashweh, 1986; Klausmeier, 1990; Roth, 1990; McDermott, 1993; Wandersee et al., 1993). Many researchers agree that misconceptions arise as people interact with their surroundings and interpret events (Hasweh, 1986). As a person's beliefs are used continually to shape their expectations, they become encoded as procedural, as opposed to declarative, knowledge. Procedural knowledge is used almost automatically and is very difficult to change unless it directly confronted (Hasweh, 1986). When taught using traditional textbook and hands-on approaches, students commonly retain their pre-instruction misconceptions (Roth, 1990). In a study where students learned about photosynthesis as the source of food for plants
by growing plants in light and dark conditions, only 7% of students gave up their notions about external sources of food (Knott et al., 1978). In another study, students who held the belief that Earth is flat interpreted instruction that Earth is round by explaining that the world is a flat circular disc (Nussbaum, 1979). The latter example supports Wandersee and others’ (1993) claim that misconceptions held today often parallel explanations of natural phenomena by previous generations of scientists and philosophers. Wandersee (1985) gave students in grades 5, 8, 11 and 14 a photosynthesis concept test in which explanations of the functions of leaves and food sources, ranging from Aristotelian beliefs to modern accepted scientific beliefs, were presented to students as potential solutions. Students at all grade levels held similar misconceptions to those held by scientists historically, but students at younger grades were more likely to have responses consistent with historical beliefs that have now been rejected or greatly modified. Studies show that children progress through a series of intermediate notions that may not be scientifically correct, but show an evolution in understanding (Driver, 1989). Thus, an understanding of the progression of scientific beliefs and sequencing of students’ beliefs could be useful in scaffolding curriculum to help students arrive at a complete understanding of science concepts.

There are many influences on students’ misconceptions including observation and perception, language, and instructional materials or teachers’ explanations (Wandersee et al., 1993). In the previous example on photosynthesis, Wandersee (1985) concluded that societal practices in activities such as raising plants can lead to misconceptions. Misunderstandings about mechanics or bodily functions can come from everyday interactions that children have with physical objects or their own bodies as they formulate ideas about how things work (Wandersee et al., 1993). When students are presented with new concepts that are in conflict with their prior knowledge, they may distort or ignore the new information in attempts to reconcile the two inconsistent conceptualizations (Roth, 1990). These interactions of prior
knowledge with formal instruction can result in unintended learning outcomes (Wandersee et al., 1993). This can be especially problematic when the student does not realize the gap between his or her understanding and the teacher’s intended meaning. The teacher can also be unaware of how the student has perceived the intended message, or attribute any discrepancies to the student’s lack of understanding rather than “understanding differently” (Nussbaum and Novick, 1982).

The confusion of everyday language and “technical” terms can be another source of misconceptions in science (Wandersee et al., 1993; Dove, 1998). The “everyday life” discussion of energy suggests that it is something that can be consumed or “used up”, which is in conflict with the scientific understanding of the conservation of energy (Wandersee, et al., 1993). In Earth Science, the everyday meaning of marble suggests it is any type of polished rock rather than being restricted to a metamorphosed limestone (Dove, 1998).

Unfortunately, science texts and teachers can be other sources of misconceptions for students. Many teachers and textbook authors introduce concepts by demonstrating a few “classical” experiments and assume that the observation or discussion of such experiments is sufficient for students to develop a conceptual understanding (Nussbaum and Novick, 1982). Textbooks also tend to be overburdened with technical vocabulary and unessential subtopics at the expense of in-depth demonstration of key concepts (Project 2061, 2001). For example, an analysis of two biology textbook chapters by Project 2061 (2001) revealed 120 technical terms about cells, compared to twelve terms deemed necessary for science literacy about cells in *Science for All Americans* (Rutherford and Ahlgren, 1990).

Teachers cannot be expected to reduce misconceptions in students if they have the same erroneous beliefs. A survey of K-12 teachers in Britain revealed their misconceptions of plate tectonics and the composition of Earth, including misunderstandings of the ductile nature of the mantle, which is a key to understanding plate motion (King, 2000). Pre-service
elementary teachers at two universities in Indiana showed key misconceptions about the earth-sun-moon system, including 86.1% of the 122 subjects who believed “at 12:00 noon, the sun is directly overhead”, and 82.8% who believed “summer is warmer than winter because the earth is nearer the sun” (Schoon, 1995).

Though many authors hold the view that misconceptions hinder learning, Clement and others (1989) and Smith and others (1993) emphasize that students’ initial understandings are important building blocks, or ‘anchoring conceptions’ for constructing understanding. According to conceptual change theorists, conceptual understanding cannot occur unless students’ misconceptions are directly confronted. Students who were taught concepts of mass, volume and density using conceptual change strategies and instructional materials that explicitly dealt with student misconceptions showed a significantly larger improvement than a control group instructed by traditional methods (Hewson and Hewson, 1983). Conceptual change strategies build on the constructivist approach to meaningful science learning. Students are viewed as active interpreters of new experiences and concepts in terms of their existing knowledge rather than passive absorbers of information (Roth, 1990). This approach does not advocate “process” or “discovery” learning isolated from content, but rather the construction of scientific understanding from the base of previous knowledge (Gil-Perez and Carrascosa, 1990).

**Conceptual Understanding and Information Processing**

Another important finding of the National Research Council (Bransford et al, 2000) was that factual knowledge in the context of a conceptual framework must be organized in a way that facilitates retrieval and application in order to develop competence in an area of scientific inquiry. Concepts are defined as packages of meaning that capture similarities, differences, patterns or relationships among objects, events, or other concepts (Pines, 1985). The term ‘concept’ also refers to a person’s
mental construct of a concrete or abstract thing, and to the scholars' meaning of the words that describe that thing (Klausmeier, 1990). These definitions of 'concept' emphasize relationships among pieces of information, so the accumulation of a large set of disconnected facts is not sufficient to attain a conceptual understanding of a topic of study. Conceptual understanding allows students to transform factual knowledge of subject matter into usable knowledge that can be applied to new situations (Roth, 1990, Bransford et al., 2000).

Although there are many models of how information is processed, the focus here will be on knowledge processing as it pertains to multimedia learning since that is the mode of learning utilized in this thesis. The cognitive theory of multimedia learning presented by Mayer (2001) relies on three assumptions based on previous research: the dual channel assumption, the limited capacity assumption, and the active processing assumption. According to the dual channel assumption, the sensory memory and working memory are divided into two channels (Fig. 12). The visual/pictoral channel is primarily responsible for processing pictures while the processing of spoken words occurs mainly in the auditory/verbal channel. Written text is initially processed in the visual/pictoral channel and then moves into the auditory/verbal channel of the working memory. The limited capacity assumption supposes that unlike long-term memory, the working memory is limited in its capacity. Therefore, the visual channel can process only a few pictures at a time and the verbal channel can only hold a few sounds.

These assumptions would lead one to predict that students who view a multimedia presentation with written text and animations will perform poorly when asked to recall and use information because they had to initially process both inputs in one channel (Mayer and Moreno, 1998). Students who view animations with spoken narration should have better retention and transfer ability because they process and hold
the two stimuli in separate channels before it moves to long term memory. In three separate studies of college students recruited from the psychology subject pool at UC Santa Barbara, Mayer and his research associates showed that students who viewed the animation with spoken narration performed better on retention and transfer tests (Mayer and Anderson, 1991; 1992; Mayer and Moreno, 1998).

The active processing assumption is that humans actively attend to and organize incoming information and integrate this information with other knowledge in order to construct a coherent mental representation of their experiences (Mayer, 2001). Some of the mental models that the learner may construct to organize information include cause-and-effect relationships, comparisons, generalizations with supporting details, enumerated lists with collections of related items, and classification hierarchies with sets and subsets. The implications for development of multimedia presentations are that the presented material should have a coherent structure and that guidance should be provided to the learner on how to build the structure (Mayer, 2001).

Novices and experts in a given area of inquiry differ in their ability to cluster related units that share underlying governing concepts (Bransford et al, 2000). According to some cognitive psychologists, knowledge is not accumulated additively, but is organized into units having their own structure called schemata (Hashweh, 1986). Learning occurs when new information is integrated into an existing schema in a learner’s brain (Roth, 1990). Experts in an area of inquiry possess more efficient organization of memory, having more “chunks” of related information, more interrelation among the chunks, and fluent retrieval methods (Bransford et al., 2000). Experts also organize information in a way that facilitates transfer, the ability to apply knowledge to novel situations and learn new related information quickly (Bransford et al, 2000). As a novice gains experience and expertise, they become more capable of these skills and
undergo a “novice-expert shift” (Carey, 1986). Some cognitive psychologists believe abilities once attributed to Piaget’s developmental stages are better described in terms of novice-expert shifts and conceptual changes in particular domains (Carey, 1986).

**Metacognition**

In addition to the importance of the effects of preconceptions and organization of information in conceptual frameworks, another key finding presented by the KRC (Bransford et al, 2000) was the importance of metacognition for learning. Metacognition is the ability to monitor one’s own current level of understanding and decide when it is not adequate. Young children often believe that they will remember something and thus fail to use strategies such as rehearsal to improve their ability to remember the information (Bransford et al, 2000). Similarly, an older student might think their reasoning is sufficient and fail to do more research before defending their position. The skills students need to become active participants in their own learning can be promoted by teaching students’ problem-solving strategies and the cognitive and motivational characteristics of thinking (Paris and Winograd, 1990). Since metacognition focuses individual students on their own understanding, it is sensitive to individual differences and abilities. Making students aware of their own learning transfers responsibility for monitoring from the teacher to the students themselves and promotes positive self-perceptions and motivation as students track their own progress (Paris and Winograd, 1990). Motivation, in turn, affects the amount of time students are willing to commit to learning (Bransford et al, 2000).

The three key findings presented by the National Research Council along with the standards setting efforts of the American Association for the Advancement of Sciences have had significant effects on the direction of science education reform in this country. Although learning theory and misconceptions research influenced the
development of the assessments and interactive computer animations for this thesis, conceptual change and metacognitive components were not specifically included. The potential effects of the absence of these aspects will be discussed in light of the findings of the study after a presentation of the results.

**Computer Animation and Visualization**

Computer animations are series of visual images displayed rapidly on a computer screen conveying a sense of motion, which can be used to convey abstract ideas, concepts and processes to students (Burke et al., 1998). Animations are capable of illustrating dynamic processes which static devices such as chalkboard drawings, overhead diagrams, and slides cannot (Slish, 2000). Computer animations are useful for simulations of experiments that are too dangerous or expensive to perform, or to introduce students to ideas that cannot be observed directly (Snir et al., 1993).

**Visualization Research and Theory**

Research on static and animated graphics has shown that they must be carefully designed to effectively convey complex systems. In order to be effective, graphics and animations must conform to the Congruence Principle and the Apprehension Principle (Tversky et al., 2002). That is, the format and content of the graphic must be compatible with the format and content of the concepts conveyed, and be accurately perceived by the viewer. Graphics that portray visual-spatial things like maps, molecules or architectural plans have an advantage over written language because they use space to convey space. By the same Congruence Principle, animations should be effective at portraying changes over time. However, animations often violate the second principle because they run too quickly or are too complex to be observed as intended (Tversky et al., 2002). Interactivity could be a solution to this issue if students are allowed to control how
they view an animation or proceed through an activity, reviewing the concepts they need to study and choosing not to spend a lot of time with familiar material (Tversky et al., 2002).

One of the challenges faced by science educators is to help students understand and internalize scientific explanations of unobservable phenomena in spite of students' misconceptions (Snir et al., 1993). Effective instructional animation sequences address misconceptions, and actively engage the learner via interactivity, decision-making and predictions (Burke et al., 1998). In some cases, animations can reinforce or create misconceptions for some students (Williamson and Abraham, 1995), so care must be taken in their creation and implementation so that their intended effect is clear. The use of computer animations and simulations has been increasing steadily since the 1980's for many purposes, such as web-based exercises, complements to lectures and laboratories, and as study aids (Reiber, 1990; Snir et al., 1993).

When Rieber (1990) reviewed the use of animation in computer-based instruction, many educators were using them for their “pyrotechnics” to capture the interest of students, and few studies had been conducted on the instructional merits of computer animations. Since that time, several qualitative and quantitative studies, to be discussed in the section that follows, have assessed the effects of computer animations on students’ achievement, attitudes and conceptual understanding. In general, “achievement” is assessed with course grades or course-related exams. “Conceptual understanding” is generally assessed by diagnostic assessments of physical, chemical, biological or geological concepts rather than specific course-related material. Students’ “attitudes” toward their understanding or towards the use of computer animations were assessed using questionnaires with multiple-choice questions, some of which also had open-ended extended response questions, and interviews.

Computer simulations have been shown to be as effective as observing real objects during concept formation (Zeitsman and Hewson, 1986), and are more practical when real-life
experiments are too expensive or dangerous or phenomena are too fast, too slow, or on too large or small of a scale to be easily observed. The use of computer animations has resulted in significant improvement of students' course grades and exam scores after the instruction involving computer animations in some cases (Dori and Yochim, 1994; Loegering and Edge, 2001). In other cases, however, there was no difference in course achievement after viewing conceptual computer animations (Williamson & Abraham, 1995). Williamson and Abraham (1995) suggested that the lack of difference in course achievement of students they studied was due to the algorithmic problem-solving nature of exam questions, which were neither addressed directly in the conceptual animations nor dependent on conceptual understanding. Ebeneezer (2001) stated that developing conceptual understanding through computer animations helped her students accomplish algorithmic tasks such as writing balanced chemical equations based on the animated processes they observed.

Several studies showed the use of computer animations and software programs resulted in positive effects on students' conceptual understanding of spatial (geological), chemical, and physical processes (Zeitsman and Hewson, 1986; Jackman et al., 1987; Kali et al., 1997; Ebeneezer, 2001). Jackman and others (1987) demonstrated that a chemical simulation was more effective in increasing students' understanding of spectrophotometry than a traditional, teacher-directed "cookbook" wet lab and a discovery/guided inquiry wet lab. As stated earlier, computer animations and simulations are most effective when they address misconceptions commonly held by students. Animations have been shown to alleviate or reduce misconceptions in some studies (Zeitsman and Hewson, 1986; Williamson and Abraham, 1995; Kali et al., 1997). Computer animations are effective in developing students' problem solving ability and verbal retention when used in conjunction with narrations or explanatory text. Mayer and Anderson (1991; 1992) found the combination of animations with simultaneous narration to be more effective in increasing students' problem solving ability than animations or narratives alone.
In questionnaires and interviews, college-level biology students expressed positive attitudes about the use of computer animations and simulations in their lecture and laboratory courses, revealing that the animations helped their understanding and increased motivation and interest in the subject matter (Fifield and Peifer, 1994; Loegering and Edge, 2001). Conversely, one study showed no difference in student attitudes about their introductory college chemistry course whether animations were incorporated or not (Williamson and Abraham, 1995).

Overall, the research seems to suggest that computer animations aid student achievement and conceptual understanding, though some contradictory results were found. The effectiveness of the animations on improving course achievement, as defined by students’ grades and class assessment scores, is not as clear. One study reported increased conceptual understanding by the group exposed to computer animations, but no difference in course achievement compared to the control group (Williamson and Abraham, 1995). The relative emphasis of conceptual versus algorithmic problem-solving content in a course likely affects how effective conceptual animations are in increasing course achievement. In a critical review of previous research claiming animated graphics produce superior learning results, Tversky and others (2002) stated that the studies were not always fair comparisons because the animated images conveyed more information than their static counterparts or were interactive, which itself provided an advantage to the user. Despite this potential advantage, a study tracking the student use of interactive multimedia related to projectile motion found that the students interacted with the software superficially and retained most of their previous misconceptions (Yeo et al, 2004).

This study contributes to geoscience education research because it is designed to reveal student misconceptions about mountain building processes at the college level and rigorously assess the effectiveness of interactive computer animations and static graphics in reducing misconceptions. With the quantity of computer animations available to students and instructors increasing, it is important to evaluate the characteristics that make them effective teaching and
learning tools. Careful determinations of what works and what does not based on rigorous assessment have the potential to drive the improvement of educational technology and help instructors learn how to best utilize the technology in their classrooms.
RESEARCH PROBLEM AND HYPOTHESES

The research problems for this study were to diagnose Introductory Geology students' misconceptions related to mountain building processes and to determine whether students were resistant to changing their initial preconceptions when given the opportunity to learn from interactive or static web activities. Two contrast groups were assigned to view web activities that included lessons on the roles of plate tectonics, isostasy, the balance of uplift and erosion, and the rock cycle in forming mountains. One contrast group, hereafter referred to as the "Interactive" group, worked with an interactive Flash web activity that allowed them to manipulate variables in four animated activities and make choices about how to navigate through the web page. The other contrast group, hereafter referred to as the "Static" group, viewed the same concepts and information on a static web page with unanimated graphics and text. The Interactive and Static groups were further subdivided into Multiple-Choice and Essay groups, depending on the method of assessment used to evaluate their conceptual understanding. Details about the mountain building web activities, assessments, and composition of the contrast groups are included in the Methods section that follows.

The following research hypotheses were tested using qualitative and quantitative data analysis methods:

1. There will be no statistical difference between the pre-test scores between the Interactive and Static groups. Both groups will have equivalent initial understandings and misconceptions about mountain building processes as shown on multiple-choice and open-response (essay) assessments.

2. Students in the Interactive and Static groups will both have significantly higher mean multiple-choice and open-response post-test scores (and fewer misconceptions) after viewing the mountain building web activity assigned to their group.
3. Students in the Static group will have significantly lower post-test and delayed post-test scores than those in the Interactive group.

4. Misconceptions in multiple-choice responses will be similar to student misconceptions written in open-ended responses and discussed in interviews. For each misconception identified, the percentage of students holding that misconception will be significantly less in the post-test than the pre-test. The percent difference will be greater in the Interactive groups than the Static groups.

5. Students in the Interactive groups will have significantly higher ratings (as determined by survey) of their own confidence about topics related to mountain building after the treatment than those in the Static groups.

6. Positive student opinions about the effectiveness of the learning object (as measured by Likert Scale items and written responses on the survey) will be proportionally higher in the Interactive groups than the Static groups.

7. Sorting variables, such as lecture professor, time spent interacting with the web activity, and student confidence in their science ability, will have a significant effect on their test scores. Gender, however, will not have a significant effect.
RESEARCH METHODS

The research design for this study consisted of three phases spread out over two years. The first phase of the study involved a preliminary, informal survey of Geology 101 lab students during Spring 2003. A pilot assessment based on the beta-version of the Flash interactive “Mountain Building Web Activity” (described in Appendix III) was administered to students during Winter quarter, 2004. Finally, the main study was conducted during Spring quarter, 2004. Each phase will be described in detail below.

Preliminary Informal Survey

Geology 101 students at Western Washington University (N=77) were surveyed during Spring quarter, 2003 to see how their written answers compared to those of the students and teachers in mountain building-related literature. The survey focused on misconceptions about mountain building. It was short in duration and was completed during regular class time without interfering in other class activities. A copy of the initial Survey of Knowledge about Mountain Building Processes is included in Appendix I. It should be noted that the lab students had already attended two or three lectures and were assigned to read text and lab material on plate tectonics before responding to this survey. The data in Table 2 and misconceptions in Table 3 are summarized from short written responses given by 77 Geology 101 students during the first week of lab.

It is notable that 90% of students surveyed recognized that mountain formation is related to plate tectonics, and that 62% of them knew that erosion is an important agent of change in mountain ranges. However, only two students demonstrated advanced knowledge of these concepts, giving responses that went beyond a simple phrase. Thirteen percent of students demonstrated misconceptions about how mountains formed, some of which are listed in Table 3. More students struggled with how much time it takes mountains to form. Forty-seven percent of
students correctly bracketed their responses in the range of millions of years, but over 25% of students believed mountains take 10,000 years or less to form. The results of this preliminary survey had important implications for the research design of this thesis and supported the results of previous studies that processes and timing of mountain building are widely misunderstood.

Pilot Study and Beta-testing

The small pilot study conducted during Winter quarter, 2004 had three major purposes. First, it provided an important opportunity for observation of students using a beta-version of the Flash interactive web activity. Secondly, students gave written feedback about the web activity and assessments. From the written comments and observations, the web activity and assessments were revised to improve clarity and usability. Finally, as part of the process required to generate a two-tier multiple choice assessment, students were given multiple-choice questions related to mountain building processes and were asked to explain the reasons for their choice in a free response essay answer. The assessment development process is described further in the “Main Study” section that follows. Examples of the instructions and assessments administered during the pilot study are included in Appendix I and screen shots and descriptions of the interactive Mountain Building Web Activity are shown in Appendix III.

The pilot study was implemented on two dates in March, 2004 in a university computer lab at Western Washington University. Sixteen of the eighteen students who participated in the pilot study were from the researcher’s lab sections. The other two students were recruited by a fellow Geology 101 teaching assistant. Fourteen additional students volunteered to participate but failed to attend the scheduled pilot assessment times. Participants were compensated with vouchers for free espresso and smoothies from the campus coffee shops.

Based on observations and student suggestions from the pilot study, several changes were made to the interactive learning object, including: 1) clarification of navigation directions, 2)
reduction of text length and increased font size, 3) further explanation of scientific terms in “Helpful Information” pop-up screens, and 4) addition of explanatory figures and graphics to increase visual appeal. Numerous other minor revisions to the interactive web activity were made in response to feedback from the participants in the pilot study as well as from Geology faculty and graduate students. Adjustments to the assessments were also made based on observations during the pilot study including reducing the number of test items to decrease student time commitment and revising or eliminating unclear questions.

For each multiple-choice question on the pilot assessments, students provided a written response to explain the reasoning for their answer. The scientifically accurate and inaccurate written responses were used to form the correct answers and distracters on the second tier of multiple-choice questions on the final assessments (Appendix IV). Several common incorrect statements about mountain building emerged in the students’ written explanations about how mountains are formed, including: 1) sediment must have time to accumulate and form a mountain, 2) continental crust is pushed upwards by subducting oceanic crust to form mountains, and 3) oceanic crust melts and leads to mountain building. Incorrect statements related to isostasy included: 1) the crustal root below a growing mountain range will be pulled upward, 2) the density of the mountain range increases as the mountain height increases, 3) isostasy causes everything to be equal, and 4) erosion of the mountain range would not affect the size or position of the crustal root because erosion only affects that which is above the surface. Several students showed confusion about erosion processes, stating that 1) glacial climates had slow erosion rates because they were too cold or that glaciers are always frozen into place and cannot erode. Another recurring statement was that 2) erosion is the only process affecting mountain elevation once subduction ceases. The student misconceptions that surfaced during the pilot study provided distracters on the final versions of the multiple-choice assessments.
Main study

Subjects

The main study involved students enrolled in Geology 101 labs during Spring quarter, 2004. Introductory Geology students are generally non-science majors ranging from 17 to 21+ years of age. At Western Washington University (WWU), Geology 101 labs reinforce concepts taught in the lecture, as well as teaching supplementary material. During Spring quarter, 2004 the lab sections met for two hours a week, covering eight geology topics and concluding with a laboratory final exam. Students from two four lecture sections each quarter were divided into sixteen lab sections of 25-35 students. Individual students were randomly placed in the Interactive Group or Static Group using a random number generator. The type of assessment given (multiple choice or essay) was also chosen at random.

To be eligible for inclusion as a subject, students needed to complete all three assessments, view the assigned web activity, and complete the pre- and post-treatment questionnaires. Of the 453 students enrolled in Geology 101 during Spring quarter, 2004, 84 students did not complete the required questionnaires or assessments, making them ineligible as subjects in the study. All students in the Geology 101 course were given the opportunity to participate in the study, but in accordance with Human Subjects Informed Consent regulations, they were given the option not to participate, or withdraw from the study at any time without penalty. An example of an Informed Consent form used in the main study is included in Appendix II. The 14 students who chose not to participate in the study were still required to complete the assignments as part of regular instruction, but their data was not included in the results. Students were given credit for completing the assessments and questionnaires, but the accuracy of answers did not affect students' grades. To protect confidentiality, students' names have not been published in any document or discussed in any presentation, nor have any identifying references been made in written or oral communication. Because of possible ethical
concerns with using the students in the researcher's lab sections as subjects, these students' data was not included in the main study. Excluding students in these lab sections, those who chose not to participate, and those who did not complete all the required assignments left 278 subjects eligible for the study out of 453 Geology 101 students during Spring quarter, 2004.

Human subjects approval was granted by the WWU Human Subjects Review Committee (HSRC) in October, 2003. A copy of the permission letter from the HSRC is included in Appendix II.

**Web-based Course Materials**

The Blackboard Learning System™ is a Web-based server software platform that allows students to access grades, course documents, announcements, discussion boards, e-mail communication, and assignments online. At WWU, students access the Geology 101 Lab Blackboard site through their “My Western” web accounts. Before every lab in Geology 101 at WWU, students complete an online Blackboard pre-lab activity based on reading material in their lab manuals and major concepts emphasized in the previous week's lab. The web activities and assessments for this study were located on a separate Blackboard site entitled “Mountain Building Web Activity”, also accessible to students online. In total, five “Mountain Building Web Activity” Blackboard sites were created for the following treatment groups (N = number of subjects in each group):

- **Group A:** Interactive web activity with essay assessments (N=13)
- **Group B:** Static web activity with essay assessments (N=16)
- **Group C:** Interactive web activity and multiple-choice assessments (N = 123)
- **Group D:** Static web activity with multiple-choice assessments (N=126)
- **Group E:** Non-subjects (N = 91, researcher's lab students and those who did not sign the informed consent letter - same web activity and assessments as Group C)
Treatement: Activity Design

Based on the benchmarks and standards established by AAAS (1993) and the NRC (1996), as well as the misconceptions presented by students in the preliminary survey, the mountain building web activities were developed with the following learning goals:

1) Mountains form by various means related to the movement of lithospheric plates over the mantle, including:
   a. Subduction of an oceanic plate under a continental plate causes volcanism, as well as tectonic shortening that thickens, folds and faults continental crust into mountains.
   b. Collision of two continental plates causes tectonic shortening which thickens, folds and faults continental crust into mountains.

2) Mountain formation occurs gradually over the course of millions of years, changing at rates of millimeters per year. Although earthquakes and volcanic eruptions can produce visible changes to Earth’s surface within a human lifetime, the process of building or eroding a mountain range takes much longer.

3) Mountains are formed and shaped through simultaneous uplift and erosion. If uplift rates exceed erosion rates, the mountains become higher. If erosion rates exceed uplift rates (or the forces causing uplift cease), the mountain ranges eventually erode away. Because continental crust is buoyant, mountains respond isostatically as mass is removed from the top by erosion.

4) Wind, water, and glacial ice transport weathered rock material away from mountains, leading to the eventual erosion of the mountain range. Climate and topographic relief affect erosion rates.

5) Rocks formed deep in continental crust (intrusive igneous and metamorphic) are exposed because of the combination of erosion and tectonic or isostatic uplift.
Two versions of the Mountain Building Web Activity were developed, which are described in detail in Appendix III. With the assistance of experts in computer graphics and programming, an interactive web activity using Flash MX 2004 was developed. Students can navigate through the interactive activity in any order they choose by clicking labeled buttons and selection menus. The interactive mountain building web activity, based on examples created by Dr. James Myers at the University of Wyoming, is composed of a “tabbed” interface where students can choose to view an introduction, a discussion of scientific models, an explore page with access to four mountain building animations, a summary of concepts, and an assessment link. Learning objects similar to the interactive mountain building web activity are used widely for educational and training purposes. According to Myers (written communication, 2003), effective learning objects are exploratory in nature, allowing students to discover important concepts by interacting with animations, graphs, dynamic visual equations or simulations. Learning objects are also designed to follow strict standards so that they are interoperable with other learning applications and are modular so that they can be reused, recombined, or customized by the instructor to meet the needs of their students (Brogan, 1999; Myers, written communication, 2003). The learning object developed in this study does not yet meet all of the interoperability criteria. One purpose of the current research was to establish whether the interactive animations in the web activity are effective learning tools before deciding to make improvements and distribute the learning object to the educational community. A static version of the web page was generated from still images and text as a contrast treatment to the interactive web activity.

In the development process of the activities, simplifying assumptions were made to ease programming and introduce concepts at a level appropriate for Geology 101 students. Many of these simplifications are discussed with students on the “Models” page of the web activity (Fig. 10). The first animated activity, entitled “How do plate tectonics build mountains?”, allows
students to step through an annotated slide show of events that occur at a convergent plate boundary during subduction of an oceanic plate and collision of a second continent (Fig. 11). The images used in this activity are vertically exaggerated to allow features to be recognizable and display appreciable change over time. The images are two-dimensional cross-sections, cartoons similar to those used in introductory geology textbooks. Another simplification used in the plate tectonics activity is that it is a slide show rather than a continuous movie. This was done to avoid creating dozens of sequenced images, and also allows students to read the text on the screen at their own pace. The timing of mountain building and rates of crustal thickening and elevation gain were approximated based on models for the development of the Himalayas (Molnar, 1986; Keller and Pinter, 2002).

The second animation, entitled “How are mountains supported from below?” allows students to explore the concept of isostasy (Fig. 12). Students can increase or decrease the mountain height (H), crust density (ρc) or mantle density (ρm) and see the resulting effects on the position of the continental crust in the mantle and size of the crustal root (R). The calculations for the animation account only for Airy isostasy based on the equation from Keller and Pinter, 2002:

\[ R = \frac{H \rho_c}{(\rho_m - \rho_c)} \]

This equation and the resulting responses in the animation ignores flexural rigidity of the lithosphere. Default settings of “average” crust and mantle densities were set at 2700 kg/m³ and 3300 kg/m³, respectively and a range of 0 to 5000 meters was allowed for mountain height. The graphic images in this animation activity are also vertically exaggerated.

The third animation activity, called “What processes shape and change mountains over time?”, enables students to observe how climate and relief affect erosion rates (Fig. 13). Students can choose from glacial, temperate, or tropical climates and gradual or steep relief. Erosion rates for each combination of relief and climate in the animation were chosen from a table of typical ranges of denudation rates (Saunders and Young, 1983 in Keller and Pinter, 2002.) The chosen
average erosion rates seemed reasonable based on more recent research and reviews by Hallet and others (1996), Burbank (2002) and Fuller and others (2003). Another feature of this activity allows students to observe elevation changes over five million years if erosion acted alone and with erosion and isostasy acting together. To calculate changes in elevation if erosion acted alone, the following equation was used:

\[
\text{New elevation} = \text{Starting elevation} \, \text{−} \, (\text{erosion rate} \, \times \, \text{# of years})
\]

To calculate the changes in elevation with erosion and isostasy acting together, it was assumed that 81.3% of the loss in elevation by erosion would be compensated by isostatic uplift based on the crust and mantle densities of 2700 kg/m³ and 3300 kg/m³, respectively. This again is based solely on Airy isostasy and discounts flexural rigidity. The equation used for this calculation was:

\[
\text{New elev.} = \text{Start elev.} \, \text{−} \, (\text{erosion rate} \, \times \, \text{# of years}) \, + \, (\text{erosion rate} \, \times \, \text{# of years} \, \times \, \frac{2700}{3300})
\]

The fourth animation activity, entitled "How can rocks formed deep within the crust come to the surface?", allows students to explore how the rock cycle works in a developing mountain belt (Fig. 14A), as well as how uplift and erosion expose deep crustal rocks at the surface (Fig. 14B). It includes a "drag and drop" activity with processes and rock types in the rock cycle, followed by animations of syn- and post-tectonic rock exhumation. The graphics and animations used in this activity are vertically exaggerated, two-dimensional cartoons and the erosion and uplift rates do not represent realistic rates. These simplifications were made to ease programming and graphics rendering, and are only meant to show an approximation of processes.

After the completion of the Flash interactive web activity, screen shots and graphics from it were used to generate the static version of the Mountain Building Web Activity using Microsoft PageMaker and HTML. Excluding instructions that were not necessary in the static version, the text is identical in both versions of the web activity. The chosen screen shots show images from all four of the animation activities described above, but do not allow the student to interact with
the activities themselves. The Interactive and Static web activities included on a CD-ROM attached to the inside back cover of this thesis document.

**Questionnaires and Assessments**

Online pre- and post-treatment questionnaires were used to collect students’ demographic information and data related to their attitudes toward geology and self-assessment of their comprehension before and after the treatment. Print versions of the pre- and post-treatment questionnaires, conducted online, are included in Appendix IV.

The assessments for this study included a “Predictions” pre-test just before the web activity was viewed, an “Observations” post-test after the treatment and a Delayed post-test at the end of the quarter. The Predictions pre-test and Observations post-test were identical in form, differing only in tense. The Predictions pre-test required students to hypothesize how continental crust would respond to plate tectonic activity, changes in density and thickness, and erosion. Once given the opportunity to view or interact with a web activity related to these concepts, they answered the same questions on the Observations post-test in light of what they had learned from the web activity. Three weeks following the treatment, students took a Delayed post-test to measure their retention of mountain building-related concepts. The test items addressed the same topics as those in the previous assessments, but required students to apply what they learned to an unfamiliar mountain range, the Caucasus Mountains in western Asia. “Correct” answers were not revealed until after students had completed the Delayed post-test.

The process for developing a two-tier diagnostic assessment consists of defining the content, obtaining information about student misconceptions, and developing the assessment based on the targeted content and misconceptions (Treagust, 1988). This process began with a list of propositional knowledge statements based on AAAS (1993) and NRC (1996) national science education standards to define the content boundaries of the assessment (Table 4). Propositional knowledge statements identify what is to be taught, but at a more comprehensive
level of detail and in greater quantity than will be finally included (Finley and Stewart, 1982).

This step was followed by content validation of the propositional knowledge statements by geology professors. This validation process also employed a review of literature about misconceptions related to mountain building, structure of Earth and plate tectonics (Table 1) and conducted an open-ended survey of WWU introductory geology students' general understanding of mountain formation and change over time. The final stage in obtaining information about student misconceptions involved development of conceptual multiple-choice content items related to the propositional knowledge statements with free response reasons. These assessments were administered during the Winter quarter, 2004 pilot study to volunteers from Geology 101 lab sections.

Based on findings from the pilot assessment, three two-tier multiple-choice assessments were developed: the Predictions pre-test, Observations post-test, and the Delayed post-test (Appendix IV). For each test item, the first tier consists of content questions and the second tier consists of reasons selected from students' free responses and literature-documented misconceptions.

Content validity is the degree to which a sample of test items represents the content the test is designed to measure (Borg and Gall, 1989). Content validity was determined with a specification grid to ensure the diagnostic test items adequately and fairly covered the propositional knowledge statements and addressed common misconceptions (Table 5). The scientific accuracy of information presented in web activities and the assessments were affirmed by WWU geology professors specializing in tectonics, orogeny, and geomorphology. Essay versions of the assessments were given to some students to compare the frequency and types of misconceptions present in the assisted-response (multiple-choice) and open-response (essay) answers. In addition, in-depth student interviews after the completion of the assessments were
conducted to determine the level to which their test responses reflected their actual level of understanding.

The reliability of the test is the level at which it remains internally consistent and stable as a measuring device over time (Borg and Gall, 1989). As previously mentioned, the Predictions pre-test and Observations post-test were identical in form. The Delayed post-test was related to an actual mountain range rather than the interactive animation models, so not all of the concepts were directly equivalent to the items on the previous assessments. Because the Delayed post-test had fewer questions, different wording, and covered slightly different concepts, the results of that assessment were not compared to those from the first two assessments. Delayed post-test scores were only used for comparison between the Interactive and Static groups rather than a longitudinal comparison.

The essay assessments cover fewer topics than the multiple-choice assessments, having only one question per animation activity or static web page topic (see Appendix IV). The first question deals with changes to continental crust during plate convergence. The second asks students to describe the effects of reducing mountain height or increasing crust density in terms of isostasy. The third essay question relates to the effects of climate and relief on erosion rates, and the final question asks students to describe two processes responsible for exposing deep crustal rocks at Earth’s surface. Each of the four questions addresses two content-related topics and asks students to explain their reasoning for their content answers. Written in similar form as the extended response items on the Washington State Assessment of Student Learning (OSPI, 2005), each question clearly states that students should “be sure to include in [his or her] answer” the bulleted points that contain the content answers and reasoning. The scoring rubric, discussed in the “Data Analysis” section, is based upon scientifically accurate answers to the bulleted points.
Student Interviews

To help ensure the content validity of the essay and multiple-choice assessments, in-depth interviews were conducted to determine whether each student's assessment results were consistent with the level of understanding he or she demonstrated during the interview. After the completion of the Delayed post-tests near the end of Spring quarter, 2004, a sample of students from the Interactive essay and multiple-choice groups were selected at random and contacted via e-mail to schedule an interview. Of the approximately 25 students contacted, nine students agreed to be interviewed. The interviews were conducted using a template of questions to elicit the subjects' explanations of the tectonic, isostatic, and erosion processes in the Interactive web activity, asking probing follow-up questions if needed to further gauge student understanding. The interview also included questions about the usability and clarity of the Interactive web activity. The template of interview questions and complete interview transcripts are included in Appendix V. The interviews were audiotaped, for which students gave permission orally. A second interviewer, who is a geology professor at WWU attended some of the interviews to ensure validity of the interview process. Subjects were compensated with movie certificates or ten dollars cash for their participation in the interviews.

Data Analysis

Testing the research hypotheses in this study involves a variety of qualitative and quantitative data analysis methods. To determine whether test score differences between and within the contrast groups were significant, a combination of unpaired two-tailed t-tests, paired one-tailed t-tests and single-factor ANOVA analyses were conducted using Microsoft Excel.

The scores for the multiple-choice assessments are compiled and reported by the Blackboard Learning System™, in addition to the percentage of students choosing each correct or incorrect response. Using these data, the common misconceptions held by the introductory geology students in this study, as well as how the percentage of students holding those
misconceptions changed after the treatment, were examined. The essay assessments were scored using a 4-point rubric developed for each question (see Appendix IV). A list of scientifically accurate, inaccurate, and partially accurate statements for each essay question was compiled based on student essay responses. The rubrics and misconceptions lists were checked for accuracy by WWU geology professors and revised based on their comments. Once the rubrics were revised, six evaluators scored a selection of 22 student responses independently to establish inter-rater reliability. This reliability scoring panel included five geology professors and a geology graduate student. Discrepancies were discussed by the researcher and a geology professor to establish firm scoring criteria before the remaining essay responses were scored. The misconceptions present in each response and compared the number of misconceptions held by each student before and after the treatment using the list of scientifically accurate and inaccurate statements agreed upon by geologists.

Seven of the nine interviews were transcribed and coded for scientifically inaccurate statements in each interview, as well as comments about the usability of the interactive web activity (Appendix V). The remaining two interviews were not preserved because of technical problems with the recording equipment. To determine the degree to which the assessments accurately represented student understanding of mountain building processes, the transcriptions from each interview were compared to that student’s essay responses or multiple-choice scores and answers. Specifically, it was determined whether each student showed the same level of understanding or misconceptions about the roles of plate tectonics, isostasy, erosion and the rock cycle in mountain formation during the interviews as they showed on the assessments.
RESULTS FROM MAIN STUDY (SPRING 2004)

To begin the analysis of the data collected from the online assessments and questionnaires, it was first important to determine whether the randomly selected Interactive and Static contrast groups were comparable demographically. This study also compared the length of time students in the contrast groups used each web activity and their opinions about the usability of the interactive and static versions of the web activity. Students were asked to rate their confidence in their own understanding of mountain building-related topics before and after using the web activity to determine whether confidence levels were affected differently by the two versions of the web activity.

The formal assessments were administered in two forms, multiple-choice and essay. In both cases, it was first determined whether the two contrast groups showed an equivalent initial understanding of mountain building by comparing their pre-test scores. Each contrast group's performance before and after using their assigned web activity was compared by determining whether there was a significant difference between its mean pre-test score and mean post-test score. The Interactive and Static groups' assessment scores were also compared to establish whether a difference existed between the performances of the contrast groups. The number and types of misconceptions present in multiple-choice selections or written responses were also compared between the Interactive and Static groups and within each contrast group over time.

Demographic Information

Random assignments of students into the Interactive and Static groups, in addition to the large number of subjects, provided two roughly equivalent contrast groups. The Interactive group was composed of 137 eligible subjects, including 123 who completed multiple-choice assessments and 13 who completed essay assessments. The Static group, 142 total, had 126 eligible subjects who took the multiple-choice assessments and 16 who completed the essay.
assessments. The equivalency of the contrast groups was determined through the collection of demographic information from a pre-activity questionnaire. One important disparity between the groups was gender of the subjects (Fig. 15). While the Interactive group had 58% female students, the Static group had 68% female students. The dominance of female students is consistent with the enrollment at WWU and typical enrollment in Geology 101. Of the 453 students enrolled in Geology 101 at WWU during Spring quarter, 2004, 59.8% were female. It is also noteworthy that 12 of the 14 students who chose not to participate in the study were male. The gender distribution of students that did not complete all of the required assignments necessary to be considered a subject was approximately equal at 41 male students and 43 female students. Although one might expect that the ratio of female and male subjects would be close in large randomly sampled groups (Gay and Airasian, 2003), that was not the case in this study. However, because the statistical analyses used in this study require random sampling and the difference in gender distribution between the groups was due to chance rather than researcher bias (Gay and Airasian, 2003), this method was more appropriate than stratified sampling that could have ensured an equivalent gender distribution in both groups.

During Spring quarter 2004, Geology 101 students were divided among three lecture instructors (Fig. 16). Instructor C taught two of four lecture sections, thus teaching approximately 50% of Geology 101 students. The distribution of instructors among the Interactive and Static groups was similar, though the Static group had 10% more students in Instructor C’s sections and fewer in Instructor A and B’s sections of Geology 101. The distribution of subjects in the Static and Interactive groups among seven graduate teaching assistants was roughly equivalent (Fig. 17). During Spring 2004, the second-year TAs (Lab TAs F, G, and H) each taught three sections of Geology 101 lab, while the first year TAs (Lab TAs D, E, I, and K) taught one section of 101 lab. One student reported having Lab TA J on the questionnaire incorrectly because students from the researcher’s (Lab TA J) lab sections were not
included in the study. Students in the Interactive group had slightly more lifetime educational experience in Geology and Earth Science classes prior to Geology 101 (Fig. 18) than did students assigned to the Static group.

Students indicated their level of interest and confidence in Earth Science and Geology on a Likert scale where “1” designated very low and “5” designated very high interest or confidence. The Interactive and Static groups had nearly equivalent levels of interest (Fig. 19), 71% and 72% indicated moderate to very high interest, respectively. Students in the Interactive group had a slightly greater rating of their confidence of their ability in science classes (Fig. 20). Nearly 85% of students in the Interactive group indicated moderate to very high confidence, while just over 80% of students in the Static group rated their confidence “3” or above.

Post-activity Questionnaire Data

On the post-activity questionnaire, students revealed their patterns of use and opinions about the interactive or static versions of the Mountain Building Web Activity. Most students spent 16 minutes or longer interacting with the web activity, with 69.6% of students in the Interactive group spending 16 minutes or longer compared to 62.2% in the Static group (Fig. 21). A small percentage of students in both groups viewed the activity web pages for more than an hour. A slightly greater percentage of students in the Interactive group (65.2%) rated their enjoyment of the web activity “3” or higher, compared to 63.6% in the Static group (Fig. 22). Approximately 50% of students in both groups rated the web activity “somewhat enjoyable, it was useful but not exciting”. A high percentage of students gave positive rating on the usability of the web activities, with 84.1% of students in the Interactive group and 83.2% in the Static group rating it fairly easy to very user-friendly (Fig. 23). Although the Likert-scale responses on the questionnaire were similar, the Static group had a higher proportion of negative written responses to an essay prompt asking their opinions of the web activity (Fig. 24). Students
viewing the static version of the Mountain Building Web Activity had several accolades and complaints in common with those who used the interactive version, as well as many other negative comments unique to the static site (Fig. 25). For example, while 24 students in the Interactive group commented that they enjoyed the interactivity of the web activity, six students in the Static group remarked that reading a web page was a passive activity or was no different than reading a text book.

On both the pre- and post-activity questionnaires, students rated their own level of confidence about their understanding of topics related to mountain building. Students in both groups had a high rating of their understanding of plate tectonics before beginning the activity. The confidence of students in both groups stayed fairly stable, but decreased slightly in both groups on the post-activity questionnaire. Ratings of moderate to very high confidence decreased from 87.7% to 85.5% in the Interactive group, and from 86.7% to 83.9% in the Static group (Fig. 26). Moderate to very high confidence ratings about how mountains form increased from 72.5% to 76.8% in the Interactive group and from 67.8% to 74.1% in the Static group (Fig. 27).

Students’ moderate to very high confidence ratings of their understanding of the age of mountain ranges increased from 33.3% to 47.8% in the Interactive group and from 32.3% to 51.0% in the Static group (Fig. 28). Students’ confidence of isostasy made the most dramatic gains, increasing from 7.2% to 49.3% rating their confidence moderate to very high in the Interactive group and 8.4% to 58.0% in the Static group (Fig. 29).

**Multiple-choice Assessment**

**Within-group and Between-group Comparisons**

The Interactive and Static groups showed equivalent initial understandings of mountain building processes on their Predictions pre-assessments. The test score distribution for both groups is normally distributed (Fig. 30), with nearly identical means and standard deviations.
(Table 6). Both groups' mean scores were approximately 14.5 out of possible 28 points. A two-tailed, two-sample t-test ($\alpha = .05$) gives a p-value of .73, which means that we can accept the null hypothesis that there is no statistical difference between the Predictions scores of the two contrast groups. The p-value is the probability that the sample means would differ by at least as much as observed due to random chance if the population means of both samples are the same. Since $p > .05$, there is no statistical difference between the sample means of the Predictions scores at the 95% confidence interval. The Observations post-test scores, on the other hand, are significantly different ($p = .04$, Table 7). The Static group has significantly higher scores, with a mean of 18.18, compared to 16.71 for the Interactive group (Table 6). The Delayed post-tests show no significant difference ($p = .11$, Tables 6, 7). To compare within-group changes over time, a one-tailed, paired t-test was used. Both the Interactive and Static groups had significant gains in Observations post-test scores compared to the Predictions pre-test ($p < .0001$ for both). The mean scores on the 28-point multiple-choice assessments increased by 2.20 points in the Interactive group and by 3.47 points in the Static group. With p-values of less than .0001, the probability of committing a Type I error in which a researcher rejects a null hypothesis that is actually true (Gay and Airasian, 2003), is very small and it is safe to assume that the increase in post-test scores cannot be solely attributed to random chance.

**Sorting Variable Comparisons**

To establish whether variables other than the treatment type of the contrast groups affected student understanding shown in assessment scores, analyses of the assessment data sorted by variables such as gender, lecture professor, lab TA, confidence in science ability and time spent using the web activity were planned. Unfortunately, individual data from the Blackboard questionnaires could not be retrieved, despite considerable effort on the part of the WWU Academic Technology staff. Gender and lecture instructor data could be compared since a subject's name from class rosters could be easily linked to his or her results, risking the
possibility that the wrong gender could have been assigned to unfamiliar or non-gender specific names. Gender had little effect on subjects' test scores (Table 8). In only one case was there a significant difference between female and male test scores. The females in the Interactive group scored significantly higher than the males on the Observations post-test ($p = .03$) at the 95% confidence interval. All other combinations of contrast groups and assessments showed no significant difference between male and female subjects ($p > .05$). Lecture instructor had no significant effect on multiple-choice test scores (Table 9). In all cases, there was no significant difference in mean test scores between students in instructor A, B, and C's lecture sections.

Item Analysis

An item-by-item analysis of the Predictions and Observations multiple-choice assessments shows that both contrast groups had positive gains on most questions between the pre-test and post-test (Fig. 31). The Static group increased the percentage of correct responses on 23 of the 28 items, while the Interactive group increased correct responses on 22 of 28 items. Students in the Static group outperformed those in the Interactive group on an item-by-item basis, scoring more positive (or less negative) gains on 19 of the 28 test items. The six test items on which one or both groups decreased their percentage correct (Table 10) related to why mountains form slowly (item 2), the effect of relief on erosion rates (items 15 and 16), changes to mountains over time as subduction continues (item 25) and after subduction ceases (items 27 and 28).

Since the Delayed post-test had a smaller number of questions and items that were not directly equivalent to those on the first two assessments, a longitudinal comparison of all three assessments was not possible. However, the performance of the Interactive and Static groups on the Delayed post-test could be compared. The percentage of students responding correctly to each of the 22 items on the Delayed post-test was similar for both contrast groups (Fig. 32). Seldom did the percentage correct responses differ by more than 5% between the Static and Interactive groups. On 17 of the 22 questions, the Static group had a greater percentage of correct
responses than did the Interactive group, yet the overall mean scores were not significantly different (Tables 6, 7). The five items in which the Interactive group outperformed the Static group were related to plate tectonic processes in mountain building (items 2 and 4), changes to buoyancy of the crust when lower-density magma intrudes (items 9 and 10), and isostasy's effect on elevation changes (item 15). Both groups tallied less than 50% correct on items related to timing and mechanisms of mountain formation (items 1 and 2), changes to buoyancy of the crust when lower-density magma intrudes (item 10), exhumation of deep crustal rocks (item 18) and uplift of sedimentary rocks (item 20).

On all three assessments, high percentages of students chose common distracters that were included on the assessments based on student misconceptions from the literature or pilot exams. In most cases, the percentage of students choosing the incorrect distracter decreased between the Predictions pre-test and Observations post-test or Delayed post-test (Figs. 33 through 39). The percentage of students choosing the incorrect distracter on the post-tests usually decreased more in the Static group. On some questions, little change occurred after students viewed the web activities (e.g. Fig. 40). Both groups chose two incorrect distracters more often in the post-tests than in the pre-test. Students choosing the response, "mountains form as the subducting plate pushes them up through the other plate," increased by 15.5% in the Static group and 7.3% in the Interactive group. The incorrect response, "isostatic uplift will completely compensate for loss in elevation due to erosion," was chosen on the Observations post-test by 13.5% more students in the Static group and 3.3% in the Interactive group.

**Essay Assessment**

**Within-group and Between-group Comparisons**

As was the case with the multiple-choice assessments, the Interactive (N = 13) and Static (N = 16) groups taking the essay assessments showed nearly equivalent mean Predictions pre-test
scores (Table 11), with no significant difference between the groups ($p = .84$, Table 12) on the pre-test. The Interactive group increased its mean score on the Observation post-test by 1.16 points on a 16 point assessment (Table 11), though the difference was not significant using a one-tailed t-test for paired samples ($p = .09$, Table 12). The mean score on the Delayed post-test then decreased, but still remained higher than the initial Predictions pre-test score (Table 11). The Static group’s gain between the Predictions pre-test and Observations post-test was 1.19 points, and was statistically significant according to a one-tailed paired t-test ($p = .03$, Table 12). The difference in gain between the Interactive and static groups was small (.03), but the larger sample size of the Static group may have influenced the results because sample size heavily influences statistical significance (Urdan, 2001). Unlike the Interactive group, the Static group made an additional slight gain on its mean Delayed post-test score (Table 11).

Looking at individual essay performance of subjects in the Interactive group (Fig. 41) and Static group (Fig. 42) over time, most students maintained or improved upon their Predictions pre-test scores when taking the Observations post-test immediately after the treatment and Delayed-post test three weeks later. One out of 13 subjects in the Interactive group maintained the same score on all three assessments. In the Interactive group, 46.1% of students maintained or improved their scores on both post-tests, compared to 68.8% in the Static group. The percentage of students who maintained or had a negative gain on post-test scores was 23.1% in the Interactive group and 18.7% in the Static group. Some students improved their pre-test score on one post-test, but had a lower score on the other post-test, including 23.1% of the Interactive group and 12.5% of the Static group.

As the essay responses were scored according to the 4-point rubrics, responses on the post-tests in which students received a lower score than on their pre-test response were coded with reasons why the lower score was awarded (Fig. 43). Three of the codes indicated that the response did not meet the criteria for a complete answer according to the rubric, including
“response does not match question asked”, “incomplete answer” when a student did not respond to all of the bulleted points in the question, or “insufficient reasoning” when the written reasoning did not show that the student had an adequate scientific understanding of the concept according to the rubric. Approximately 64% of post-test responses in the Interactive group fit into this category, compared to 56% in the Static group. The other three codes indicated that the response showed a lack of understanding or misunderstanding of a scientific concept, including a “new misconception” that emerged since the pre-test, “reverted to a previous misconception” when a scientifically inaccurate statement from the pre-test that was not present on the Observations post-test reappears on the Delayed post-test, and “reverts to previous lack of understanding – ‘I don’t know’ ” on the Delayed post-test. About 36% of Interactive group and 44% of Static group post-test responses fit in this category.

Looking at changes in individual subject’s misconceptions over the three essay assessments (Figs. 44 and 45), one student in each contrast group had the same number of misconceptions on all three tests. The majority of students maintained or reduced the number of misconceptions on the post-tests, including 76.9% of students in the Interactive group and 62.5% of the Static group. In the Interactive group, 15.4% of students maintained or increased the number of scientifically inaccurate statements written in their post-test responses, compared to 18.8% of students in the Static group. Also, 12.5% of students in the Static group increased the number of misconceptions on one post-test, but decreased on the other.

**Sorting Variable Comparisons**

As with the multiple-choice groups, individual questionnaire data for the subjects completing essay assessments collected by Blackboard surveys could not be retrieved. It was not possible to perform the analyses linking sorting variables such as lab teaching assistant, previous earth science educational experience, confidence in science or time spent using the web activity, to the test scores and misconceptions for each individual subject. Therefore, gender and lecture
instructor comparisons were the only analyses conducted. In the Interactive group, male subjects (N = 6) had a higher mean Predictions post-test score, outscoring the female subjects (N = 7) by 1.90 points on the 16 point assessment (Table 13). The male students in the Interactive group consistently outscored the females, by 1.31 points on the Observations post-test and 4.00 points on the Delayed post-test. Unlike the Interactive group, the female (N = 11) and male (N = 5) subjects in the Static group had similar mean scores on all three assessments (Table 13). Lecture instructor A’s students in the Interactive group had significantly higher scores on the Observations post-test (p = .014, Table 14) and Delayed post-test (p = .005, Table 14), but all other comparisons revealed no significant difference. It should be noted that Instructor A’s students in the Interactive group also had slightly higher scores on the pre-test than students in Instructor B or C’s lecture sections, and the number of students in each section is small. Caution should be used before generalizing these results to the whole class populations.

Item Analysis

To determine whether the static or interactive web activities affected students’ understanding of specific topics and common misconceptions, the performance of the contrast groups on each essay item was compared (Table 15). The first essay question dealt with plate tectonics, the second with isostasy, the third with erosion, and the fourth question with rock exhumation. Each essay question was scored on a 4-point scale. On Question 1, both groups improved upon their mean pre-test score on each successive post-test. The Interactive group increased their mean Delayed post-test score by .46 points over the mean pre-test score, compared to a .69 increase in the Static group. Both groups also decreased the mean number of scientifically inaccurate statements written on Question 1 over the course of the assessments; the Interactive group reduced the mean number of misconceptions by 1.08 and the Static group had a .62 reduction.
The Interactive group increased their Observations post-test score by .62 on Question 2, followed by a .77 point decrease on the Delayed post-test. The Static group increased their scores successively by .56 points over the course of both post-tests. Both groups reduced their mean number of written misconceptions on the Observations post-test, the Interactive group by .61 and the Static group by .25. However, both the Interactive and Static groups then increased the mean number of misconceptions slightly on the Delayed post-test, by .15 and .12, respectively.

The performance of the two groups on the third essay question was quite different. The Interactive group slightly increased their mean Observations post-test score by .07 points, followed by a .38 point decrease on the Delayed post-test. The Static group experienced a negative gain on both post-tests, dropping the mean score by 1.06 points on a 4 point question. The Interactive group decreased their mean number of misconceptions on Question 3 by .31 overall, while the Static group maintained the same number of misconceptions on the Observations post-test followed by an increase of .12 on the Delayed post-test.

Both groups scored the lowest mean pre-test score on Question 4, both scored approximately 1 point out of 4. Both groups improved their mean scores over the successive post-tests, the Interactive group by .54 points and the Static group by 1.13 points. The Interactive and Static groups reduced the mean number of scientifically inaccurate statements on the post-tests by .31 and .50, respectively.

Ten categories of student misconceptions appeared recurrently in written essay responses by students in both contrast groups (Table 16). Of these ten common misconceptions, eight of them were present in fewer responses on the post-tests than on the Prediction pre-test. One misconception, that magma or lava flows exposes deep crustal rocks to the surface, increased in prevalence on post-tests in the Interactive group. The Static group increased the number of inaccurate statements on post-tests regarding crustal responses to changes in density or thickness and distinguishing mass/weight, volume and density. Of the ten common misconceptions written
in the essay responses, the four most prevalent were: 1) subducting oceanic crust pushes up on continental crust, 2) crustal responses to changes in density or thickness, 3) more precipitation or more water necessarily causes higher erosion rates and 4) volcanism or magma exposes deep crustal rocks. A discussion of the accepted scientific explanations for each of these misconceptions will be included in the Discussion section that follows.

Data Summary and Comparison to Research Hypotheses

As predicted in research hypothesis #1, the two contrast groups showed equivalent understanding of mountain building processes on the multiple-choice and essay pre-assessments. Both contrast groups scored approximately 14.5 out of 28 points on the multiple-choice test and about 8 out of 16 on the essay assessment. On the multiple-choice assessments, both contrast groups significantly increased their Observations post-test scores, supporting research hypothesis #2. However, research hypothesis #3, that the Static group would score lower than the Interactive group, was incorrect because the Interactive group’s mean score only increased by 2.20 points compared to the Static group’s 3.47 point increase. There was no significant difference between the groups on the multiple-choice Delayed post-test. On the essay assessments, the Static group showed a significant gain between the pre-test and post-test, while the Interactive did not. However, there was only a .03 difference in the mean score increase between the groups, so the statistical significance of the Static group may be due in part to its larger sample size. The essay Delayed post-test scores were not significantly different, though it is notable that the mean score in the Interactive group decreased below the Observations post-test score while the mean score in the Static group continued to increase.

Most of the misconceptions that occurred on the multiple-choice and essay assessments were common to both versions of the assessment. A few additional scientifically inaccurate statements were present on the multiple-choice assessment because the test items covered a larger
range of topics. Seventy percent of the misconceptions chosen on the multiple-choice pre-tests or written on the essay pre-assessments decreased in frequency on the post-tests. The Static group decreased the percentage of incorrect multiple-choice responses more than the Interactive group, but the Interactive group had the greater reduction in the average number of misconceptions written on essay post-tests. Research hypothesis #4, dealing with the comparative frequency of misconceptions between the contrast groups and within groups over time, is partly supported by the data and partially refuted. It is notable that the Interactive group scored lower on the essay post-assessments despite having a greater reduction in misconceptions. Approximately two-thirds of the mean score decrease by the Interactive group was coded as resulting from incomplete or inadequate answers rather than new misconceptions.

Students’ confidence ratings about their understanding of “plate tectonics” were similar between the two contrast groups; both experienced a 2-3% drop in moderate to very high confidence (“3” to “5” on the Likert scale) after using the web activity. Moderate to very high confidence ratings increased for both groups for “how mountains form”, “age of mountain ranges” and “isostasy”. In all three cases, the confidence ratings increased more for the Static group, which refutes research hypothesis #5 that the Interactive group would have higher confidence after using the web activity.

Time spent using the web activity was slightly greater in the Interactive group, where nearly 70% of that group used the web activity for 16 minutes or longer, compared to 62% in the Static group. Likert scale responses regarding how enjoyable and user-friendly the web activities were similar, but students in the Static group wrote a higher proportion of negative comments about the web activity. The written comments support research hypothesis #6 that the Interactive group would consider the web activity more effective than those who viewed the static web page. The interactive version of the web activity received more positive feedback and was used more by students, but was it as effective in increasing confidence and performance on assessments?
The Interactive and Static contrast groups were roughly equivalent demographically, differing only in gender distribution. Although both groups had more female than male subjects, the Static group was composed of a higher proportion of female students. This disparity in gender distribution led to an important question: Is there a difference in test performance by males and females? As predicted in research hypothesis #7, gender had no effect on test performance, with two exceptions. The female subjects in the Interactive group scored significantly higher than their male counterparts on the multiple-choice Observations post-test. The female students also scored higher on the pre-assessment, but the difference was not significant. On the essay assessments, the male students in the Interactive group started with a higher pre-test score, and increased the gap by 4.00 points on a 16-point assessment. All other comparisons of the genders showed no difference in scores. Lecture instructor also appeared to have no significant effect on student performance on the multiple-choice or essay assessments.
DISCUSSION

An analysis of the data from this study raises the following questions: 1) To what degree were the data collection instruments accurate representations of student confidence and understanding?, 2) Why did the web activities not have more of an effect on student misconceptions and why was there no difference between the Interactive and Static web activities?, 3) What could be done differently to improve the research methods and instructional design of the web learning object?, 4) What implications for policy and practice can this study contribute to the science education community?, and 5) What future research could logically follow from the findings of this study?

This study does not support the idea that we can uncritically utilize interactive computer animations as a means to increase students' conceptual understanding of scientific processes. This section critically examines both the findings and the methods and assumptions of the instructional and research design of this study to determine how the findings of this study can contribute to the geoscience education community.

Discussion of Assessment, Interview and Questionnaire Data

A cursory review of the results might lead to the conclusion that, in this case, the additional development time and costs to create an interactive Flash web activity did not bring about any greater gains in student understanding of mountain building than did the viewing of a static web page. The Interactive group had a greater reduction in the average number of misconceptions written in their essay responses and had more positive written comments about the web activity than did the Static group. However, every other measure, including self-reported confidence level, showed no difference between the groups or favored the Static group. In fact, the members of the Interactive group who took the essay exam did not even show a significant
gain between the pre-test and post-test, while all other groups increased their mean score significantly.

Student Misconceptions Revealed in Interviews and Assessments

The interview excerpts in the section that follows are included to reveal common student misconceptions in their own words, and to compare the level of understanding each student demonstrated in the interview to their assessment performance. After the completion of the Delayed Post-test near the end of Spring quarter, 2004, interviews were conducted with nine students in the Interactive group, seven of which were transcribed. In all cases but one, students demonstrated the same the same level of understanding and misconceptions on the assessments as they did in the interviews. One student showed a low level of understanding during the interview, but performed well on the multiple-choice tests, possibly because of guessing or good test-taking skills that allowed her to eliminate implausible distractors (Haladyna, 2004). Melting of the subducting plate was the only misconception that occurred frequently on assessments that did not surface during the interviews.

A common misconception present in the interview and on the assessments was confusion between weathering and erosion. On their essay and multiple-choice tests, several students indicated that erosion rates occur fastest in tropical climates because of the high temperature and humidity. This statement is true of chemical weathering, which is a component of erosion, but warm, wet climates do not necessarily facilitate high rates of transport for the weathered material. The student from the following interview excerpt indicated that her initial ideas came from in-class instruction, which she misinterpreted to assume high rates of chemical weathering were the same as high rates of erosion. In this case, her answer on the climate type changed because of the

Key to transcription symbols:
I: interviewer
F: female student
M: male student
= continuous speaking
() unintelligible utterance
(2.0) length of a pause
[] speakers are talking simultaneously
interaction with the animation, but it is not clear whether she changed her ideas about warm and wet climates necessarily having high erosion rates.

I: Do you remember which climate had the highest erosion rates?

F1: It was the glacial one ((referring to climate)) on the steep ((referring to relief)).

I: Why do you think that was the case?

F1: Uhh....because of like, the ice of the glacier would just, like, it like rips away the rock, and because it's, like, jutting out at different angles it can take off more from the top instead of just, like, the thin layer on the gradual.

I: Do you remember in your predictions questions, um, when you first did the Blackboard assessment, do you remember which of the three climates, temperate, tropical or glacial that you chose that you thought would have had the most erosion?

F1: I said the tropical.

I: What was your reasoning for that?

F1: Um....because we had gone over in class (), of what type of climate (.5), I don’t remember exactly, but it was like a warm, wet climate was more.

Another common misconception is that more rain necessarily equals higher erosion rates. Students who make this statement without discussing the velocity of moving water on the surface as a mechanism for erosion or do not account for relief in their discussion have an inaccurate or incomplete understanding of the conditions necessary for high erosion rates. High precipitation in heavily vegetated or low relief areas, for example, does not cause high erosion rates. The student in the following interview excerpt also revealed his misconception that glaciers erode only when they melt. He gave inadequate reasoning with no explanation of processes on erosion-related questions on the essay assessment as well.

I: When you looked at the three variations of climate types, 'cause you’ve pretty well explained the effects of relief, there was temperate, tropical and glacial. Do you recall which had the greatest erosion rate?

M1: Tropical?

I: Why do you think that's the case?

M1: More rain.
I: In looking at a glacial situation where you’ve got alpine glaciers, what is going to control the erosion rate?

M1: (2.0) Um, alpine being in the mountains =

I: =yes=

M1: Um, again I would say whether the amount of rainfall that the area receives and temperature. If it stays cold enough to keep everything frozen, you wouldn’t have as much erosion. Whereas if, for some reason, global warming or what-have-you, the temperature rose and it started melting, you could have glaciation taking place

I: [okay

M1: [and it would carve out the surrounding area.

In the following excerpt, a second student expressed the same two misconceptions in her explanations of how climate affects erosion rates.

I: So which of the climates (temperate, tropical or glacial), which would have had the greatest erosion rates?

F4: Tropical.

I: Why do you think tropical has the highest erosion rates?

F4: Because it’s gonna get the most precipitation that increases....oh, wait, it is glacier

I: Okay, so why could glacial be the right one?

F4: Um, I don’t remember now.(laughs) Um, well I know what has a big part to do with it, I know glaciers are big erosional factors when they melt, probably more than rain.

Test scores seemed to over-represent understanding for the student in the next interview excerpt. She did not show an understanding of how climate and relief affect erosion rate during the interview, yet she answered all of the erosion-related questions correctly on the pre-test and post-test. She says she guessed at the correct answers and gave a brief statement of her reasoning during the interview, but did not show a complete understanding. In this case, test-taking skills such as using a process of elimination on a multiple-choice exam may have skewed her test score.

I: Let’s go ahead and move on to the third one. And, what were some of the main ideas of this one? ((referring to the third animation activity about climate, relief and erosion))

F2: ((laughs)) Oh, I did not get this one at all.
I: Okay.

F2: I think that there wasn’t enough text, so I just kind of like, I don’t know, I did that and like, didn’t spend much time with it.

I: Just pointing around and clicking and it didn’t really mean much?

F2: Yeah.

I: You can choose different climate types and relief. You could choose temperate, tropical, and glacial climates and you could also choose steep or gradual relief. So what do you think ‘relief’ means?

F2: Like, slope?

I: Would you expect the erosion rate to be higher on a steep slope or a gradual slope.

F2: Uh, steep.

I: Okay. How come?

F2: Because, gravity?

I: Yeah, pretty much. Um, it affects the way that water and ice and wind and all that sort of stuff will affect it. So, between the temperate... tropical and glacial, what of those three climates would you expect to have the highest erosion rate.

F2: Probably glacial because it all comes out in like an avalanche or, like. Oh yeah, I think so. Unless there’s a lot of rain, that could do it. But I would guess glacial.

Numerous students in essays and on multiple-choice assessments attributed the exposure of metamorphic and intrusive igneous rocks at Earth’s surface to volcanic eruptions. Their explanations varied from rocks blasted out of the volcano, carried to the surface by magma, or exposed as parts of the mountain are blown away by the explosion. While it is true that xenoliths can be incorporated from the wall rock of a volcanic chamber or conduit into the magma, or caldera formation and erosion can expose intrusive rocks underneath, the student responses do not display this level of specificity. The student from the following interview excerpt also wrote the same scientifically inaccurate statement in all of her essay responses.

I: How do those rocks, such as the, um, deep igneous and metamorphic rocks eventually get exposed?

F1: Um, well part of it is, like, if a volcano erupts and part of the mountain is gone, then you can like see underneath it. And also, like, erosion will strip away the top layers until you can see down to the bottom.
The student from the next interview excerpt stated that the flow of magma pushes deep crustal rocks to the surface on pre- and post-test, but had a good explanation on the Delayed post-test that did not include magma. His misconception could be an effect of visuals in the animations or visuals used on the tests.

I: Going back to the idea of deep rocks, like the metamorphic rocks and the intrusive igneous rocks coming to the surface, how does that happen?

M1: Um, a lot of it’s erosion and when, uh, what is it, uh, when the magma flows from under it can push large plutons and stuff like that towards the surface where and then over millions of years the erosion finishes it off.

If one looks at the graphics used on Question #4 of the assessment (Appendix IV) or Animation #4, entitled “How can rocks formed deep within Earth come to the surface?” (Appendix III), it is possible to see how students might misinterpret these cartoonish graphics to think that magma pushes metamorphic or intrusive rocks to the surface or that the subducting oceanic crust melts, despite text to the contrary. These misunderstandings seem even more plausible if one looks at the moving images in animation #4. Students remember the picture, not the process (Michelle Hall-Wallace, oral communication, 2004), so it is important that the pictures used in learning activities do not offer an unintended message. Six students who took the essay version of the assessment related exposure of deep rocks to volcanism or moving magma on the Prediction pre-test and Observations post-test, but did not mention volcanism in their Delayed post-test. The cartoon image of a subduction zone was not included on the Delayed post-test, which could account for the change in these students’ responses.

The following student also indicated that deep crustal rocks were exposed by volcanism on her multiple-choice pre- and post-tests, which was consistent with her initial interview response.

I: When we go over the Cascades, or some other mountain range, we can actually see those rocks exposed that the surface.=" (referring to metamorphic and intrusive igneous rocks)"
F3: Right.

I: So, how does that happen?

F3: Well, when the mountain erodes away over time, they’re exposed, or, um, through an explosion. The plutonic ones, I guess, they get exploded and they, um, get outside and they’re no longer a batholith.

I: Okay, by exploded, do you mean they become volcanic, or what do you mean?

F3: Well, I guess then that would make them extrusive, not intrusive anymore. Yeah, basically just the erosion.

The student from the following interview excerpt indicated on the assessments that oceanic crust pushes the continental crust upwards, and her interview comments seemed consistent with this answer. She also showed in the interview that she was unclear whether all mountains are volcanic peaks. She did not, however, choose any distracters on the multiple-choice text that indicated that all mountains were volcanic (Questions 23, 24, and 26). The assessments, therefore, may not have accurately captured the number of people who associated all mountains with volcanoes.

I: Are all mountains volcanic?

F2: I don’t know! I was wondering that in class! I don’t think so.

I: What is another way a mountain can form if it’s not all volcanic peaks?

F2: Um (2.5). Well, if it’s a convergent boundary that makes a volcano, right?

I: Yeah, but what else would happen to the crust at that convergent boundary?

F2: Besides raising?

I: Mmmm hmmm. So why though? You’ve talked about the elevation increasing quite a bit, but why does that happen?

F2: Because (1.0) the rocks down there ((pointing to deep crustal rocks on the diagram on the screen)) are pushed up?=

I: = mmm hmmm=

F2: Underneath it?

I: Yep.
F2: So are they all volcanic?

I: No, they're not all volcanic.

F2: But why, not?

I: So you've got the situation where you do have magma coming to the surface and forming volcanic peaks like Mt. Baker, Mt. Rainier, and stuff like that, but if you think of the other mountains in the Cascade Range, they're not all those nice conical volcanic peaks, right?

F2: Yeah. Are they the erosion from the first ones?

I: Erosion has a lot to do with the way that they're shaped, yeah, but if you have two plates coming together, you've got stresses that are squeezing the crust and pushing some of it up, and increasing the elevation like you said, and pushing some of it down to form this crustal root. So, when you squeeze that crust, it reacts by folding and faulting and all that sort of thing=

F2: =Ohhhhh....=

I: So that's what forms the mountains that you drive across that aren't just volcanoes. That was one of the reasons why I wanted to do this activity in particular because I got out of Geology 101 and didn't necessarily understand that all mountains weren't volcanoes.

F2: ((laughs)) That is definitely a question that should be, like, blatantly answered. Because I think a lot of people have it. My lab partner asked me too. And I said, "I don't know, that's a good question".

I: So let's talk about how these rocks that formed deep within the crust could possible get up to the surface. In the Cascades, you can see metamorphic rocks at the surface, and you can see coarse-grained igneous rocks at the surface.

F2: An eruption? Or the top erodes down and then, like, it comes up because it wants to stay balanced.

Another student also showed confusion about all mountains at subduction zone being volcanic, though she recognized that mountains could form by other means at collisional boundaries. The mountains just "bowing up" may represent a misconception itself, if she is not also picturing thickening of the crust below the mountain range.

I: How is the continental crust affected as the oceanic crust subducts underneath it?

F3: It gets pushed up or further...uh ((laughs)) this one goes down ((using hand motions to demonstrate plate convergence)) and then it builds up the lava and whatnot, and then it comes up to the surface further down, it can be miles down or over, and finally it comes up it becomes a volcano? So, it gets squished and forms a mountain?

I: What's getting squished?
F3: The continental plate, er, yeah, the continental plate overriding the oceanic crust.

I: Are all of the mountains that are created volcanoes? Or is there....

F3: With this one ((pointing to a diagram of an oceanic-continental convergent boundary on the computer screen)), with the subduction zone, yes. But when they, they also come together ((referring to a collisional boundary?)) and then, just like bow up, and then it's not necessarily a volcano?

The following two interview subjects stated that oceanic crust pushes continental crust upward, which they also indicated on their multiple-choice test answers.

I: As you go through ((pointing to a sequence of plate tectonics slides)), and this plate boundary becomes an active subduction zone, what happens to the continental crust over time?

F4: Do you mean when another one is subsiding under?

I: Mmm hmm.

F4: Well, I guess it's more affected by the earthquakes as it goes under, and it gets pushed up.

I: So why does it get pushed up?

F4: Um, because the other land mass, or the ocean crust is coming under it and pushing it up.

I: So, how was the continental crust affected when the plates came together at this plate boundary?

F6: Um, usually there would be earthquakes happening at the subduction zone, and possibly some forming of volcanic landforms.

I: So as far as the shape of the crust itself, what happens as the plates continue to come together?

F6: Um, well, the oceanic crust subducts underneath and (1.0) and, you know, pushes up the continental crust on that side of the plate boundary.

Numerous students displayed the misconception that the subducting plate pushes the continental crust upwards in their multiple-choice and essay responses. The subducting plate sinks downward into the mantle because of its negative buoyancy; therefore it cannot “push up” on the continental plate to form a mountain. Shallowly subducting oceanic slabs, such as in parts
of the Andes, support the overlying continental crust, but do not have an upward vertical component to "push up" the continental crust. It is not clear whether students actually mean that the subducting plate displaces the continental crust vertically or if they are just misstating their understanding that the compressive stress of the converging plates cause thickening, which "pushes up" the continental crust into a mountain range. Further interview probing that asks students to draw or show with their hands what they mean would be necessary to determine what each individual student means by their statement that the oceanic crust pushes up the continental crust.

The student in the following interview excerpt often relied on memories from lecture and did not show an understanding of the relationship between changes in mountain height and the crustal root's response. Her Delayed post-test score was very low (8 points out of 16 possible), indicating that she did not have a true conceptual understanding because she could not apply what she has recalled to a new situation.

I: What were some of the main ideas of this activity? (referring to the second animation activity dealing with isostasy)

F4: Isostatic rebound?

I: So what does that mean?

F4: Um, well, I just remember it from there's a glacier over it, the glacier will compress it, and then it will pop back up after the glacier melts after a long time.

I: That's what somebody talked about in lecture?

F4: Yeah, I think so. But I remember doing it on here because I remember it in lecture, but I remember the pictures here. But I remember the example of a glacier better.

I: Yeah, it's a similar concept, for sure. Um, this particular one doesn't have glaciers involved in it, but it the isostasy idea.

F4: I think maybe I first heard the word on this, and then maybe I learned it in class, and then was like, oh yeah, I remember that.

I: Cool. You made some connections. So, um, why does, when you have a mountain range up here, why does the crustal root form in the crust?

F4: Um. (3.0) Grounds it, maybe. Gives it more, like, I mean, obviously it has to go down to give it a stable base.
I: And what do you predict would happen if we increased the height of the mountain? (referring to the crustal root)

F4: Um, I remember these. These were the questions that were on the....

I: Yeah, pretty similar. ((both laugh))

F4: I did really bad on this. I think that was the one were it came back up, right?

I: Do you have any idea why that would happen?

F4: Um (3.0) Well, I guess maybe just because the mountain is forming, it would be harder for it to grow both ways.

In most cases the assessments revealed equivalent misconceptions to those discussed in the interviews, and the test scores were indicative of the students' overall understanding. This correlation helped to establish the content validity of the assessments, that is, that the assessments actually measured what they were designed to measure. The interviews also provided an opportunity to look more deeply into students' misconceptions. The interviews were "blind", meaning that the interviewer did not look at each student's assessment ahead of time to avoid bias during the interview. Since interviews were conducted shortly after the assessments were completed, the key misconceptions that many students had in common had not been identified. In retrospect, the interviews would have been more valuable if common misconceptions were pre-identified and the interview subjects were probed to further explain their reasoning about their scientifically inaccurate beliefs.

Although shortcomings in the assessments or learning activities may be partially responsible for the small gain in post-test scores and student confidence, students' resistance to changing their misconceptions despite instruction also likely played a major role. In several cases, students who displayed a misconception on a pre-assessment, and answered the question after the treatment reverted back to the original misconception on the Delayed post-assessment or interview. Often times peoples' beliefs persevere despite contradictory evidence or experiences
Motivational factors such as wanting to hold onto faith-based beliefs or findings based on one's life's work despite competing evidence could be a factor. However, explanations involving information processing such as biased recollection and interpretation of evidence seems more likely (Nisbett and Ross, 1980, Roth, 1990). Studies conducted by Ross and others (in Nisbett and Ross, 1980) suggest that people actively attempt to find causal explanations for events, and once they have generated these explanations and find them to be plausible, they are reluctant to let go of them even if evidence does not support their beliefs. More extensive interviews targeting misconceptions would be necessary to test the idea of resistance to changing original ideas.

Threats to Validity and Reliability of the Assessments

Although the content validity of the assessments was established by the interviews and collaboration with geology experts, there were threats to the validity and reliability of the assessments that likely affected their effectiveness as measures of students' understanding. Three categories of possible threats to the validity and reliability of the assessments are interaction of testing and treatment, assessment fatigue and the students' lack of motivation to participate.

Interaction of Testing and Treatment

Changes from my original research design brought about potential problems with reliability and validity. In the original research design, three versions of the assessment were planned with equivalent questions that related to three different mountain ranges that were not well known to students. To determine equivalent forms reliability of tests forms A, B and C, counterbalancing was planned to assure their equivalence. One-third of the students in the main study would have taken form A, one-third form B, and the remaining one-third would have taken form C as the pretest. Scores from each version would have then been correlated to ensure equivalence. That research design was abandoned in favor of creating a Predictions pre-test and Observations post-test that related directly to the activities in the interactive learning object and
topics on the static web page. The purpose of the Prediction questions was to give students a
direction to pursue as they explored the web activity by asking them to predict what changes
would result from manipulating variables or observing processes occurring over time. According
to most of the students interviewed, the Prediction questions did serve that purpose. The
interview excerpts that follow demonstrate how the Predictions questions influenced students' use
of the web activity.

I: Did answering those Predictions questions before using the interactive activity affect
the way that you used this at all?

F4: Um, (1.0) kind of, I mean, some of them I, like, I remember some of the Predictions
questions and I didn’t know what they were talking about (laughs), so then when I got
to it, I was like “oh, that’s what they were talking about”. But maybe, I guess, only the
things I didn’t get, didn’t know what they were referring to, those are the things that I
really paid attention to once I got there.

Although answering the Predictions questions did seem to give direction to the students’
use of the web activities, changing the research design compromised the reliability of the
assessments. Instead of having three different but equivalent forms of the assessments, two
identical assessments were used that differed only in tense, and one Delayed post-test that was
completely different. Although most of the concepts covered on the Delayed post-test were the
same as those on the Predictions pre-test and Observations post-test, the questions were applied to
an actual mountain range, the Caucasus Mountains. The application of knowledge to an
unfamiliar situation is a more complex process than recalling what students may have directly
experienced when they used the web activity (Mayer, 2001), so the Delayed post-test was not
comparable with the other assessments. Because there were not three different but equivalent
forms of the assessment to administer as the pre-test, counterbalancing could not be used to
determine whether they were equally difficult.

Another potentially disadvantageous decision made in the research design was to have
students take the Predictions pre-assessment, interact with the web activity, and take the
Observations post-assessment in one sitting. This choice was made so that the Predictions questions could guide interaction with the web activity and to reduce the chances that students would forget or choose not to complete an assignment. However, this choice brought about three potential threats to the internal validity of the assessments. The first, pre-test sensitization, is the possibility that the pre-test will condition the subjects' interactions with the experimental stimulus (Cook and Campbell, 1979). Another possibility is that students may have performed better on the post-test because of familiarity of the items from the pre-test (Cook and Campbell, 1979).

**Assessment fatigue**

The temporal proximity of the pre-test, treatment and post-test may have caused some students to score lower than their level of understanding should reflect because of assessment fatigue. In interviews, written comments on the post-activity questionnaires, and even within the essay responses themselves, several students expressed fatigue or frustration with the length of the assessments.

The student whose pre-test, post-test and Delayed post-test responses to Question #4 are shown below indicated during his interview that he would have preferred more multiple-choice questions because the essay questions were “daunting”. He did not express fatigue or frustration directly in the interview, but his performance on the post-test signal the possibility that he was not putting forth the same effort as he did on the other two assessments. His answers to the Observations post-test questions were consistently shorter than pre-test and Delayed post-test with no improvement in score, which may indicate assessment fatigue. The point values for each response were assigned according to the pre-determined rubric for Question #4.

Predictions pre-test response to Question #4

There are 2 main processes that would expose both igneous and metamorphic rocks at the surface of the crust. They could be exposed by the flow of lava that brings these rocks to the surface in heavy flows. The other major process that would expose these rocks would be that they make it close to the surface of the crust but not all the
way, erosion of the mountain (sic) (volcano) would expose the rest of the rocks. Evidence for this would be pyroclastic explosions, heavy volatile explosions (Mt. St. Helens) and stocks (erosion) (sic). 2 points

Observations post-test response

UPLIFTING through volcanism is the one of the two contributors to the exposition (sic) of igneous and metamorphic rocks. Erosion (sic) is the other key factor in this process. 1 point

Delayed post-test response

High grade metamorphic rocks and igneous rocks formed deep within the earth can be seen at the surface of the mountains is possible with upwelling and erosion. As the two plates converge the rocks are formed deep within the crust over the millions of years as after the rocks have been formed the converging plates form new mountain base and rocks under the old rocks pushing them upwards. As they ascend to the surface erosion slowly but surely strips away the top layers finally exposing the rocks that were formed long ago deep beneath the surface. 4 points

Several other students who took the essay assessment also answered briefly or did not answer all parts of the question on their Observations post-test, which often negatively affected their post-test score. It is also possible that some students who took the multiple-choice version of the Observations post-assessment may have rushed through it and guessed, or had more difficulty comprehending the questions due to fatigue.

The following student expressed his or her exhaustion on an essay answer to Question #3. The student wrote brief answers on all Observations post-test questions, though 2 of the 4 scored higher than her pre-test responses because they were more scientifically correct despite their brevity.

Observations post-test response

I'm still fairly unclear about these questions and it could be because i'm exhausted and can't focus on much right now. In fact I don't even remember reading much about this question. however, I still think areas of steep relief and glacial climate would have the fastest rate of erosion due to the harsher conditions.

Several students indicated test fatigue or frustration with the length of the assessments on the post-activity questionnaire. The following statements are copied directly from the online questionnaire in which students responded to the question, “Please provide brief written
comments about what you considered useful or enjoyable about the web activity, as well as what could be improved."

Post-questionnaire comment: Group A (essay Interactive)

I thought it was a very helpful activity to better understand the way these processes occur, but it seemed very tedious that I was answering the same question over and over again. I probably felt this way because that was what was happening. I felt pretty confident in my initial ideas about what would happen and then going through the web activity increase my confidence much more. After than the last thing I wanted to do was answer those questions again.

Post-questionnaire comment: Group C (multiple-choice Interactive)

I understand that asking the same questions before and after the presentation of the flash diagrams was necessary in determining how informative the presentation was, it felt very redundant and long.... toward the end I stated to feel like I would rather be anywhere but at this computer answering questions.... I found myself losing focus and having to sometimes read questions three or four times before I took in any of it.... They were not particularly difficult questions; the length of the assignment just cause me to lose focus....

Post-questionnaire comment: Group B (essay Static)

It may be that I'm tired, but I do not feel that his (sic) was very productive. I think it would be much easier to actually learn in a classroom and talk about it than read it on a computer screen. I found myself having to read the questions over about 5 times before I could concentrate long enough to comprehend what they were even asking.

Motivation to Participate

A few students commented on their post-activity questionnaires about their lack of motivation to perform well on the assessments and interact meaningfully with the web activities because they knew their score would not affect their grade. To satisfy ethical considerations for the Human Subjects Review Committee and to separate the research from students’ course grades for Geology 101, only the students’ completion, or lack thereof, of the assignment was considered for their lab grade. The validity of educational research can be compromised by practical and ethical issues when working with human subjects in an academic setting. Many students chose not to complete the activities at all and were therefore not considered as subjects in the study. The penalty for not completing the assignment was small, likely resulting in some students’ choice not to participate.
Post-questionnaire comment: Group C (multiple-choice Interactive)

I think it would have been really helpful had it been something I knew I was going to be test (sic) on. Honestly, I had a hard time dedicating myself to it knowing I would not be graded (which says how much I really care about learning I suppose). One thing I would improve about the lab activity is possibly making it a little shorting (sic). Especially the tests, which were a little too much to keep your mind focused on. Overall it was helpful and would have been a great study tool if we were using it for the class. Thanks!

Interpretation of Questionnaire Data

In addition to the interviews and assessments administered self-reported online questionnaires were administered to the subjects about their confidence in their understanding of four topics related to mountain building processes. The self-reported confidence levels increased more in most cases for students in the Static group. The confidence levels in “plate tectonics” actually decreased slightly for both groups. It is possible Likert scale measurement may not have been sensitive enough to accurately reflect change about a subject that students already knew a great deal and reported high confidence. Other possibilities are that students realized they had prior misconceptions or did not know as much as they originally thought, or that the learning activity generated new misconceptions or misgivings about their previous ways of thinking.

In the case of the age of mountain ranges, there was only a slight increase in confidence by both groups. Several students’ written comments about the activity indicated that they felt that the age of mountain ranges was not adequately covered. This was a deficiency in the both web activities because age progression was shown in only one of the activities and was not emphasized. Confidence in isostasy increased the most dramatically between the pre- and post-activity questionnaire. This is logical because most students had very little or no prior experience with isostasy. Most students’ written comments indicated that they learned a great deal about isostasy, while others expressed confusion about the equation or frustration that they did not have background from lecture or lab before learning about it in the web activity.
The Likert-scale ratings about opinions about the web activity may have been more useful with 4 or 6 rating levels because of the tendency toward the mean that often occurs on Likert-scale surveys with an odd number of levels on the scale. Most students in both groups chose “3” for their opinions about the usability of the web activity and their enjoyment of using it, despite, or perhaps because of, more clear definitions of what a “1”, “3” and “5” meant. The students’ written comments for the interactive web activity were far more favorable, but the Likert scale ratings were approximately the same.

Another potential reason for the persistence of misconceptions in the interviews and post-assessments is ineffective instructional design of the interactive and static web activities. It is also important to consider, despite some research findings to the contrary, that interactive computer animations may not be an effective means for reducing student misconceptions.

**Instructional Design of the Interactive Learning Object**

Although students who used the interactive Flash learning object gave more positive reviews than those who viewed the static web page, they did not perform as well on most measures of student conceptual understanding. The Flash learning object engaged students in both behavioral active learning and cognitive activity because they had to physically choose variables for most of the animation activities rather than just pushing “Play” as is common on many animations. The Predictions and Observations questions were designed such that students needed to find relationships between the variables they changed and the resulting outcome, which is a form of cognitive active learning. It is not clear, however, how cognitively engaged every student was in using this activity, and according to Mayer (2001), learning research shows that cognitive activity is more important than behavioral activity in fostering meaningful learning. This study shows that the benefits of interactivity described by Mayer (2001) and Tversky (2002) did not translate into more meaningful learning in this case. There are a number of possible
reasons why the interactive learning object was not more successful at increasing student conceptual understanding, including unstructured navigation, insufficient text information, lack of audio narration to aid information processing, and a lack of metacognitive and conceptual change strategies.

One feature of Flash learning objects is non-sequential navigation that allows students to move through the web activity in whatever way they choose. A disadvantage of the way the learning activity was structured is that much of the text is optional to read. Therefore, it is quite possible that students interacted with the activities without reading the supporting text that explained the reasons for their observations. “Helpful Information” buttons were available on each activity to explain concepts such as tectonic shortening, isostasy, and the rock cycle. One student interviewed made it apparent that not everyone read the text accompanying the animations that explained the processes they were observing.

I: A general question about the parts of the learning activity like the Intro, Models, Summary pages, and, um, the Instructions and Helpful Information. How much time would you say, or did you spend much time reading those text and were they very helpful?

F2: I did go back to the introduction to read how (), 'cause I skipped right to the Explore part =

I: =Oh. Okay.=

F2: and I’m like, ‘okay, I need to go back and read what I need to do here’.

I: ((laughs))

F2: So yeah, I did spend time with that. The Summary, I spent definite time reading.

I: Did you feel like you got anything out of it?

F2: Yeah. ()

I: Okay. Did you use the Helpful Information buttons at all?

F2: Nope.

I: This is just some text ((shows student Helpful Information pop-up box on the computer monitor)) that explains what you just went through and what isostasy is all about and that kind of thing, but because it doesn’t force you to use it, I expected that not everybody would, so.
F2: Oh, I guess I didn’t know.

In the interview, students commented that it was difficult to pay attention to text on the screen and the animation activity itself. This difficulty is consistent with Mayer’s (2001) dual-channel and limited-capacity assumptions of the cognitive theory of multimedia learning. In this case, the students’ inability to process written text and graphics simultaneously has important implications because the dynamic text above the plate tectonics activity was the only cue that dealt with age of mountains or progression of time.

I: As you stepped through ((referring to the sequence of plate tectonics slides)), how much time were you spending reading the stuff or looking up here ((pointing to the dynamic text at the top of the screen))? Did that attract your attention at all?

F3: For the volcano, I mean, for the plate tectonics, not much ((referring to the text within the plate tectonics graphics)) because we had talked about it a lot in class. But the stuff above it, um were, I didn’t pay nearly as much attention. Obviously since that was 50 million years ago and I said 6, it didn’t exactly hit too hard.

The student in the following interview excerpt indicated uncertainty about how to interact with the isostasy activity. She was unsure what to do with the “+” and “-” buttons until she clicked them and saw changes, and would have liked directions on the screen with the animation activity. She also said that the formula was unclear and intimidating. Other student comments on the post-activity questionnaire indicated that there was not enough written information to explain certain topics, such as the effect of climate on erosion rates.

Post-questionnaire comment: Group A (essay Interactive)

It was a good program but didn’t seem to fully cover some of the information that we needed to answer the questions.

Post-questionnaire comment: Group C (multiple-choice Interactive)

The part about climate was not explained well. The question about how climate affects erosion asked me to explain my reasoning, but I just had to guess.

A solution for many of the problems discussed by the students is to use narrative voice-overs for conceptual explanations and instructions. With written text, space constraints
necessitated instructions on a separate page than the animation activities and only allowed for brief informational text. Narrative voice-overs would be a solution to the space problem, and would allow students to simultaneously interact with the animation activities while listening to instructions and content explanations. For example, explanations of why isostatic equilibrium and erosion rates changed could be included as audio sound bytes that respond to students manipulating variables. The research conducted by Mayer and others (1991; 1992; 1998) has shown that students perform better on retention and transfer tests after viewing an animation with oral narration than the same animation with written text, so narratives could have the potential to increase the effectiveness of the interactive learning object dramatically. The increased file size, and therefore loading time, associated with audio narration could be a potential disadvantage for students with low-bandwidth Internet connections.

Although adding narration would improve most of the animation activities, a substantially different approach for the plate tectonics activity could be helpful to alleviate the common misconception that the oceanic crust pushes up the continental crust to form mountains. An interactive animation showing downward motion vectors on subduction oceanic plate that allows students to thicken continental crust by applying compressive stress as they actively move the plates toward each other would likely reduce this misconception more than a passive slide show of tectonic stages. It also would be possible to include alternative models where students try to make the subducting plate push the continental plate upwards only to see that it is not possible because the subducting plate is moving downwards with no upward vertical component. This would deal directly with a commonly held misconception.

Seeing the crust thicken upwards and downwards as it shortens would also deal directly with the misconception that the crust below the mountain range thins during plate convergence because it “bows upward” to form the mountain. According to conceptual change theorists (e.g. Posner et al., 1982, Hewson and Hewson, 1983), students need to be forced to reveal their
misconceptions and be dissatisfied with them before being willing to assimilate new conceptions into their understanding. This process could begin with an “exposing event” that invites a student to explain what they observe, such as mountain formation at a convergent plate boundary, in terms of his or her own initial understanding (Nussbaum and Novick, 1982). Conceptual conflict could be creating by presenting a discrepant event, such as interactive animations showing thickening of the crust above and below the surface, that students need to explain. Finally, students could be encouraged to invent a new conceptual model that is consistent with the accepted scientific understanding of the concept. Posner and others (1982) added that students can integrate new concepts with their existing knowledge only if there is dissatisfaction with existing conceptions and the new conception is understandable, potentially true and believable, and has a convincing reason to be considered more useful than his or her previous conception. Because students might be willing to accept the inconsistency, it is the role of the instructor to insist that students confront and resolve the issue (McDermott, 1993).

The interactive web activity, in its current form, did not have a component that allowed students to explore their own misconceptions and compare them to contradictory evidence. The interactive web activity could be modified so that students who answer assessment questions incorrectly are directed to animation activities targeted to address their misconception.

Conceptual change can also be facilitated by the combination of the animations to provide visual evidence and a knowledgeable lecture or lab instructor to question and guide students.

Some students indicated that the interactive web activity gave the user too much autonomy in the navigation without enough direction about the intended learning outcomes or a clear purpose.

Post-questionnaire comment: Group C (multiple-choice Interactive)

It seemed as if you had too much freedom on what to learn but the test only asked for certain things.
Effective multimedia presentations present material with a coherent structure and provide guidance to the learner on how to build the structure (Mayer, 2001). As developed, the interactive web activity did not provide a guide, besides a brief text summary, that allowed learners to incorporate the knowledge they gained in each animation activity into a coherent structure about the interactions of processes that contribute to mountain formation. Another potential deficiency of the web activities was the lack of metacognition required of the students. The Predictions questions they answered before interacting with the web activity focused the learning of some students who used metacognition to determine whether they had found the information they needed to answer the questions that initially challenged them. Beyond that, however, no metacognitive strategies were directly taught in the learning object.

**Limitations of the Study**

In addition to the aforementioned shortcomings of the interactive web activity and the assessments, the effectiveness of this study may have been hindered by the scope of the research topic and objectives. The topic “mountain building” may have been too broad, both for the web activity and as a research topic, to be managed effectively in the context of a master’s thesis. Likely it would have been more effective to focus the research on specific concepts such as isostasy, stresses caused by plate convergence, or other important aspects of mountain building, without attempting to teach the whole topic superficially.

Geoscience instructors, cognitive scientists and educational researchers at a National Association of Geoscience Teachers conference titled “Teaching Geoscience with Visualizations: Using Images, Animations and Models Effectively” synthesized three recommendations to guide the creation and use of effective visualization tools in undergraduate science courses (NAGT, 2004). Their first recommendation is that more cognitive research needs to be conducted on how students learn through visualization of geoscience concepts and what preconceived notions
students bring to the classroom about those topics. This recommendation also states that “targeted research is needed to quantitatively evaluate the effectiveness of visualizations” in order to compile a list of general guidelines for developing effective visualization tools. The second recommendation is that specific content areas in which visualizations are needed, including time-based processes, should be researched and targeted for visualization development. Hopefully my thesis research, when published in a form accessible to the geoscience education community, will make a contribution towards these recommendations.

Finally, the group recommends that educational researchers, cognitive scientists, visualization developers and geoscience educators should form partnerships to “carefully design and implement innovative assessments of the effectiveness of visualizations” and publish their findings so that they are available to the geoscience education community. The lack of collaboration with these types of experts is a limitation to this study. As the instructor, developer of the web activities, questionnaires and assessments, as well as the collector and interpreter of data, it was difficult to fill all roles effectively. It might have been more appropriate to write effective data collection instruments such as surveys or assessments to diagnose misconceptions in order to evaluate existing educational technology.

**Implications for Policy and Practice**

Although the original goal to develop and distribute a highly effective interactive learning object of mountain building processes has not been accomplished satisfactorily, the results of this research have revealed important implications for geoscience instruction, multimedia design and research practice.

**Implications for Research Design**

A focused research question and collaboration with professionals in other fields would benefit geoscience education researchers. Partnerships between educational researchers,
geoscience educators, curriculum developers and cognitive psychologists, for example, would allow each researcher to contribute their expertise to a well-rounded, rigorous research study that evaluates the effectiveness of well-designed multimedia activities with valid and reliable assessment instruments.

Researchers evaluating the effectiveness of instructional methods should consider finding assessments that have already been tested extensively or collaborate with assessment experts to validate new assessments because the process to develop and validate test items properly is quite complex. The Geoscience Concept Inventory, for example, has been developed over a two-year period and administered to 4500 students in 43 geoscience courses (Libarkin and Anderson, 2005). A pool of 73 items was narrowed down to 29 via qualitative validation by experts in education and the geosciences, and by quantitative analysis of student test data. Item analysis based on classical test theory was used to observe statistical characteristics of particular items to determine which questions are appropriate to include on the final assessments instrument.

Classical test theory focuses on item difficulty and item discrimination, which are both dependent on the populations sampled (Libarkin and Anderson, 2005). Item Response Theory uses curve-fitting models where test data are fit to equations of probability, and are thus independent of the populations sampled (Sadler, 2000). Haladyna (2004) advocates an 8-step item review process in which items developed are checked to see if they 1) violate any item-writing guidelines, 2) elicit the intended cognitive process, 3) contain accurate content, 4) are written clearly and grammatically correctly, 5) avoid stereotyping or insensitive use of language, 6) have only one correct answer, 7) credits alternative explanations for their choices when justified during a field-test, and 8) are subjected to a round-table discussion by test takers who “think-aloud” to inform the developers of the effectiveness of the item for its intended cognitive process and content.

These assessment validation procedures are not all practical for course exams and quizzes, but should be employed for published diagnostic assessments. The geoscience education community
should be encouraged to produce and validate test more items on Earth science topics such as those in the Geoscience Concept Inventory (Libarkin and Anderson, 2005).

Assessment fatigue and meaningful incentive are important to consider when asking students to be part of research. It is not realistic to expect that all students will put 100% effort into an activity that takes a long period of their time and will not affect their course grade. Ethical considerations and accuracy of data seemed to be at odds in this study, and should be considered carefully when developing an effective research design.

Implications for Multimedia Curriculum Design

In this study, the interactive Flash web activity did not lead to significant gains in student understanding of mountain building processes compared to a passive activity such as viewing a static web page. The results of this study suggest that interactivity in itself is not sufficient to increase conceptual understanding of geological processes. Although many students in this study reported that they were engaged and interested in the interactive learning activities, the learning objectives they were supposed to accomplish were not made clear to the students. Multimedia designers may help facilitate learning by including explicit learning objectives to provide a structured framework for each animation activity (Mayer, 2001), and building pre- and post-assessments into the activity so students can be made aware of their preconceptions and track their own progress. Embedded assessments would prevent students from exiting an animation activity with their misconceptions intact (Yeo et al, 2004), and would encourage students to read text information or repeat the activity until they could successfully complete the questions. As previously discussed, audio narration and straightforward graphics may help students process the desired information without generating further misconceptions.

In-depth assessment of students’ misconceptions should be completed before the development process of a learning activity begins. Knowing what questions to ask to elicit misconceptions is difficult, so several types of written tests, performance assessments or oral
interviews should be attempted. Once a list of key misconceptions has been established, the learning activity should target these misconceptions specifically to narrow the focus of the concepts in the lesson. The misconceptions revealed during the main study could have been directly addressed in my interactive animations if the right questions were asked in the initial survey stage of my research (Appendix I) to discover the students’ beliefs earlier. Consequently, many students’ misconceptions were not directly confronted during the web activities and were therefore unlikely to change. Not all computer animation activities need to be designed to address specific misconceptions, but those that are designed to facilitate conceptual change should be based on a thorough investigation of students’ beliefs.

Implications for Geoscience Instruction

The findings of this study also have implications for assessment and instructional practices used in university science classrooms. Instructors and department chairs are asked to make decisions about textbooks and educational technology, so it is important for them to critically evaluate the effectiveness of that technology before incorporating it into their instruction. A brief evaluation of visualization tools included with introductory geology textbooks and available on the Internet revealed many animations that proceeded quickly or contained highly simplified illustrations or processes that could be misinterpreted by students. As previously mentioned, instructors who choose to use animations in their classrooms may need to help students understand what the visualizations are intended to show and relate that information to students’ preconceived notions. Geoscience instructors would benefit from a pool of validated test items for their courses to diagnose misconceptions and evaluate students’ progress towards conceptual understanding of key Earth science topics. When teaching or developing educational curriculum, instructors should take care when using catch phrases such as “recycling of the crust”, a statement which was misinterpreted by students in this study and in laboratory settings at WWU. If differences between closely related topics such as weathering and erosion are
important to geoscience instructors, they need to be clear about the distinctions between them so that conceptual understanding is not confused. Also, instructors and curriculum developers should use caution with illustrations and graphics that can be misinterpreted and create misconceptions rather than alleviating them such as rising ‘blobs’ of magma from subducting oceanic crust.

Focusing on key ideas and unifying themes could be beneficial to increasing students’ conceptual understanding of geoscience topics. Project 2061, a science education reform project funded by the American Association for the Advancement of Sciences, advocates “unburdening the curriculum” by cutting topics and subtopics and reducing technical vocabulary, and instead focusing in depth on the understanding of central themes (Project 2061, 2001). Research findings rarely support the notion that students may ‘forget the details but remember the general ideas’ when taught by traditional instruction. To increase students’ conceptual understanding instructors should find a balance between how much is learned and how well it is learned (Project 2061, 2001). Mountain building could be one such unifying theme in which students’ thinking can be elicited, discussed and challenged, and geological concepts can be introduced throughout the course as part of a bigger picture. Mountain building would also lend itself well to a course taught using an Earth System approach that emphasizes the interactions and feedbacks of internal, surface, atmospheric and biological processes on Earth. Several other unifying themes have been suggested by professors at WWU to frame introductory geology curriculum reform, all of which could be interesting contexts to utilize conceptual change strategies to help students develop an understanding of important geology concepts.

To begin to understand students’ ways of thinking about scientific processes, geoscience educators can collect responses from their own students or look to previous research. In the case of mountain building processes, the existing published literature mainly focused on K-12 students. An important contribution of this study is the addition of fourteen misconceptions held
by college-level students after some instruction on plate tectonics (Table 17). This list may serve as a starting point for introductory geology instructors to confront their students' misconceptions about how mountains form.

**Future research**

A number of topics for future research could extend from the findings or unanswered questions from this study. The literature review revealed no focused research about misconceptions related to isostasy or rock exhumation. Study of misconceptions related to buoyancy and density have been conducted in the context of physics (e.g. Loverude et al, 2003) but these concepts also affect students' understanding of the behavior of the lithosphere and would be an interesting topic of study.

A second question is whether interactive learning objects about specific misconceptions could bring about conceptual change. For example, would development of an animation showing downward motion vectors on a subducting oceanic plate in which students thicken continental crust by applying horizontal compression reduce the misconception that the subducting plate pushes up the continental crust to form mountains?

A third question is whether teaching geology concepts in a course with a unifying theme would help increase students' conceptual understanding of those topics. Using Libarkin and Anderson's (2005) Geoscience Concept Inventory, a researcher could evaluate students' understanding before and after the proposed introductory geology course reform occurs at WWU.

A research topic that extends from the possible creation of misconceptions by the graphic images used in the web activities is an in-depth study on how these graphics are interpreted by students. Although interpretations of visualizations has been studied in the past (e.g. Hall-Wallace, oral communication, 2004), a specific look at student interpretations of the graphic
images used in the animated web activity could lend further insight into why certain misconceptions were not eliminated or were newly created for some students.

Further observation of the way students choose to use interactive multimedia would also be useful. Geoscience multimedia developers would benefit from studies that videotape and quantify students’ interactions with software to determine effective ways to encourage students to navigate through interactive web activities in ways that would facilitate learning rather than completing the activity quickly.

Finally, the development and validation of diagnostic assessments about additional key Earth Science topics could benefit geoscience educators in the same way that assessments about mechanics, photosynthesis, and the particulate nature of matter have contributed to the disciplines of physics, biology and chemistry.
REFERENCES


King, C., 2000, The Earth’s mantle is solid: teacher’s misconceptions about the Earth and plate tectonics, School Science Review, v. 82, p. 57-64.


Libarkin, J.C., and Anderson, S.W., 2005, Assessment of learning in entry-level geoscience courses: Results from the Geoscience Concept Inventory, Journal of Geoscience Education; in press.


Table 1 Misconceptions cited in the literature related to mountain building.

<table>
<thead>
<tr>
<th>Research Study</th>
<th>Age group</th>
<th>Misconceptions</th>
</tr>
</thead>
</table>
| Chang and Barufaldi (1999)               | 9th grade                  | • Mountains are formed by erosion from rivers and glaciers  
• Mountains show up after the regression of the sea  
• Mountains grow  
• Mountains are formed by earthquakes                                                                                                                   |
| Dove (1988)                              | 11-17 years old            | • Magma flows from the center of the Earth  
• Mountains are created by God or man  
• Mountains grow from stones  
• Volcanoes are not found in cold climates                                                                                                               |
| Dove (1997)                              | College-level              | • All erosional processes are physical  
• All weathering processes are chemical  
• Weathering processes are connected to the weather (atmospheric processes such as wind and rain)  
• Erosion requires that the whole object being eroded (e.g. stone or figure) moves                                                                     |
| Happs (1982)                             | 11-17 years old (New Zealand) | • Mountains have always been present  
• Mountains are created by God  
• Mountains are formed by tides removing material from the edges, leaving an upstanding mass  
• Mountains are formed by underground pressure  
• Mountains are high rock made up of either molten rock or rock pushed up  
• Mountains are extinct volcanoes  
• Mountains are volcanoes, dormant or active  
• Mountains have always been there (since the landmass was formed)  
• Mountains have been there “since time began”  
• No changes will occur to mountains in the future  
• Uplift (or volcanism) that created mountains is not occurring at present or in the future                                                                   |
| King (2000)                              | Adult science teachers (England) | • The mantle (asthenosphere) is completely liquid  
• The mantle (asthenosphere) is completely solid                                                                                                            |
| Libarkin (2001)                          | Distractors on assessment, based on misconceptions in literature | • Gravitational attraction of the moon causes rocks to bend  
• Minerals pushing up from beneath Earth’s surface  
• Landslides creating piles of rocks  
• Oceans receding and leaving rocks behind                                                                                                                |
| Marques and Thompson (1997)              | 16 & 17 years old (Portugal) | • Vertical forces push up the bottom of the oceans and originate the continents  
• Cooling of Earth results in the appearance of topography                                                                                               |
| Muthukrishna, et al (1993)               | 8th grade                  | • Mountains are made from earthquakes and volcanoes shaking the earth  
• Mountains are made from wind blowing dust and dirt and the dirt piling up in a certain area and being covered by snow  
• Mountains start out “just as they were” and erode down to sand and earth, and then some sand and earth is pushed together by weather and nature to form mountains  
• Mountains are made with lava or rock                                                                                                                       |
| Philips (1991)                           | 7th-12th grade             | • Mountains are rapidly formed                                                                                                                                                                                  |
Table 2 Results from Preliminary Informal Survey during Spring quarter, 2003.

<table>
<thead>
<tr>
<th>Selected Survey Questions and Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>How are mountains formed?</strong></td>
</tr>
<tr>
<td>• Related to plate tectonics</td>
</tr>
<tr>
<td>• Two plates colliding/converging</td>
</tr>
<tr>
<td>• Subduction-related</td>
</tr>
<tr>
<td>• Related to volcanism</td>
</tr>
<tr>
<td>• Related to earthquakes</td>
</tr>
<tr>
<td><strong>Do mountains change over time? Explain what you mean by your answer or provide an example if you can.</strong></td>
</tr>
<tr>
<td>• Erosion</td>
</tr>
<tr>
<td>• Glaciers</td>
</tr>
<tr>
<td>• Volcanism (as agent of change)</td>
</tr>
<tr>
<td>• Continued uplift/plate convergence</td>
</tr>
<tr>
<td>• Earthquakes (as agent of change)</td>
</tr>
<tr>
<td><strong>How long does it take for mountains to form?</strong></td>
</tr>
<tr>
<td>• 100s of years</td>
</tr>
<tr>
<td>• 1000s of years</td>
</tr>
<tr>
<td>• 10,000s</td>
</tr>
<tr>
<td>• 100,000s</td>
</tr>
<tr>
<td>• Millions of years</td>
</tr>
<tr>
<td>• Billions of years</td>
</tr>
<tr>
<td>• Thousands to millions</td>
</tr>
<tr>
<td>• A really long time/many, many years</td>
</tr>
<tr>
<td>• Depends on speed of plate movement</td>
</tr>
</tbody>
</table>

Table 3 Selected misconceptions present in student responses from Preliminary Informal Survey.

<table>
<thead>
<tr>
<th>Selected Misconceptions/Alternate Frameworks (quoted from Geology 101 student responses):</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Mountains are formed by “some kind of mid-Earth activity”</td>
</tr>
<tr>
<td>• All mountain formation is related to volcanism</td>
</tr>
<tr>
<td>• A mountain is “a volcano at its resting state”</td>
</tr>
<tr>
<td>• Mountains form when “earth comes together and mounds up”</td>
</tr>
<tr>
<td>• Mountains form “from wind and weather pushing and pulling rocks and soil together”</td>
</tr>
<tr>
<td>• Mountains form when “ice glaciers melt and the mountains underneath them raise above sea level”</td>
</tr>
<tr>
<td>• “Mountains have always been here”</td>
</tr>
<tr>
<td>• “All mountains are made of the same rocks”</td>
</tr>
</tbody>
</table>
Table 4 Propositional knowledge statements used to develop assessments.

<table>
<thead>
<tr>
<th>Propositional Knowledge Statements related to Mountain Building:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mountains are formed and shaped through simultaneous uplift (driven by tectonic processes and isostasy) and erosion.</td>
</tr>
<tr>
<td>2. Continental and oceanic crust is brittle and less dense than the mantle below, allow the crust to “float” atop the denser mantle.</td>
</tr>
<tr>
<td>3. The asthenosphere is 90-99% solid but contains a small amount of molten material (as is indicated by seismic evidence).</td>
</tr>
<tr>
<td>4. The forces acting on lithospheric plates and the ductile nature (hot, deformable) of the underlying mantle allows the lithospheric plates to move.</td>
</tr>
<tr>
<td>5. Subduction of an oceanic plate under a continental plate causes volcanism, as well as compression that folds, faults, and thickens continental lithosphere.</td>
</tr>
<tr>
<td>6. Continental crust thickens and becomes more buoyant as molten magma intrudes from below during subduction.</td>
</tr>
<tr>
<td>7. Collision of two continental plates or the collision of a terrane causes compression which folds, faults, and thickens continental lithosphere.</td>
</tr>
<tr>
<td>8. As continental crust thickens a crustal root forms below the mountain range which isostatically supports the weight of the mountain range.</td>
</tr>
<tr>
<td>9. Extension of continental lithosphere pulls it apart forming mountain ranges with basins in between.</td>
</tr>
<tr>
<td>10. Mountain formation occurs gradually over the course of millions of years, with average elevations changing at rates of millimeters per year.</td>
</tr>
<tr>
<td>11. Although earthquakes and volcanic eruptions can produce visible changes to Earth’s surface within a human lifetime, the process of building or eroding a mountain range takes millions of years.</td>
</tr>
<tr>
<td>12. If uplift rates exceed erosion rates, the mountains become higher. If erosion rates exceed uplift rates (or the forces causing uplift cease), the mountain ranges eventually erode away.</td>
</tr>
<tr>
<td>13. Because continental crust is buoyant, mountains respond isostatically as material is removed from the top by erosion.</td>
</tr>
<tr>
<td>14. Continental crust is 80-85% as dense as the mantle beneath it, allowing it to float buoyantly in the mantle. Hypothetical changes to the crust or mantle would cause the crust to respond to maintain isostatic equilibrium.</td>
</tr>
<tr>
<td>15. Wind, water, and glacial ice transport weathered rock material away from mountains, leading to the eventual erosion of the mountain range.</td>
</tr>
<tr>
<td>16. Earth’s lithosphere and hydrosphere/atmosphere interact as an Earth System. Mountain building/uplift, erosion and climate are connected in complex relationships.</td>
</tr>
<tr>
<td>17. Uplifted mountain ranges affect climate, which affects erosion style (precipitation, moisture and glaciation) and rates.</td>
</tr>
<tr>
<td>18. Erosion rates are greater in regions with greater topographic relief (difference in elevation between peaks and valleys).</td>
</tr>
<tr>
<td>19. Sedimentary rocks formed in depositional basins or in the ocean can be found at the top of mountain ranges due to uplift.</td>
</tr>
<tr>
<td>20. Erosion and uplift can expose intrusive igneous rocks and metamorphic rocks at Earth’s surface.</td>
</tr>
</tbody>
</table>
Table 5 Item specification grid for two-tier multiple choice assessments

<table>
<thead>
<tr>
<th>Item #</th>
<th>Topic</th>
<th>Prepositional Knowledge Statements</th>
<th>Related misconceptions from the literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Age of mountains/processes and time scale of mountain formation</td>
<td>1, 10, 11</td>
<td>• Mountains have always been present</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Mountains are rapidly formed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• All mountain formation is related to</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>volcanism</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Mountains form when “earth comes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>together and mounds up”</td>
</tr>
<tr>
<td>3-6</td>
<td>Mountain formation – crustal thickening</td>
<td>1, 5, 6, 7, 8</td>
<td>• Vertical forces push up the bottom</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>of the oceans and originate the</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>continents</td>
</tr>
<tr>
<td>7-10</td>
<td>Isostasy (height/thickness)</td>
<td>2, 8, 13</td>
<td></td>
</tr>
<tr>
<td>11-14</td>
<td>Isostasy (density)</td>
<td>2, 8, 14</td>
<td></td>
</tr>
<tr>
<td>15-16</td>
<td>Relief and erosion</td>
<td>13, 18</td>
<td></td>
</tr>
<tr>
<td>17-18</td>
<td>Climate and erosion</td>
<td>13, 15, 16, 17</td>
<td>• All erosional processes are physical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• All weathering processes are chemical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Weathering processes are</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>connected to the weather</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(atmospheric processes such as wind and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>rain)</td>
</tr>
<tr>
<td>19-20</td>
<td>Interaction between erosion and isostatic uplift</td>
<td>1, 12, 13</td>
<td>• No changes will occur to mountains</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in the future</td>
</tr>
<tr>
<td>21-22</td>
<td>Exhumation/rock uplift</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>23-28</td>
<td>Changes to mountains over time</td>
<td>12, 13, 15, 20</td>
<td>• No changes will occur to mountains</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in the future</td>
</tr>
</tbody>
</table>
Table 6 Multiple-choice assessment results in Spring quarter, 2004 main study.

<table>
<thead>
<tr>
<th>Group</th>
<th>Assessment</th>
<th>Pts. Possible</th>
<th>Mean</th>
<th>SD</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive</td>
<td>Predictions</td>
<td>28</td>
<td>14.51</td>
<td>4.44</td>
<td>19.71</td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>28</td>
<td>16.71</td>
<td>5.86</td>
<td>34.29</td>
</tr>
<tr>
<td></td>
<td>Delayed Post-test</td>
<td>22</td>
<td>13.58</td>
<td>4.49</td>
<td>20.20</td>
</tr>
<tr>
<td>Static</td>
<td>Predictions</td>
<td>28</td>
<td>14.71</td>
<td>4.68</td>
<td>21.92</td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>28</td>
<td>18.18</td>
<td>5.36</td>
<td>28.76</td>
</tr>
<tr>
<td></td>
<td>Delayed Post-test</td>
<td>22</td>
<td>14.46</td>
<td>4.26</td>
<td>18.14</td>
</tr>
</tbody>
</table>

Table 7 T-test comparisons of multiple-choice assessments.

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>T-test type</th>
<th>α</th>
<th>p-value</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>There will be no difference in the pre-test (Predictions) scores between the two contrast groups</td>
<td>Two-tailed, two-sample t-test (assuming equal variances)</td>
<td>.05</td>
<td>p = .74</td>
<td>Accept null</td>
</tr>
<tr>
<td>There will be no difference between the Predictions and Observations mean scores in the Interactive group</td>
<td>One-tailed, paired t-test</td>
<td>.05</td>
<td>p &lt; .0001</td>
<td>Reject null</td>
</tr>
<tr>
<td>There will be no difference between the Predictions and Observations mean scores in the Static group</td>
<td>One-tailed, paired t-test</td>
<td>.05</td>
<td>p &lt; .0001</td>
<td>Reject null</td>
</tr>
<tr>
<td>There will be no difference in the post-test (Observations) scores between the two contrast groups</td>
<td>Two-tailed, two-sample t-test (assuming equal variances)</td>
<td>.05</td>
<td>p = .04</td>
<td>Reject null</td>
</tr>
<tr>
<td>There will be no difference in the Delayed Post-test scores between the two contrast groups</td>
<td>Two-tailed, two-sample t-test (assuming equal variances)</td>
<td>.05</td>
<td>p = .11</td>
<td>Accept null</td>
</tr>
</tbody>
</table>

Table 8 Multiple-choice assessment t-test comparisons by gender.

<table>
<thead>
<tr>
<th>Group</th>
<th>Assessment</th>
<th>Gender</th>
<th>Mean</th>
<th>SD</th>
<th>α</th>
<th>p-value</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive</td>
<td>Predictions</td>
<td>F</td>
<td>15.09</td>
<td>4.34</td>
<td>.05</td>
<td>p = .10</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>13.78</td>
<td>4.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>F</td>
<td>17.71</td>
<td>5.82</td>
<td>.05</td>
<td>p = .03</td>
<td>Female &gt; Male (significant at 95% C.I.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>15.44</td>
<td>5.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delayed post-test</td>
<td>F</td>
<td>14.28</td>
<td>4.12</td>
<td>.05</td>
<td>p = .051</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>12.69</td>
<td>4.82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static</td>
<td>Predictions</td>
<td>F</td>
<td>14.57</td>
<td>4.61</td>
<td>.05</td>
<td>p = .64</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>14.96</td>
<td>4.87</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>F</td>
<td>17.77</td>
<td>5.50</td>
<td>.05</td>
<td>p = .22</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>19.00</td>
<td>5.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delayed post-test</td>
<td>F</td>
<td>14.21</td>
<td>4.30</td>
<td>.05</td>
<td>p = .36</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>14.95</td>
<td>4.19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 9 Multiple-choice assessment ANOVA comparisons by lecture instructor.

<table>
<thead>
<tr>
<th>Group</th>
<th>Assessment</th>
<th>Lecture Instructor</th>
<th>Mean</th>
<th>SD</th>
<th>α</th>
<th>p-value</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive</td>
<td>Predictions</td>
<td>A</td>
<td>15.24</td>
<td>4.75</td>
<td>.05</td>
<td>p = .44</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>13.90</td>
<td>3.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>14.36</td>
<td>4.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>A</td>
<td>16.94</td>
<td>5.94</td>
<td>.05</td>
<td>p = .90</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>16.35</td>
<td>5.79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>16.89</td>
<td>5.91</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delayed post-test</td>
<td>A</td>
<td>13.91</td>
<td>5.14</td>
<td>.05</td>
<td>p = .83</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>13.68</td>
<td>3.49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>13.33</td>
<td>4.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Predictions</td>
<td>A</td>
<td>15.32</td>
<td>4.72</td>
<td>.05</td>
<td>p = .45</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>13.72</td>
<td>3.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>14.73</td>
<td>4.99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static</td>
<td>Observations</td>
<td>A</td>
<td>17.88</td>
<td>5.18</td>
<td>.05</td>
<td>p = .38</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>19.52</td>
<td>4.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>17.84</td>
<td>5.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Delayed post-test</td>
<td>A</td>
<td>14.94</td>
<td>3.98</td>
<td>.05</td>
<td>p = .75</td>
<td>No significant difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>14.68</td>
<td>3.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>14.25</td>
<td>4.65</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 10 Six assessment items from Predictions pre-test and Observations post-test with negative gains between the pre-test and post-test. Responses in bold type indicate correct answers. Responses in italics indicate incorrect answers chosen by at least 20% of students. Percentages in red indicate a decrease in correct responses or increase in incorrect responses. See Appendix IV for assessment questions.

<table>
<thead>
<tr>
<th>#</th>
<th>Response</th>
<th>Int. Pre</th>
<th>Int. Post</th>
<th>Static Pre</th>
<th>Static Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>mountains formed during the formation of Earth</td>
<td>2.4</td>
<td>4.9</td>
<td>1.6</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td><em>mountains form and change at rates of millimeters per year</em></td>
<td>50.4</td>
<td><strong>42.3</strong></td>
<td>48.4</td>
<td><strong>46.8</strong></td>
</tr>
<tr>
<td></td>
<td>it takes that long for volcanoes to form the entire mountain chain</td>
<td>10.6</td>
<td>10.5</td>
<td>15.9</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>enough time must pass to allow sediments to accumulate and form a mountain</td>
<td>13.7</td>
<td>14.5</td>
<td>6.3</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td><em>the subducting plate must have sufficient time to push the mountain up through the other plate</em></td>
<td>22.8</td>
<td><strong>27.5</strong></td>
<td>27.8</td>
<td><strong>28.6</strong></td>
</tr>
<tr>
<td>15</td>
<td>Regions with gradual relief will have faster erosion rates</td>
<td>9.8</td>
<td>5.7</td>
<td>11.1</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td><strong>Regions with steep relief will have faster erosion rates</strong></td>
<td><strong>82.9</strong></td>
<td><strong>84.6</strong></td>
<td><strong>82.5</strong></td>
<td><strong>79.4</strong></td>
</tr>
<tr>
<td></td>
<td>Relief will have no effect on erosion rates</td>
<td>6.5</td>
<td>9.8</td>
<td>6.3</td>
<td>6.3</td>
</tr>
<tr>
<td>16</td>
<td>The force of gravity is greater closer to the center of Earth</td>
<td>2.4</td>
<td>4.1</td>
<td>2.4</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Weathering has a greater effect in the plains than in mountainous regions</td>
<td>12.2</td>
<td>11.4</td>
<td>10.3</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>Erosion is dependent on temperature and moisture rather than elevation differences</td>
<td>9.8</td>
<td>13.8</td>
<td>9.5</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>Water and ice move faster on steeper slopes, increasing its ability to erode and transport sediment</td>
<td>75.6</td>
<td>70.7</td>
<td>77.8</td>
<td>72.2</td>
</tr>
<tr>
<td>25</td>
<td>The mountain range will erode down until it reaches the average thickness of the crust</td>
<td>5.7</td>
<td>10.5</td>
<td>7.9</td>
<td>11.9</td>
</tr>
<tr>
<td></td>
<td><strong>Rock material from the deep crust will move up within the mountain range</strong></td>
<td><strong>69.9</strong></td>
<td><strong>64.2</strong></td>
<td><strong>65.1</strong></td>
<td><strong>58.7</strong></td>
</tr>
<tr>
<td></td>
<td>The average elevation of the mountain range will approximately double</td>
<td>11.4</td>
<td>9.8</td>
<td>10.3</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>The mountain range will increase infinitely in elevation</td>
<td>13</td>
<td>15.4</td>
<td>16.7</td>
<td>15.1</td>
</tr>
<tr>
<td>27</td>
<td>The mountain range will slowly erode down until it reaches the average thickness of the crust</td>
<td>82.9</td>
<td>78</td>
<td>81</td>
<td>79.4</td>
</tr>
<tr>
<td></td>
<td>The average elevation of the mountain range will approximately double before growth stops</td>
<td>8.9</td>
<td>4.9</td>
<td>9.5</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>The average elevation of the mountain range will rapidly decrease</td>
<td>4.9</td>
<td>13</td>
<td>4.8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>The mountain range will continually increase in elevation</td>
<td>3.3</td>
<td>4.1</td>
<td>4.8</td>
<td>10.3</td>
</tr>
<tr>
<td>28</td>
<td>When subduction ceases, mountain uplift will stop</td>
<td>43.9</td>
<td>41.5</td>
<td>25.4</td>
<td>23.8</td>
</tr>
<tr>
<td></td>
<td>Erosion rates will exceed isostatic and tectonic uplift rates</td>
<td><strong>17.9</strong></td>
<td><strong>14.6</strong></td>
<td><strong>24.6</strong></td>
<td><strong>28.6</strong></td>
</tr>
<tr>
<td></td>
<td>Once mountain growth ceases, erosion processes will begin</td>
<td>24.4</td>
<td>25.2</td>
<td>41.3</td>
<td>21.4</td>
</tr>
<tr>
<td></td>
<td>Isostatic uplift will completely compensate for loss due to erosion</td>
<td>7.3</td>
<td>10.6</td>
<td>4.8</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td>Rock material will stay where it is because of lack of heat and pressure</td>
<td>0.8</td>
<td>0.8</td>
<td>2.4</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>When the subduction zone becomes inactive, elevation will no longer change</td>
<td>5.7</td>
<td>7.3</td>
<td>1.6</td>
<td>6.3</td>
</tr>
</tbody>
</table>
Table 11 Essay assessment results from the Spring quarter, 2004 main study.

<table>
<thead>
<tr>
<th>Group</th>
<th>Assessment</th>
<th>Pts. Possible</th>
<th>Mean</th>
<th>SD</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive</td>
<td>Predictions</td>
<td>16</td>
<td>8.30</td>
<td>2.69</td>
<td>7.23</td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>16</td>
<td>9.46</td>
<td>3.10</td>
<td>9.60</td>
</tr>
<tr>
<td></td>
<td>Delayed Post-test</td>
<td>16</td>
<td>8.85</td>
<td>3.16</td>
<td>9.97</td>
</tr>
<tr>
<td>Static</td>
<td>Predictions</td>
<td>16</td>
<td>8.06</td>
<td>3.79</td>
<td>14.33</td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>16</td>
<td>9.25</td>
<td>3.55</td>
<td>12.60</td>
</tr>
<tr>
<td></td>
<td>Delayed Post-test</td>
<td>16</td>
<td>9.38</td>
<td>3.63</td>
<td>13.18</td>
</tr>
</tbody>
</table>

Table 12 T-test comparisons of essay assessments.

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>T-test type</th>
<th>α</th>
<th>p-value</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>There will be no difference in the Pre-test (Predictions) scores between the two contrast groups</td>
<td>Two-tailed, two-sample t-test (assuming equal variances)</td>
<td>.05</td>
<td>p = .84</td>
<td>Accept null</td>
</tr>
<tr>
<td>There will be no difference between the essay Pre-test and Post-test mean scores in the Interactive group</td>
<td>One-tailed, paired t-test</td>
<td>.05</td>
<td>p = .09</td>
<td>Accept null</td>
</tr>
<tr>
<td>There will be no difference between the essay Pre-test and Post-test mean scores in the Static group</td>
<td>One-tailed, paired t-test</td>
<td>.05</td>
<td>p = .03</td>
<td>Reject null</td>
</tr>
<tr>
<td>There will be no difference in the Post-test (Observations) scores between the two contrast groups</td>
<td>Two-tailed, two-sample t-test (assuming equal variances)</td>
<td>.05</td>
<td>p = .86</td>
<td>Accept null</td>
</tr>
<tr>
<td>There will be no difference in the Delayed Post-test scores between the two contrast groups</td>
<td>Two-tailed, two-sample t-test (assuming equal variances)</td>
<td>.05</td>
<td>p = .68</td>
<td>Accept null</td>
</tr>
</tbody>
</table>

Table 13 Essay assessment mean score and mean misconceptions comparisons by gender.

<table>
<thead>
<tr>
<th>Contrast Group</th>
<th>Gender</th>
<th>Pre-test Score</th>
<th>Post-test Score</th>
<th>Delayed Post-test Score</th>
<th>Pre-test Misconceptions</th>
<th>Post-test Misconceptions</th>
<th>Delayed Post-test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive</td>
<td>Female  (N=7)</td>
<td>7.43</td>
<td>8.86</td>
<td>7.00</td>
<td>4.14</td>
<td>2.37</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Male    (N=6)</td>
<td>9.33</td>
<td>10.17</td>
<td>11.00</td>
<td>5.17</td>
<td>1.80</td>
<td>2.60</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>8.31</td>
<td>9.46</td>
<td>8.85</td>
<td>4.62</td>
<td>2.69</td>
<td>2.46</td>
</tr>
<tr>
<td>Static</td>
<td>Female  (N=5)</td>
<td>8.00</td>
<td>9.18</td>
<td>9.36</td>
<td>4.36</td>
<td>4.00</td>
<td>3.64</td>
</tr>
<tr>
<td></td>
<td>Male    (N=11)</td>
<td>8.20</td>
<td>9.40</td>
<td>9.40</td>
<td>4.60</td>
<td>1.80</td>
<td>2.60</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>8.06</td>
<td>9.25</td>
<td>8.77</td>
<td>4.62</td>
<td>3.46</td>
<td>3.46</td>
</tr>
</tbody>
</table>
Table 14 Essay assessment mean score and mean misconceptions comparisons by lecture instructor.

<table>
<thead>
<tr>
<th>Contrast Group</th>
<th>Lecture Instructor</th>
<th>Pre-test Score</th>
<th>Post-test Score</th>
<th>Delayed Post-test Score</th>
<th>Pre-test Misconceptions</th>
<th>Post-test Misconceptions</th>
<th>Delayed Post-test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive</td>
<td>A (N=6)</td>
<td>9.67</td>
<td>11.83</td>
<td>11.33</td>
<td>5.00</td>
<td>2.50</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td>B (N=2)</td>
<td>7.50</td>
<td>8.50</td>
<td>8.50</td>
<td>4.50</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>C (N=5)</td>
<td>7.00</td>
<td>7.00</td>
<td>6.00</td>
<td>4.20</td>
<td>3.20</td>
<td>3.60</td>
</tr>
<tr>
<td>Static</td>
<td>A (N=1)</td>
<td>5.00</td>
<td>12.00</td>
<td>11.00</td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>B (N=4)</td>
<td>9.00</td>
<td>8.50</td>
<td>6.75</td>
<td>2.75</td>
<td>2.25</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>C (N=11)</td>
<td>8.00</td>
<td>9.27</td>
<td>10.18</td>
<td>4.91</td>
<td>3.45</td>
<td>2.81</td>
</tr>
</tbody>
</table>

Table 15 Item analysis for four essay questions. Mean scores for each essay item are out of four points possible. “Misconceptions” represent the mean number of scientifically inaccurate statements written in essay responses for each question.

<table>
<thead>
<tr>
<th>Contrast Group</th>
<th>Question #</th>
<th>Pre-test Score</th>
<th>Post-test Score</th>
<th>Delayed Post-test Score</th>
<th>Pre-test Misconceptions</th>
<th>Post-test Misconceptions</th>
<th>Delayed Post-test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive</td>
<td>1</td>
<td>2.54</td>
<td>2.69</td>
<td>3.00</td>
<td>1.46</td>
<td>0.38</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.92</td>
<td>2.54</td>
<td>1.77</td>
<td>1.23</td>
<td>0.62</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.62</td>
<td>2.69</td>
<td>2.31</td>
<td>0.85</td>
<td>0.69</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.23</td>
<td>1.54</td>
<td>1.77</td>
<td>1.08</td>
<td>1.00</td>
<td>0.77</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td><strong>8.31</strong></td>
<td><strong>9.46</strong></td>
<td><strong>8.85</strong></td>
<td><strong>4.62</strong></td>
<td><strong>2.69</strong></td>
<td><strong>2.46</strong></td>
</tr>
<tr>
<td>Static</td>
<td>1</td>
<td>2.31</td>
<td>2.81</td>
<td>3.00</td>
<td>1.06</td>
<td>0.69</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.75</td>
<td>2.13</td>
<td>2.31</td>
<td>1.19</td>
<td>0.94</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.00</td>
<td>2.44</td>
<td>1.94</td>
<td>0.94</td>
<td>0.94</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.00</td>
<td>1.88</td>
<td>2.13</td>
<td>1.25</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td><strong>8.00</strong></td>
<td><strong>8.85</strong></td>
<td><strong>8.77</strong></td>
<td><strong>4.62</strong></td>
<td><strong>3.46</strong></td>
<td><strong>3.46</strong></td>
</tr>
</tbody>
</table>
Table 16 Common misconceptions presented in written essay responses by subjects in Interactive and Static contrast groups.

<table>
<thead>
<tr>
<th>MISCONCEPTION</th>
<th>INTERACTIVE (N = 13)</th>
<th>STATIC (N = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subducting oceanic crust melts to form volcanoes</td>
<td>5 4 0</td>
<td>5 1 0</td>
</tr>
<tr>
<td>Continental crust beneath the mountain range becomes thinner during mountain formation</td>
<td>4 0 0</td>
<td>3 1 0</td>
</tr>
<tr>
<td>Subducting oceanic plate pushes up on the continental crust to form mountains</td>
<td>4 2 1</td>
<td>5 4 2</td>
</tr>
<tr>
<td>Failure to distinguish mass/weight, density, and volume/thickness</td>
<td>1 2 0</td>
<td>1 1 4</td>
</tr>
<tr>
<td>Confusion about crustal responses to changes in density or thickness</td>
<td>9 3 6</td>
<td>7 8 3</td>
</tr>
<tr>
<td>Confusion between weathering and erosion (e.g. high humidity and temperature causes high erosion rates)</td>
<td>4 3 1</td>
<td>3 2 2</td>
</tr>
<tr>
<td>Glacial climate is too cold to produce high erosion rates / glaciers are frozen in place</td>
<td>0 0 0</td>
<td>3 2 2</td>
</tr>
<tr>
<td>More water or higher precipitation rates = faster erosion (does not account for water velocity or relief)</td>
<td>5 4 3</td>
<td>8 6 7</td>
</tr>
<tr>
<td>Magma or lava flows exposes deep crustal rocks to the surface</td>
<td>5 8 3</td>
<td>10 4 3</td>
</tr>
<tr>
<td>Explosive volcanic eruptions bring deep crustal rocks (intrusive and metamorphic) to the surface</td>
<td>4 3 3</td>
<td>4 3 2</td>
</tr>
</tbody>
</table>
Table 17: Common misconceptions about mountain building processes revealed in essay assessments, multiple-choice assessments and interviews by college-level introductory geology students.

### Common Misconceptions about Mountain Building Processes:

<table>
<thead>
<tr>
<th>Misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subducting oceanic crust melts to form volcanoes</td>
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<tr>
<td>Continental crust beneath the mountain range becomes thinner during mountain formation</td>
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<tr>
<td>Subducting oceanic plate pushes up on the continental crust to form mountains</td>
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<tr>
<td>Failure to distinguish mass/weight, density, and volume/thickness when describing changes in continental crust</td>
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<tr>
<td>As mountain range elevation increases, the crustal root will move up with the mountain since they are connected</td>
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<tr>
<td>As mountain range elevation decreases due to erosion, the crustal root will not change size or position. Erosion only affects the top of the mountain, not the crustal root.</td>
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<tr>
<td>Confusion between weathering and erosion (i.e. high humidity and temperature causes high erosion rates)</td>
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<tr>
<td>Glacial climate is too cold to produce high erosion rates / glaciers are frozen in place and cannot erode underlying bedrock</td>
</tr>
<tr>
<td>More water or higher precipitation rates = faster erosion (does not account for water velocity or relief)</td>
</tr>
<tr>
<td>As mass is removed from a mountain range by erosion over time, isostasy speeds up the rate at which average elevation decreases</td>
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<tr>
<td>Magma or lava flows exposes deep crustal rocks at the surface</td>
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<tr>
<td>Explosive volcanic eruptions bring deep crustal rocks (intrusive and metamorphic) to the surface</td>
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<tr>
<td>When subduction ceases, mountain uplift will stop</td>
</tr>
<tr>
<td>All mountains, or at least those created at subduction zones, are volcanoes</td>
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</table>
Figure 1. A schematic diagram of the feedback processes contributing to mountain formation (from Keller and Pinter, 2002).
Figure 2. Schematic cross-sections illustrating the tectonic processes contributing to mountain building occur as plates converge (modified after Fichter and Poche, 2001).

Figure 3. Schematic 1:1 cross-section of the contributions of tectonic shortening and magmatic addition to mountain building in the Bolivian Andes. The minimum restored length was determined from balanced cross-sections (from Sheffels, 1990).
Figure 4. Tectonic models of two modes of orogenic wedge growth. A) Frontal accretion causes growth of the orogenic wedge as mass scraps off the subducting plate and accumulates to the front outboard side of the accretionary wedge. A column within the orogenic wedge deforms by shortening horizontally and extending vertically. B) Underplating occurs as material scraped off the subducting plate accumulates at the base of the accretionary wedge rather than the front of the wedge. No horizontal shortening occurs as columns of rock uplift vertically as new material is added to the base of the orogenic wedge (from Willett et al., 2001).
Figure 5. Schematic cartoons of the roles of isostasy and flexural rigidity in support of mountainous topography. 

a) Airy isostasy is based on the premise of deep crustal roots with constant crustal density beneath mountains. The total weight of column “1” and column “2” must be equal at the depth of compensation, so the greater height of column “1” is compensated by the greater thickness of low-density crust compared to column “2”, which has a higher proportion of higher-density mantle. R = crustal root that extends into the mantle below the depth of the average crustal thickness (T). 

b) Pratt isostasy is based on a column made of thicker, less dense crust material to have equal weights at the depth of compensation. 

c) Since the lithosphere has strength, part of the load of the mountain range is supported by the flexural rigidity of the lithosphere beneath the mountain range (modified after Keller and Pinter, 2002).
Figure 6. Stylized cartoon of the effects of isostasy and viscous (ductile) flow in the lower crust on the shape of a mountain range. A) Formation of a thickened crustal root due to isostasy and foreland basin due to flexural support. B) As lower crustal temperature increases due to thickening, the basal shear strength decreases allowing ductile flow in the mountain range, creating a broad plateau. C) As ductile flow at the base continues, gravitational collapse of the mountain range can occur. Dashed lines represent instantaneous flow lines (from Willett et al., 1993).
Figure 7. Illustration of the isostatic uplift of mountain peaks in response to valley incision. A) An initially level plateau with a given mean elevation above sea level. B) Erosion of deep valleys through glacial or fluvial processes decreases the mean elevation. Because isostasy responds to changes in mean elevation, mountain peaks can rise above the level of the original plateau. C) Erosion that does not increase relief lowers both the mean elevation and the mountain peaks (from Montgomery., 1994).

Figure 8. Effective bedrock erosion rates in extensively glaciated basins in Alaska (small and large circles), Swiss Alps (small squares), Norway (open triangles) and other areas including New Zealand, Asia and Iceland (large squares) (from Hallett et al., 1996).
Figure 9. The auditory/verbal channel (top frame) and visual/pictoral channel (bottom frame) in a cognitive theory of multimedia learning. Written words are initially processed in the visual/pictoral channel before being transferred to the verbal channel (from Mayer, 2001).
Models

Computer and hands-on models are useful tools for scientists and students to understand scientific concepts that are not easily observable with the human eye or within a human lifetime. Because scientists do not know everything about Earth and computers programs are limited in their ability to recreate reality, simplifying assumptions must be made when developing models of real-world processes. The goal of the models in this web activity is to increase student understanding of important scientific concepts, not to recreate the processes occurring on Earth precisely.

Some of the simplifications made in the animations you will see include:
* 2-dimensional models rather than 3-D
* simplified topography and processes
* erosion rates averaged over long periods of time rather than punctuated events such as landslides or years of heavy precipitation or glaciation
* constant uplift that averages out periodic punctuated events such as earthquakes
* vertically exaggerated diagrams so that important features can be seen visibly

Figure 10. “Models” tab of the interactive “Mountain Building Web Activity” learning object.

Figure 11. Sample screen shot from interactive animation activity #1, “How do plate tectonics build mountains?”. Graphic images are vertically exaggerated to emphasize features.
Figure 12. Sample screen shot from interactive animation activity #2, “How are mountains supported from below?”. $H$ = height of mountain above average crustal thickness, $R$ = thickness of crustal root below average crustal thickness, $\rho_c$ = density of crust, $\rho_m$ = density of mantle.

Figure 13. Sample screen shot from interactive animation activity #3, “What processes shape and change mountains over time?”. 
Explore

Please select a question to explore:

How can rocks formed deep within the crust come to the surface?

As subduction continues, the crust continues to thicken by shortening and magma intrusion. Erosion removes mass from the top of the mountain while the crust uplifts isostatically. These processes move plutonic and deep metamorphic rocks closer to the surface. Also, the added weight of sediment deposited at the base of the mountain range causes the crust beneath the depositional basins to sink further into the mantle due to isostasy.

Figure 14. Sample screen shots from interactive animation activity #4, “How can rocks formed deep within the crust come to the surface?” A) Sample screen shot from rock cycle drag and drop activity. B) Sample screen shot of one of the animated sequences showing erosion and isostatic compensation of the mountain range..
Figure 15. Gender distribution of subjects in the Interactive and Static contrast groups during Spring 2004 main study.

Figure 16. Geology 101 lecture instructor distribution of subjects in the Interactive and Static contrast groups during Spring 2004 main study.
Figure 17. Geology 101 lab teaching assistant distribution of subjects in the Interactive and Static contrast groups during Spring 2004 main study.

Figure 18. Previous experience in Earth Science or Geology classes (prior to Geology 101) of subjects in Interactive and Static contrast groups during Spring 2004 main study.
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Figure 25. Venn diagram of comment categories based on common student responses on post-activity questionnaire for essay and multiple-choice groups. Green comments are positive, while red are negative or suggest improvements. The comments in the outer circles are unique to the interactive or static Mountain Building Web Activity, while the comments in the center are common to both versions.
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A) Interactive groups’ percentage distribution of confidence ratings
B) Static groups’ percentage distribution of confidence ratings

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A) Interactive groups’ percentage distribution of confidence ratings
B) Static groups’ percentage distribution of confidence ratings
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A) Interactive groups' percentage distribution of confidence ratings
B) Static groups' percentage distribution of confidence ratings

Figure 29. Students' rating of their confidence in understanding **Isostasy** before and after interacting with the interactive or static Mountain Building Web Activity.
A) Interactive groups' percentage distribution of confidence ratings
B) Static groups' percentage distribution of confidence ratings
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A) Interactive group: Predictions pre-test
B) Static group: Predictions pre-test
C) Interactive group: Observations post-test
D) Static group: Observations post-test
E) Interactive group: Delayed post-test
F) Static group: Delayed post-test
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Figure 33. Percentage of students responding to the incorrect multiple-choice response: “The elevation of continental crust above sea level will increase because subducting oceanic crust pushes continental crust upwards” during the Spring 2004 main study.

Figure 34. Percentage of students responding to the incorrect multiple-choice response: “During subduction and collision, continental crust gets thinner below the surface” during the Spring 2004 main study.
Figure 35. Percentage of students responding to the incorrect multiple-choice response: “As mountain range elevation increases, the crustal root will move up with the mountain since they are connected” during the Spring 2004 main study.

Figure 36. Percentage of students responding to the incorrect multiple-choice response: “As mountain range elevation decreases due to erosion, the crustal root will not change size or position. Erosion only affects the top of the mountain, not the crustal root” during the Spring 2004 main study.
Figure 37. Percentage of students responding to the incorrect multiple-choice response: "In regions of steep relief, glacial climates have the lowest erosion rates because the water is frozen in place and cannot erode underlying bedrock" during the Spring 2004 main study. No comparable response was a choice on the Delayed Post-test.

Figure 38. Percentage of students responding to the incorrect multiple-choice response: "As mass is removed from a mountain range by erosion over time, isostasy speeds up the rate at which average elevation decreases" during the Spring 2004 main study.
Figure 39. Percentage of students responding to the incorrect multiple-choice response: "Deep crustal rocks (intrusive igneous and metamorphic rocks) erupt onto the surface through volcanoes" during the Spring 2004 main study.

Figure 40. Percentage of students responding to the incorrect multiple-choice response: "When subduction ceases, mountain uplift will stop" during the Spring 2004 main study.
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Pre = Pre-test  Post = Post-test  DPT = Delayed Post-test

Figure 45. Number of scientifically inaccurate statements in written responses on Essay assessments by the Static group during the spring 2004 main study.
Pre = Pre-test  Post = Post-test  DPT = Delayed Post-test
APPENDIX I: Documents related to Initial Survey and Pilot Study

Survey of Knowledge about Mountain Building Processes

**Your name will only be used to give you credit for filling out this survey and will not be used in any research document.**

Name: __________________

1. In your own words, tell me what is a mountain?

2. List a few examples of mountains you can think of (either local or around the world).

3. How do mountains form?

4. Do mountains change over time? Explain what you mean by your answer or provide an example if you can.

5. How long do you think it takes a mountain to form?

6. What was your previous background in Earth Science, Geology or Geography before enrolling in Geology 101?

7. Has anything you have learned in the first week of Geology 101 changed your way of thinking about how mountains form? YES / NO
   
   **If yes, a)** What has changed your thinking?
   
   **b)** How did you think mountains formed before you enrolled in Geology 101?

8. If you would be willing to talk with me about your ideas in a short, informal interview, please write your email address below. I will select a few students to talk with further, and may contact you within the next week to arrange a time to meet.
Instructions for Pilot Study – Mountain Building Web Activity

Thanks for volunteering to be part of the pilot study for my thesis! I appreciate you taking time out of your schedule to give me your input and feedback on this project. It will be most helpful to me if you are totally honest in your questionnaire answers, predictions and observations, and your feedback of the web activity itself. Constructive criticism is a GOOD thing! The goal of conducting a pilot study is to “work out the bugs” and get helpful feedback from students so that the main study will be successful. You will be looking at “rough draft” versions of the surveys, assessments and the web activity itself. I will judge by your answers and the comments you write (or verbally tell or show me) what will need to be improved before next quarter. As you are working, feel free to call me over to make verbal comments or suggestions, or just write them down on the page you are working on. Also, if you have any questions about this research project or anything else, feel free to ask.

1. Log on to the computer using your Universal Password. It will take several minutes to log on in this computer lab, so please listen to and read along with the Informed Consent letter on the next page while you are waiting.

2. BEFORE interacting with the web activity, answer the Prediction questions for Animation #1 - #4 in your packet. You should complete all of the multiple choice prediction questions and write a brief, clear explanation of your reasoning for each question.

3. After you have completed the Predictions question, bring your packet to Michelle and she’ll provide you instructions for the next part of the pilot study.
Mountain Building Web Activity -- Predictions

Instructions: The following questions are designed to assess students' knowledge of mountain building processes before interacting with four web activities (animations). Please answer each multiple choice or multiple answer question as is indicated below, and write a brief explanation of your reasoning. If any questions are confusing in their wording, or would benefit from additional illustrations, please make notes in the margins about problems or suggested solutions.

Animation #1: How do plate tectonics build mountains?

1.1.a. Which of the following is the most reasonable estimate for how long it will take for a mountain range to form in the continental crust at this new convergent boundary? (choose one answer that best fits your prediction)
- 700 years
- 6,000 years
- 100,000 years
- 20 million years
- 2 billion years
- 4.6 billion years

Provide a brief, clear explanation of your reasoning:

1.2.a. How will the continental crust be affected during subduction of the oceanic plate? (check all statements you predict will occur)

The continental crust will:
- become thinner vertically
- become thicker vertically
- be extended (become longer) horizontally
- be shortened (become shorter) horizontally
- not be affected by subduction of oceanic crust

Provide a brief, clear explanation of your reasoning:
1.3.a. How will the continental crust be affected by the intrusion of molten magma from the mantle during subduction? (check all statements you predict will occur)

The continental crust will:
- become thinner vertically
- become thicker vertically
- become more buoyant (less dense)
- become less buoyant (more dense)
- not be affected by the intrusion of molten magma

Provide a brief, clear explanation of your reasoning:

1.4.a. How will the continental crust be affected when a second continent collides into the continental crust? (check all statements you predict will occur)

The continental crust will:
- become thinner vertically
- become thicker vertically
- be extended (become longer) horizontally
- be shortened (become shorter) horizontally
- not be affected by continental collisions

Provide a brief, clear explanation of your reasoning:

1.5.a. What will happen to the elevation of the continental crust above sea level during subduction of the oceanic crust and continental collision? (choose one answer that best fits your prediction)

The elevation of the continental crust will:
- increase
- decrease
- stay the same

Provide a brief, clear explanation of your reasoning:

1.6.a. What will happen to the continental crust below Earth’s surface during subduction of the oceanic crust and continental collision? (choose one answer that best fits your prediction)

- The continental crust will become thinner below the surface
- The continental crust will become thicker below the surface
- The continental crust below Earth’s surface will not be affected

Provide a brief, clear explanation of your reasoning:
Animation #2: How are high mountain ranges supported from below?

2.1.a. When using Earth-like values for average density of the crust (2700 kg/m³) and mantle (3300 kg/m³), what will happen to the crustal root (R) as the mountain range elevation (H) increases? (choose one answer that best fits your prediction)

The crustal root will:
- move farther down into the mantle
- move up within the mantle
- not change size or position

Provide a brief, clear explanation of your reasoning:

2.2.a. When mass is removed from the top of a mountain range by erosion (H decreases), what will happen to the position of the crustal root within the mantle? (choose one answer that best fits your prediction)

The crustal root will:
- move farther down into the mantle
- move up within the mantle
- not change size or position

Provide a brief, clear explanation of your reasoning:
2.3.a. Using the model in Animation #2, you can change the density of the crust and mantle to explore how density affects isostasy (the position in which the crust “floats” in equilibrium in the mantle).

What will happen to the position of the continental crust if the crustal density is increased to greater than Earth-like values (2700 kg/m$^3$)? (choose one answer that best fits your prediction)

The continental crust will:
- O float higher in the mantle
- O sink lower in the mantle
- O remain in the same position

Provide a brief, clear explanation of your reasoning:

2.4.a. What will happen to the position of the crustal root if the mantle density is increased to greater than Earth-like values (3300 kg/m$^3$)? (choose one answer that best fits your prediction)

The crustal root will:
- O move farther down into the mantle
- O move up within the mantle
- O not change size or position

Provide a brief, clear explanation of your reasoning:
Animation #3: What processes shape and change mountains over time?

3.1.a. How will the relief of a region (the difference between the highest and lowest elevations in a region) affect glacial erosion rates? (choose one answer that best fits your prediction)

- Continental ice sheets will have faster erosion rates
- Alpine glaciers will have faster erosion rates
- Relief will have no effect on erosion rates

Provide a brief, clear explanation of your reasoning:

3.2.a. Which climate would you predict will have the lowest erosion rates in regions with steep relief? (choose one answer that best fits your prediction)

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Tropical (warm, humid climate and heavy precipitation)
- Climate will have no effect on erosion rates

Provide a brief, clear explanation of your reasoning:

3.3.a. Which climate would you predict will have the highest erosion rates in regions with steep relief? (choose one answer that best fits your prediction)

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Tropical (warm, humid climate and heavy precipitation)
- Climate will have no effect on erosion rates

Provide a brief, clear explanation of your reasoning:

3.4.a. What type of landforms will likely be formed by glacial erosion in the mountains? (choose one answer that best fits your prediction)

- Jagged peaks and broad, U-shaped valleys
- Rounded peaks and V-shaped valleys
- Flat plateaus at high elevation

Provide a brief, clear explanation of your reasoning:
3.5.a. In which climate will erosion create rounded mountain peaks and V-shaped valleys? (choose one answer that best fits your prediction)

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Climate will have no effect on landform development

Provide a brief, clear explanation of your reasoning:

3.6.a. How will the movement of the crustal root (due to isostasy) affect the average elevation of mountains over time as mass is removed from the mountain range by erosion? (choose one answer that best fits your prediction)

Isostasy will:

- Not have any affect on average elevation over time
- Increase the average elevation of the mountain over time
- Slow the rate at which average elevation decreases over time
- Speed up the rate at which average elevation decreases over time

Provide a brief, clear explanation of your reasoning:

Comments about Animation #3 Prediction Questions:
Animation #4: How can rocks formed deep within the crust come to the surface?

4.1 a. Which of the following rock types can be found in a mountain range? (check all rock types you predict will occur)

- [ ] Igneous (plutonic)
- [ ] Igneous (volcanic)
- [ ] Metamorphic
- [ ] Sedimentary

Provide a brief, clear explanation of your reasoning:

4.2 a. Which processes will be responsible for bringing intrusive igneous rocks and metamorphic rocks that are formed deep within the crust to the surface of the mountain range? (choose one answer that best fits your prediction)

Deep crustal rocks will be brought to the surface by:

- [ ] Melting and cooling of magma
- [ ] Erosion, crustal shortening and uplift
- [ ] Decrease in density of the rocks after they form
- [ ] Increased pressure and temperature conditions in the crust

Provide a brief, clear explanation of your reasoning:
4.3.a. What will happen to the mountain range shown in Animation #4 as the subduction of the oceanic plate continues?
(choose one answer that best fits your prediction)

- The mountain range will erode down until it reaches the average thickness of the crust
- Rock material from the deep crust will move up within the mountain range
- The average elevation of the mountain range will approximately double
- The mountain range will increase infinitely in elevation

Provide a brief, clear explanation of your reasoning:

4.4.a. What will eventually happen to the mountain range once the subduction zone is no longer active?
(choose one answer that best fits your prediction)

- Rock material from the deep crust will move up within the range with little change to its overall elevation
- The average elevation of the mountain range will approximately double before growth stops
- The mountain range will erode down until it reaches the average thickness of the crust
- The mountain range will continually increase in elevation

Provide a brief, clear explanation of your reasoning:

Comments about Animation #4 Prediction Questions:
Instructions for Pilot Study – Mountain Building Web Activity – Part 2 (Group A)

4. Open Internet Explorer and type in the following web address:

   http://www25.brinkster.com/sivart97/geology/cs402.html

5. Take a couple minutes to explore the web activity, pushing each tabbed "button" at the top and the "drop down menu" on the Explore screen to navigate through the web activity. Don't begin any of the interactive activities just yet.

Record your general impressions about the web activity in the space below:
(How easy or difficult is it to use/navigate? Any suggestions for improvement?)

6. Once you are ready to go the Explore animations, select the first animation (How do plate tectonics affect build mountains?). Spend as much time as you'd like exploring the four animations. Record your impressions and suggestions for improvement below.

Suggestions/Comments:

You are welcome to make whatever comments or suggestions you choose.

Here are some things to address if you choose:

- Some of the "Help" directions are incorrect because they were written before changes were made to the animations. They will obviously be changed for the next version. Other than that, is the animation easy or difficult to use? What would be helpful in making it more "user-friendly"?
- Are you “paying attention” to all of the information on the screen? If not, what changes would help you focus on all parts of the animation?
- How well did the Prediction questions help guide you for what to look for in this animation? Do you feel you are interacting with each animation for a purpose, or just playing around with it?
**Animation #1:** How do plate tectonics build mountains?

Main idea(s) of the animation:

Comments/Suggestions:

**Animation #2:** How are high mountain ranges supported from below?

Main idea(s) of the animation:

Comments/Suggestions:

**Animation #3:** What processes shape and change mountains over time?

Main idea(s) of the animation:

Comments/Suggestions:

**Animation #4:** How can rocks formed deep within the crust come to the surface?

Main idea(s) of the animation:

Comments/Suggestions:

7. Read the text on the Summary tab to see if this information agrees with your observations from the four animation activities.

8. Complete the post-test “Observations” questions or as much as you can of it in the time left.

9. Please complete the “Post-Activity Questionnaire” as honestly and completely as possible. In addition to answering the questions, feel free to make comments in the margins. I want to know if a question you are confused by what a question is asking or if you have suggestions for improvement.

10. Log off your computer and turn in the whole packet to Michelle.
Mountain Building Web Activity – Observations (after interaction w/ animations)

Instructions: The following questions are designed to assess students’ ability to make observations and explain what they saw after interacting with four web animations. After interacting with the web activity, please answer each multiple choice or multiple answer question as indicated below, and write a brief explanation of your reasoning. If your reasoning is the same as in the Prediction question, there is no need to write your explanation again. If any questions are confusing in their wording, or would benefit from additional illustrations, please make notes in the margins about problems or suggested solutions.

Animation #1: How do plate tectonics build mountains?

1.1.b. Which of the following is the most reasonable estimate for how long it takes for a mountain range to form in the continental crust at a new convergent boundary? (choose one answer that best fits your observation)
- 700 years
- 6,000 years
- 100,000 years
- 20 million years
- 2.0 billion years
- 4.6 billion years

Provide a brief, clear explanation WHY you think the observation occurred:

1.2.b. How is continental crust affected by the subduction of the oceanic plate? (check all statements that match your observation(s))

The continental crust:
- becomes thinner vertically
- becomes thicker vertically
- is extended (become longer) horizontally
- is shortened (become shorter) horizontally
- is not affected by subduction of oceanic crust

Provide a brief, clear explanation WHY you think the observation(s) occurred:
1.3.b. How is continental crust affected by the intrusion of molten magma from the mantle during subduction? (check all statements that match your observation(s))

The continental crust:
- becomes thinner vertically
- becomes thicker vertically
- becomes more buoyant (less dense)
- becomes less buoyant (more dense)
- is not affected by the intrusion of molten magma

Provide a brief, clear explanation WHY you think the observation(s) occurred:

1.4.b. How is continental crust affected when a second continent collides into the continental crust? (check all statements that match your observation(s))

The continental crust:
- becomes thinner vertically
- becomes thicker vertically
- is extended (become longer) horizontally
- is shortened (become shorter) horizontally
- is not affected by continental collisions

Provide a brief, clear explanation WHY you think the observation(s) occurred:

1.5.b. What happens to the elevation of the continental crust above sea level during subduction of the oceanic crust and continental collision? (choose one answer that best fits your observation)

The elevation of the continental crust:
- increases
- decreases
- stays the same

Provide a brief, clear explanation WHY you think the observation occurred:

1.6.b. What happens to continental crust below Earth’s surface during subduction of the oceanic crust and continental collision? (choose one answer that best fits your observation)

- The continental crust becomes thinner below the surface
- The continental crust becomes thicker below the surface
- The continental crust below Earth’s surface is not affected

Provide a brief, clear explanation WHY you think the observation occurred:

Comments about Animation #1 Observation Questions:
Animation #2: How are high mountain ranges supported from below?

2.1.b. When using Earth-like values for average density of the crust (2700 kg/m$^3$) and mantle (3300 kg/m$^3$), what happens to the crustal root (R) as the mountain range elevation (H) increases? (choose one answer that best fits your observation)

The crustal root:
- moves farther down into the mantle
- moves up within the mantle
- does not change size or position

Provide a brief, clear explanation WHY you think the observation occurred:

2.2.b. When mass is removed from the top of a mountain range by erosion (H decreases), what happens to the position of the crustal root within the mantle? (choose one answer that best fits your observation)

The crustal root:
- moves farther down into the mantle
- moves up within the mantle
- does not change size or position

Provide a brief, clear explanation WHY you think the observation occurred:
2.3.b. Using the model in Animation #2, you can change the density of the crust and mantle to explore how density affects isostasy (the position in which the crust "floats" in equilibrium in the mantle).

What happens to the position of the continental crust when the crustal density is increased to greater than Earth-like values (2700 kg/m³)? (choose one answer that best fits your observation)

The continental crust:
- floats higher in the mantle
- sinks lower in the mantle
- remains in the same position

Provide a brief, clear explanation WHY you think the observation occurred:

2.4.b. What happens to the position of the crustal root when the mantle density is increased to greater than Earth-like values (3300 kg/m³)? (choose one answer that best fits your observation)

The crustal root:
- moves farther down into the mantle
- moves up within the mantle
- does not change size or position

Provide a brief, clear explanation WHY you think the observation occurred:

Comments about Animation #2 Observation Questions:
**Animation #3**: What processes shape and change mountains over time?

3.1.b. How does the relief of a region (the difference between the highest and lowest elevations in a region) affect glacial erosion rates? (choose one answer that best fits your observation)

- Continental ice sheets have faster erosion rates
- Alpine glaciers have faster erosion rates
- Relief has no effect on erosion rates

Provide a brief, clear explanation WHY you think the observation occurred:

3.2.b. Which climate has the lowest erosion rates in regions with steep relief? (choose one answer that best fits your observation)

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Tropical (warm, humid climate and heavy precipitation)
- Climate will has no effect on erosion rates

Provide a brief, clear explanation WHY you think the observation occurred:

3.3.b. Which climate has the highest erosion rates in regions with steep relief? (choose one answer that best fits your observation)

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Tropical (warm, humid climate and heavy precipitation)
- Climate has no effect on erosion rates

Provide a brief, clear explanation WHY you think the observation occurred:

3.4.b. What type of landforms are most likely formed by glacial erosion in the mountains? (choose one answer that best fits your observation)

- Jagged peaks and broad, U-shaped valleys
- Rounded peaks and V-shaped valleys
- Flat plateaus at high elevation

Provide a brief, clear explanation WHY you think the observation occurred
3.5.b. In which climate does erosion create rounded mountain peaks and V-shaped valleys? (choose one answer that best fits your observation)

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Climate has no effect on landform development

Provide a brief, clear explanation WHY you think the observation occurred:

3.6.b. How does the movement of the crustal root (due to isostasy) affect the average elevation of mountains over time as mass is removed from the mountain range by erosion? (choose one answer that best fits your observation)

Isostasy:

- Does not have any affect on average elevation over time
- Increases the average elevation of the mountain over time
- Slows the rate at which average elevation decreases over time
- Speeds up the rate at which average elevation decreases over time

Provide a brief, clear explanation WHY you think the observation occurred:

Comments about Animation #3 Observation Questions:
Animation #4: How can rocks formed deep within the crust come to the surface?

4.1.b. Which of the following rock types can be found in a mountain range? (check all rock types that match your observation(s))

- □ Igneous (plutonic)
- □ Igneous (volcanic)
- □ Metamorphic
- □ Sedimentary

Provide a brief, clear explanation WHY you think the observation(s) occurred:

4.2.b. Which processes are responsible for bringing intrusive igneous rocks and metamorphic rocks that form deep within the crust to the surface of the mountain range? (choose one answer that best fits your observation)

Deep crustal rocks are brought to the surface by:

- □ Melting and cooling of magma
- □ Erosion, crustal shortening and uplift
- □ Decrease in density of the rocks after they form
- □ Increased pressure and temperature conditions in the crust

Provide a brief, clear explanation WHY you think the observation occurred:
4.3.b. What happens to a mountain range such as is shown in Animation #4 as the subduction of an oceanic plate continues?
(choose one answer that best fits your observation)

- The mountain range erodes down until it reaches the average thickness of the crust
- Rock material from the deep crust moves up within the mountain range
- The average elevation of the mountain range approximately doubles
- The mountain range increases infinitely in elevation

Provide a brief, clear explanation WHY you think the observation occurred:

4.4.b. What eventually happens to the mountain range once the subduction zone is no longer active?
(choose one answer that best fits your observation)

- Rock material from the deep crust moves up within the range with little change to its overall elevation
- The average elevation of the mountain range approximately doubles before growth stops
- The mountain range erodes down until it reaches the average thickness of the crust
- The mountain range continually increases in elevation

Provide a brief, clear explanation WHY you think the observation occurred:

Comments about Animation #4 Observation Questions:
APPENDIX II: Human Subjects Research Committee Documents

WESTERN WASHINGTON UNIVERSITY
Bureau for Faculty Research
MEMORANDUM

TO: Michelle Malone, Geology Department, MS 9080
FROM: Geri Walker, Bureau for Faculty Research, MS 9038
DATE: October 16, 2003
SUBJECT: Human Subjects Review

Thank you for submitting a human subject research exemption request for your research project "The Effect of Interactive Computer Animations on Introductory Geology Students' Conceptual Understanding of Mountain Building Processes," for review by the Human Subjects Review Committee (HSRC). The project described falls into exemption category #2 for research involving the use of educational tests, survey/interview procedures or observation of public behavior where subject identities remain confidential and the research activity will not put the subjects at psychological, physical, or social risk. This category is exempt from HSRC review per 45 CFR Part 46.101(b)(2).

If the involvement of human subjects changes over the course of the study in a way that would increase risks, please submit a revised protocol. If you have any questions, please feel free to call me at 650-3220.

cc: Dr. Scott Linneman, Geology Department
Spring 2004 – Main Study
The Effect of Web Activities on Knowledge of Mountain Building Processes

Informed Consent

Participation in this Master’s thesis research study will involve completing online questionnaires, online assessments and interacting with a web activity related to mountain building processes. All of the assignments are part of regular course instruction for Geology 101 lab students. However, the inclusion of your results is completely voluntary and you are free to withdraw from the study at any time. If you choose not to sign the letter of consent, your results will not be included in study. To avoid a conflict of interest, data from Michelle Malone’s lab students will not be included, though they will complete the assignments as part of the Geology 101 lab curriculum.

All of the information you provide will remain anonymous. Data collected during this study will be analyzed in terms of groups, not individuals. Any of the information you write or respond to on the questionnaires or assessments will not be individually identifiable. Your name will not be linked to any document related to this research project.

Benefits and Risks
There are no known physical or psychological risks associated with participation in this study and there are no financial costs associated with participation. Although there may be no direct benefit to you for participating, you will be contributing to a study designed to improve instruction and student understanding about mountain building, an important geological topic. To date, there has been no systematic study of such experiences. The hope is that such study will provide information that could result in positive effects for teachers and students in years to come. Following completion of the main study, results will be available by contacting the researcher directly.

Contact Information
This research is being conducted by Michelle Malone, through the Department of Geology at Western Washington University under the supervision of Dr. Scott Linneman. If you have any questions about the study, you may contact Michelle Malone by telephone at (360) 650-3000 x5709, or via e-mail at brucem@cc.wwu.edu. Dr. Linneman can be contacted at (360) 650-7207 or via email at scott.linneman@wwu.edu.

Consent to Participate
If you agree to participate in this study, please read instructions and questions carefully and complete the questionnaires and assessments as fully and honestly as possible. Student effort and thoughtful participation is vital to accurate and reliable data collection. Your participation is entirely voluntary and you are free to withdraw from the study at any time without any penalty to your course grade.

Please sign below if you are 18 years of age or older and agree to participate in the study. (If you are not yet 18 years of age, please do not sign below. You may complete the assignments, but your responses cannot be included in the study without parent permission.)

__________________________________________
Name:

__________________________________________
Student #: W

__________________________________________
WWU username:
(for Blackboard enrollment purposes only)
APPENDIX III: Interactive and Static Mountain Building Web Activities

The Interactive version of the Mountain Building Web Activity was created using Flash MX 2004 and requires installation of Flash Player 7 to be viewed properly. The original graphics were generated by Karl Schoessler using Adobe Photoshop based on my sketches and instructions. The dynamic template for the web activity was developed by Adam Barrus based on my specifications. A majority of the programming for the learning activity, including the four interactive animations, was completed by Travis Chun based on sketches and specifications I provided. Final testing and alterations were completed by Michelle and Shad Malone. Dr. James Myers (University of Wyoming) provided the inspiration, format ideas and initial Flash MX programming instruction that were vital to the process of creating this learning activity. Western Washington University professors Scott Linneman, Liz Schermer, David Hirsch and Doug Clark, as well as several Geology 101 students, provided helpful editorial comments and ideas. My thanks goes out to everyone involved in the creation of the learning activity.

The current version of the Interactive web activity can be viewed at the following URL: http://myweb.students.wwu.edu/brucem/geology.html or on the CD-ROM included with this thesis.

The following images are screen shots from the Interactive learning activity. Students can navigate through the web activity by clicking the labeled “tabs” or the arrow buttons. Once on the Explore tab, students choose one of four animations by selecting a question from the selection (“drop-down”) menu. Within each of the animation activities, students can click “Instructions” or “Helpful Information” buttons to view text that explains the concepts related to each animation.
Models

Computer and hands-on models are useful tools for scientists and students to understand scientific concepts that are not easily observable with the human eye or within a human lifetime. Because scientists do not know everything about Earth and computers programs are limited in their ability to recreate reality, simplifying assumptions must be made when developing models of real-world processes. The goal of the models in this web activity is to increase student understanding of important scientific concepts, not to recreate the processes occurring on Earth precisely.

Some of the simplifications made in the animations you will see include:

- 2-dimensional models rather than 3-D
- simplified topography and processes
- erosion rates averaged over long periods of time rather than punctuated events such as landslides or years of heavy precipitation or glaciation
- constant uplift that averages out periodic punctuated events such as earthquakes
- vertically exaggerated diagrams so that important features can be seen visibly

Explore

Choose a topic to explore from the selection menu below by clicking the triangle on the right to open the menu, then clicking on a question.

- How do plate tectonics build mountains?
- How are mountains supported from below?
- What processes shape and change mountains over time?
- How can rocks formed deep within the crust come to the surface?
- How do plate tectonics build mountains?
ANIMATION #1: How do plate tectonics build mountains?

**Purpose:** To show students how subduction and collision affects continental crust OVER TIME. Students see how compression stresses and magmatism thicken crust, allowing mountains to form. During the animation, the mountains are shaped by erosion and uplift processes, which students will learn about specifically in subsequent activities.

**Functions:** Students progress through slide images of a convergent plate boundary. “Continue” and “Back” buttons allow them to move forward and backward through time, viewing a series of changing images. Dynamic text on the images and in the information bar above allows students to see processes and changes in crustal thickness and elevation as they progress through time.
**ANIMATION #2: How are mountains supported from below?**

**Purpose:** This Explore activity combines a dynamic equation with a graphic illustration that shows the effects of manipulating thickness and density variables. These objects allow students to experiment with the factors affecting isostasy and the buoyancy of continental crust.

**Functions:** Students manipulate variables in the equation through pre-determined acceptable ranges using “+” and “−” buttons in the dynamic equation field. The crustal root average thickness (R) is calculated programmatically. The numbers in the dynamic equation and the continental crust in the animation respond to the parameters established by the students.
**ANIMATION #3: What processes shape and change mountains over time?**

**Purpose:** Students can select combinations of climatic conditions and relief (change in elevation) and see the resulting erosion rate and its affect on a mountain range. Students can also compare how quickly mountains erode with and without isostatic compensation.

**Functions:** Students select a climate condition and steep or gradual relief from drop-down menus. The program will choose the appropriate erosion rate (based on values inputted from the Keller and Pinter, 2002). Students then click age buttons to observe the erosion progress over time in two windows that show changes to the mountain range with and without isostasy.
ANIMATION #4: How can rocks formed deep within Earth come to the surface?

Purpose: This drag and drop activity will allow students to place small labeled pictures of rocks and rock cycle terms in their appropriate locations within a mountain range. They also can observe how erosion and uplift brings deep rocks to the surface.

Function: Students will choose from a “list” of rock pictures and rock cycle terms and drag each picture or term to its appropriate location within the rock cycle. The diagram will only “accept” the picture/term if it is correct, otherwise it will bounce back to its original position. Once the placements are correct, a series of erosion and uplift animations with explanatory text follow.

As subduction continues, the crust continues to thicken by shortening and magma intrusion. Erosion removes mass from the top of the mountain while the crust uplifts isostatically. These processes move plutonic and deep metamorphic rocks closer to the surface. Also, the added weight of sediment deposited at the base of the mountain range causes the crust beneath the depositional basins to sink further into the mantle due to isostasy.
Summary

As you have seen in the animation activities on the Explore tab, mountains are formed and shaped through a complex interaction of cycles within the Earth system:

Plate tectonic processes at convergent boundaries thicken continental crust by shortening the crust and adding magma from the mantle below. As the crust is thickened, mountain ranges and a crustal root below the mountains form. The crustal root becomes larger as the crust thickens and the mountain range gains elevation. When material is removed from the top of the mountain range by erosion, isostasy causes the crust to move upward to maintain equilibrium. The climate and relief of a region affect how quickly it erodes by affecting the weathering and transport processes that remove material from the region. These erosion and uplift processes allow igneous and metamorphic rocks formed deep within the crust to be exposed at the surface, and can uplift sedimentary rocks formed in basins to high elevations.

The interactions shown in this web activity are only a few of the complicated relationships in the Earth system. For example, uplifted topography affects climate by changing the temperatures and precipitation at high elevations, as well as rain shadows behind mountain ranges. What other interactions between mountain building processes affect the Earth system?

Assess

Once you have finished interacting with the animations and information, please click "Back" at the top of the browser window to return to the Assignments page of the Mountain Building Web Activity Blackboard site. Complete the Observations (Post-Test), followed by the brief Post-Activity Questionnaire.

Thank you!
The Static version of the Mountain Building Web Activity was created by Michelle Malone using Microsoft FrontPage and HTML. It can be viewed on any graphics based web browser such as Internet Explorer or Netscape. The original graphics were generated by Karl Schoessler using Adobe Photoshop based on sketches and instructions from Michelle Malone.

The current version of the Static web activity can be viewed at the following URL: http://myweb.students.wwu.edu/brucem/thesis_project/index.htm or on the included CD-ROM.

The following images are screen shots from the Static learning activity. Students can navigate through the web activity by clicking the labeled links in the top frame. Once a topic is selected, users scroll up and down using the scroll bar to the right of the bottom content frame.

The “Introduction”, “Models” and “Summary” links are identical in content to the corresponding pages on the Interactive web activity. The “Plate Tectonics”, “Isostasy”, “Erosion” and “Rock Cycle” links consist of text and screen shots from the Interactive web activity. The content is the same in both web activities, but is not animated or interactive in the Static web activity. Rather than students choosing and manipulating variables, static images of chosen variables and situations are shown.

The following pages show selections from the Static web activity. More detail can be seen by viewing the web activity on the CD-ROM included with this thesis.
Plate Tectonics

How do plate tectonics build mountains?

Observe how the movement of plates at a convergent plate boundary affects continental crust from 120 million years ago to the Present. Also observe how the horizontal shortening and vertical thickening of the crust, as well as the elevation of the mountain range above sea level change over time as the plates converge.

120 million years ago
- oceanic crust
- accumulating sediments
- passive continental margin
- subduction begins
- horizontal shortening: 0%
- crustal thickness: 35 km
- average elevation above sea level: 840 m

110 million years ago
- oceanic crust becomes dense enough to begin subduction
- horizontal shortening: 0%
- crustal thickness: 35 km
- average elevation above sea level: 940 m

Isostasy

H = 3000 m
$\rho_c = 2900 \text{ kg/m}^3$
$\rho_m = 3300 \text{ kg/m}^3$  $R = 9375 \text{ m}$

Increase crustal density ($\rho_c$)

H = 3000 m
$\rho_c = 2500 \text{ kg/m}^3$
$\rho_m = 3300 \text{ kg/m}^3$  $R = 21750 \text{ m}$

Decrease crustal density ($\rho_c$)
**Erosion**

Climate: Glacial  Relief: Steep  Erosion Rate: 1.0 mm/yr (1000 m/m.y.)

**Rock Cycle**

*How can rocks formed deep within the crust come to the surface?*

All of the processes of the rock cycle are active in the development of the mountain ranges at this subduction zone. Plutonic (intrusive) igneous rocks and metamorphic rocks form deep within the crust while sedimentary and volcanic igneous rocks form at or near Earth's surface.
APPENDIX IV: Questionnaires and Assessments

Pre-Treatment Questionnaire:

1. My gender is:
   ___ Male
   ___ Female

2. My lecture professor is:
   ___ [Instructor A]
   ___ [Instructor B]
   ___ [Instructor C]

3. My lab TA is:
   ___ [Lab TA A]
   ___ [Lab TA B]
   ___ [Lab TA C]
   ___ [Lab TA D]
   ___ [Lab TA E]
   ___ [Lab TA F]
   ___ [Lab TA G]
   ___ [Lab TA H]

4. How much previous experience have you had with Earth Science or Geology?
   ___ none
   ___ <1 year
   ___ 1 year
   ___ 1+ years
   ___ 2 years
   ___ >2 years

5. If you have taken Earth Science or Geology courses in the past, at what grade level did you take them? (check all that apply)
   ___ no Earth Science or Geology
   ___ elementary school
   ___ middle school/junior high
   ___ high school
   ___ college
   ___ informal education (an interest rather than a class)

6. On a scale of 1 to 5 (with 5 being highest) rate your level of interest in Earth Science/Geology:

   1  2  3  4  5
   very low interest  very high interest

7. What is your primary reason for choosing to take Geology 101? (check all that apply)
I needed a Science GUR
I am interested in learning more about Geology
It is supposed to be an easy class
I have taken Geology in the past and enjoy it
I would rather take Geology than Chemistry, Physics or Biology
Geology 101 was the only science GUR open when I registered

8. On a scale from 1-5 (5 being highest), what is your level of confidence about your ability in science classes?

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very low confidence

On a scale from 1-5 (5 being highest), what is your level of confidence about your knowledge about the following subjects:

9. Plate tectonics:

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no experience/low confidence

very high confidence

10. How mountains form:

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no experience/low confidence

very high confidence

11. Age of mountains in Washington and throughout the world:

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no experience/low confidence

very high confidence

12. Isostasy:

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no experience/low confidence

very high confidence
Post-Treatment Questionnaire:

1. How much time did you spend using the Mountain Building web activity?
   - 0 minutes
   - 0-5 minutes
   - 5-10 minutes
   - 10-15 minutes
   - 15-20 minutes
   - 20-30 minutes
   - 30-45 minutes
   - 45-60 minutes
   - > 60 minutes

On a scale from 1-5 (5 being highest), what is your level of confidence about your knowledge about the following subjects:

2. Plate tectonics:
   - 1  2  3  4  5
   no experience/low confidence very high confidence

3. How mountains form:
   - 1  2  3  4  5
   no experience/low confidence very high confidence

4. Age of mountains in Washington and throughout the world:
   - 1  2  3  4  5
   no experience/low confidence very high confidence

5. Isostasy:
   - 1  2  3  4  5
   no experience/low confidence very high confidence

6. On a scale from 1-5 (5 being a high level of enjoyment), how enjoyable was the web activity to use?
   - 1 - not enjoyable (I was bored and felt the activity was a waste of time)
   - 2
   - 3 - somewhat enjoyable (the web activity was useful but not exciting)
   - 4
   - 5 - very enjoyable (I enjoyed learning with this web activity very much)

7. On a scale from 1-5 (5 being a high level of comfort), how easy was the web activity to use?
   - 1 - very difficult (I was confused or frustrated most of the time)
   - 2
   - 3 (I could use the web activity fairly easily with minor problems)
   - 4
   - 5 - very easy (the web activity was user-friendly and easy to navigate)
On a scale from 1-5 (5 being very effective), how useful was the web activity in helping you understand:

8. How mountains form:
   1 - not useful (I don't understand any more than I did before)
   2
   3 (my understanding has increased somewhat)
   4
   5 - very useful (I understand much more about this topic than I did previously)

9. Age and timing of mountain formation:
   1 - not useful (I don't understand any more than I did before)
   2
   3 (my understanding has increased somewhat)
   4
   5 - very useful (I understand much more about this topic than I did previously)

10. Changes to mountains over time:
    1 - not useful (I don't understand any more than I did before)
    2
    3 (my understanding has increased somewhat)
    4
    5 - very useful (I understand much more about this topic than I did previously)

11. The balance between uplift and erosion:
    1 - not useful (I don't understand any more than I did before)
    2
    3 (my understanding has increased somewhat)
    4
    5 - very useful (I understand much more about this topic than I did previously)

12. The interaction between climate, relief, and erosion:
    1 - not useful (I don't understand any more than I did before)
    2
    3 (my understanding has increased somewhat)
    4
    5 - very useful (I understand much more about this topic than I did previously)

13. Isostasy:
    1 - not useful (I don't understand any more than I did before)
    2
    3 (my understanding has increased somewhat)
    4
    5 - very useful (I understand much more about this topic than I did previously)

14. Please provide brief written comments about what you considered useful or enjoyable about the web activity, as well as what could be improved:
Mountain Building Web Activity -- Predictions (Multiple-Choice)

Instructions: The following questions are designed to assess students' knowledge of mountain building processes before interacting with a mountain building web activity. Within each set of multiple choice questions, the first part will ask you to choose one answer that best fits your prediction about mountain building processes. The second multiple choice question will ask you to choose one statement that best explains your reasoning for the prediction you made in the first part.

Animation #1: How do plate tectonics build mountains?

1.1.a. Which of the following is the most reasonable estimate for how long it will take for a mountain range to form in the continental crust at this new convergent boundary?

- 700 years
- 6,000 years
- 100,000 years
- 20 million years
- 2 billion years
- 4.6 billion years

1.1.b. The reason for my answer is because:

- mountains formed during the formation of Earth
- mountains form and change at rates of millimeters per year
- it takes that long for volcanoes to form the entire mountain chain
- enough time must pass to allow sediments to accumulate and form a mountain
- the subducting plate must have sufficient time to push the mountain up through the other plate

1.2.a. What will happen to the elevation of the continental crust above sea level during subduction of the oceanic crust and continental collision?

The elevation of the continental crust will:

- increase
- decrease
- stay the same
1.2.b. The reason for my answer is because:

- the subducting oceanic crust will push the continental crust upwards
- the pressure of subduction will pull the continental crust downwards
- the subducting oceanic plate scrapes off the bottom of the mountain range
- magma intruding into the crust will add height, but will also increase its density
- tectonic stresses during subduction and collision will uplift the continental crust

1.3.a. What will happen to the continental crust below a mountain belt during subduction of the oceanic crust and continental collision?

- The continental crust will become thinner below the surface
- The continental crust will become thicker below the surface
- The continental crust below Earth’s surface will not be affected

1.3.b. The reason for my answer is because:

- the base of the continental crust is not related to the mountain belt
- crust moves up into the mountain belt, leaving less crust below the surface
- the oceanic plate rubs away the bottom of the mountain range as it subducts
- continental crust thickens downwards as well as upwards when it is compressed
Animation #2: How are mountain ranges supported from below?

2.1.a. The position of Earth's crust as it floats upon the mantle depends on isostasy. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

Using average density of the crust (2700 kg/m^3) and mantle (3300 kg/m^3) on Earth, what will happen to the crustal root as the mountain range elevation increases?

The crustal root will:
- move farther down into the mantle
- move up within the mantle
- not change size or position

2.1.b. The reason for my answer is because:
- the crustal root will move up with the mountain since they are connected
- higher mountains require a thicker crustal root to compensate for the added weight
- the crustal root is below the surface and is not affected by the mountain range above it
- the crust will need more support, and the mantle provides better support than the crust

2.2.a. When material is removed from the top of a mountain range by erosion (elevation decreases), what will happen to the position of the crustal root within the mantle?

The crustal root will:
- move farther down into the mantle
- move up within the mantle
- not change size or position
2.2.b. The reason for my answer is because:

- the mountain range will lose mass and become more buoyant
- erosion only affects the top of the mountain, not the crustal root
- the root will not change since the mountain is no longer growing
- the root must move downward as the mountain elevation decreases
- the position will not be affected because the density has not changed

2.3.a. On Earth, continental crust has an average density of about 2700 kg/m$^3$. If the crustal density could hypothetically be increased, what would likely happen to the position of the continental crust within the mantle?

The continental crust would:
- float higher in the mantle
- sink lower in the mantle
- remain in the same position

2.3.b. The reason for my answer is because:

- the upward buoyancy forces will increase as crustal density increases
- the downward gravitational forces will increase as crustal density increases
- buoyancy forces and gravitational forces will become equal when crustal density increases

2.4.a. On Earth, the mantle has an average density of about 3300 kg/m$^3$. If the mantle density could hypothetically be increased, what would likely happen to the position of the crustal root?

The crustal root would:
- move farther down into the mantle
- move up within the mantle
- not change size or position

2.4.b. The reason for my answer is because:

- the buoyancy force pushing up on the crust will increase
- the root density must increase as the mantle density increases
- the crust will become less dense as the mantle density increases
- the mantle is already denser than the crust, so further increases will have no effect
Animation #3: What processes shape and change mountains over time?

3.1.a. How will the relief of a region (the difference between the highest and lowest elevations) affect erosion rates?

- Regions with gradual relief will have faster erosion rates
- Regions with steep relief will have faster erosion rates
- Relief will have no effect on erosion rates

3.1.b. The reason for my answer is because:

- The force of gravity is greater closer to the center of Earth
- Weathering has a greater effect in the plains than in mountainous regions
- Erosion is dependent on temperature and moisture rather than elevation differences
- Water and ice move faster on steeper slopes, increasing its ability to erode and transport sediment

3.2.a. Which climate would you predict will have the lowest erosion rates in regions with steep relief?

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Tropical (warm, humid climate and heavy precipitation)
- Climate will have no effect on erosion rates
3.2.b. The reason for my answer is because:

- The climate is not cold enough to have high erosion rates
- Lowest amount of glaciation, landslides and surface runoff
- Water is frozen in place and cannot erode underlying bedrock
- All of these regions will erode equally since they have the same relief

3.3.a. Which climate would you predict will have the highest erosion rates in regions with steep relief?

- Glacial (alpine glaciers)
- Temperate (mild climate and moderate precipitation)
- Tropical (warm, humid climate and heavy precipitation)
- Climate will have no effect on erosion rates

3.3.b. The reason for my answer is because:

- All of these regions have the same relief
- Weathering is affected by moisture and temperature
- Moving ice and water erode and transport sediments
- The most rainfall is available to contribute to erosion

3.4.a. How will isostasy affect the average elevation of mountains over time as mass is removed from the mountain range by erosion?

Isostasy will:

- Not have an effect on average elevation over time
- Slow the rate at which average elevation decreases over time
- Speed up the rate at which average elevation decreases over time
- Increase the average elevation of the mountainous region over time

3.4.b. The reason for my answer is because:

- The mantle density will increase and push the mountains upward
- As material is eroded away, the elevation will lower at an increasing rate
- Movement of the crustal root will uplift the mountain range to greater average elevation
- As the mountain belt gets smaller, isostasy will push the mountain up to maintain equilibrium
Animation #4: How can rocks formed deep within the crust come to the surface?

4.1.a. Which processes will be responsible for exposing intrusive igneous and metamorphic rocks, which form deep within the crust, at the surface of the mountain range?

Deep crustal rocks will be exposed at the surface by:

- Melting and cooling of magma
- Erosion, crustal shortening, and uplift
- Decrease in density of the rocks after they form
- Erosion down to the depth where the rocks originated

4.1.b. The reason for my answer is because:

- Deep crust uplifts as upper crustal layers are removed
- Rocks can buoyantly rise through the surrounding crust
- Deep crustal rocks erupt onto the surface through volcanoes
- Rocks formed in Earth’s interior are exposed only in deep canyons

4.2.a. What will happen to the mountain range such as the one shown above as the subduction of the oceanic plate continues?

- The mountain range will erode down until it reaches the average thickness of the crust
- Rock material from the deep crust will move up within the mountain range
- The average elevation of the mountain range will approximately double
- The mountain range will increase infinitely in elevation

4.2.b. The reason for my answer is because:

- Convergence of plates will lead to unlimited mountain growth
- Volcanic eruptions will replace all of the material lost to erosion
- Subduction can only build mountains for so long before they erode away
- Crustal shortening will squeeze crust up from below as erosion removes material
4.3.a. What will eventually happen to the mountain range once the subduction zone is no longer active?

- The mountain range will slowly erode down until it reaches the average thickness of the crust
- The average elevation of the mountain range will approximately double before growth stops
- The average elevation of the mountain range will rapidly decrease
- The mountain range will continually increase in elevation

4.3.b. The reason for my answer is because:

- When subduction ceases, mountain uplift will stop
- Erosion rates will exceed isostatic and tectonic uplift rates
- Once mountain growth ceases, erosion processes will begin
- Isostatic uplift will completely compensate for loss due to erosion
- Rock material will stay where it is because of lack of heat and pressure
- When the subduction zone becomes inactive, elevation will no longer change

OBSERVATIONS POST-TEST IS IDENTICAL TO THE PREDICTIONS PRE-TEST. THE ONLY DIFFERENCE IS THE TENSE USED IN THE QUESTIONS.
Animation #1: How do plate tectonics build mountains?

How will the elevation of the crust above sea level and thickness of the crust below the mountain range be affected by continued subduction of the oceanic plate and collision of a second continent?

**Be sure to include in your answer:**
- Whether the elevation of the crust above sea level will increase, decrease, or stay the same
- Whether the thickness of the crust below the mountain range will become thicker, become thinner, or remain the same
- Your reasoning for both of your predictions about the continental crust
**Animation #2**: How are mountain ranges supported from below?

The position of Earth's crust as it floats upon the mantle depends on **isostasy**. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

How will the position of Earth's crust floating in the mantle be affected by changes in mountain height or changes in crustal density? Specifically, a) what will happen to the size or position of the crustal root if the height of the mountain range is decreased by erosion?, and b) how would the position of the crust be affected if the crustal density could increase to greater than 2700 kg/m³?

**Be sure to include in your answer:**
- Whether the crustal root will move farther down into the mantle, move up within the mantle, or remain the same size/position when the height of the mountain range is decreased by erosion
- Whether the crust would move up, move down or remain in the same position in the mantle if the crustal density increased
- Your reasoning for both of your predictions about the continental crust
Landforms on Earth are shaped and changed by erosion and other geologic processes. How will relief (the difference between the highest and lowest elevations in a region) and climate affect average erosion rates in a region?

Be sure to include in your answer:
- Whether faster average erosion rates will occur in regions with steep relief or regions with gradual relief (or whether erosion rates will be unaffected by relief)
- Which of the climates above (glacial, temperate or tropical) will have the fastest average erosion rates (or whether erosion rates will be unaffected by climate)
- Your reasoning for both of your predictions about erosion rates
Animation #4: How can rocks formed deep within the crust come to the surface?

Which processes that occur during mountain formation will be responsible for exposing intrusive igneous and metamorphic rocks, which form deep within the crust, at the surface of the mountain range?

Be sure to include in your answer:
- At least two processes associated with the formation and evolution of a mountain range that would be involved with exposing deep crustal rocks at the surface of the mountain range
- Your reasoning for both of your predictions about how deep rocks can be exposed

Observations post-test is identical to the predictions pre-test. The only difference is the tense used in the questions.
The Caucasus Mountains are located between the Black Sea and Caspian Sea, separating Europe from Asia. This 550-mile long mountain range lies between Russia to the north and the countries of Georgia, Azerbaijan and Armenia to the south. With an average elevation of 6000-9000 feet (~1800-2700 meters), the Caucasus Mountains contain several 4000 meter (13,000 feet) peaks, including Mt. Elbrus at 5642 m (18,481 feet) in height. The western Caucasus Mountains, because of its proximity to the Black Sea, have a warm, humid and rainy climate with thick conifer and deciduous forests. The Central Caucasus Mountains are glaciated at high elevations with high, jagged peaks and 30 small glaciers. At lower elevations, the Central Caucasus consists of alpine meadows and pine forests in the valleys. The Eastern Caucasus has a drier, semi-desert climate and contains barren foothills with isolated peaks.

Instructions: Answer the following questions about the Caucasus Mountains based on the brief information given above and your knowledge of mountain building processes. YOU WILL NOT NEED ANY OTHER REFERENCES TO COMPLETE THIS ASSESSMENT. For each multiple choice question, please choose the one answer that best reflects how a geologist would answer. In the space provided below each multiple choice question, please provide a brief, but clear. The second multiple choice question in each set will ask you to explain your reasoning for your choice to the previous question.

1. Which of the following is the most reasonable estimate for the age of the Caucasus Mountain range?
   - 800 years
   - 6,000 years
   - 100,000 years
   - 3 million years
   - 700 million years
   - 4.6 billion years
2. The reason for my answer to Question 1 is because:
   - mountains formed during the formation of Earth
   - mountains form and change at rates of millimeters per year
   - it takes that long for volcanoes to form the entire mountain chain
   - enough time must pass to allow sediments to accumulate and form a mountain
   - the subducting plate must have sufficient time to push the mountain up through the other plate

3. Which of the following processes is primarily responsible for the formation of the Caucasus Mountains?
   - volcanic eruptions extending between the Black and Caspian Seas
   - the separation of the Eurasian continent from Pangaea
   - sea level decreasing in the Black and Caspian Seas
   - the collision of the Eurasian and Arabian plates

4. The reason for my answer to Question 3 is because:
   - linear mountain ranges form at the edge of rifting continents
   - the subducting oceanic crust pushed the continental crust upwards
   - the entire mountain chain is formed of volcanic peaks and fissures
   - the mountain range has been gradually exposed as the ocean recedes
   - tectonic stresses during subduction and collision uplift the continental crust

5. The position of Earth's crust as it floats upon the mantle depends on isostasy. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

What is likely happening to the position of the crustal root below the Caucasus Mountains as the average elevation of the range above sea level is increasing?

The crustal root:
   - moves farther down into the mantle
   - moves up within the mantle
   - does not change size or position

6. The reason for my answer to Question 5 is because:
   - the crustal root moves up with the mountain since they are connected
   - higher mountains require a thicker crustal root to compensate for the added weight
   - the crustal root is below the surface and is not affected by the mountain range above it
   - the crust needs more support, and the mantle provides better support than the crust

7. How does the crustal root below the Caucasus Mountains likely respond when erosion removes material from the top of the mountain range?

The crustal root:
   - moves farther down into the mantle
   - moves up within the mantle
   - does not change size or position
8. The reason for my answer to Question 7 is because:
   o the mountain range loses mass and becomes more buoyant
   o erosion only affects the top of the mountain, not the crustal root
   o the root must move downward as the mountain elevation decreases
   o the position is not affected because the density has not changed
   o the root does not change since the mountain is no longer growing

9. The presence of volcanic rocks such as tuff and andesite in addition to exposed granite and granodiorite plutons in the Caucasus Mountains are evidence that magma has intruded into the continental crust from the underlying mantle. How has the input of lower-density molten magma most likely affected the continental crust forming the Caucasus Mountains?

   The intrusion of liquid magma has caused the crust to:
   o remain in the same position relative to the mantle
   o float higher in the mantle
   o sink lower in the mantle

10. The reason for my answer to Question 9 is because:
    o the continental crust has become more buoyant
    o added material of any kind will cause the crust to sink
    o the mantle density changes in proportion to the crust density
    o the crust is already less dense than the mantle, so there will be no effect

11. Based on the relationship between relief and erosion, which of the following places of the Caucasus Mountains is likely to experience the highest erosion rate?
    o areas of steep relief with high peaks and deep valleys
    o areas of moderate relief such as foothills
    o areas of gradual relief such as plains
    o all areas should have the same erosion rate

12. The reason for my answer to Question 11 is because:
    o the force of gravity is greater closer to the center of Earth
    o weathering has a greater effect in the plains than in mountainous regions
    o erosion is dependent on temperature and moisture rather than elevation differences
    o water and ice move faster on steeper slopes, increasing its ability to erode and transport sediment

13. According the climate information provided in the introductory paragraph, which of the following regions of the Caucasus Mountains is likely to experience the lowest erosion rate?
    o Western (warm, humid, rainy, temperate forested)
    o Central (glacial in mountain regions, temperate forests at lower elevations)
    o Eastern (drier, semi-arid climate)
    o all regions should have the same erosion rate
14. The reason for my answer to Question 13 is because:
   o cold, dry climates allow little weathering
   o less water is available to contribute to erosion
   o more glaciers and jagged peaks slow erosion rates
   o all regions will erode equally because of similar relief

15. How does **isostasy** affect the average elevation of the Caucasus Mountains over time as mass is removed from the mountain range by erosion?

   **Isostasy:**
   o does not have an effect on average elevation over time
   o slows the rate at which average elevation decreases over time
   o speeds up the rate at which average elevation decreases over time
   o increases the average elevation of the mountainous region over time

16. The reason for my answer to Question 15 is because:
   o the mantle density increases and pushes the mountains upward
   o as material is eroded away, the elevation decreases at a faster rate
   o movement of the crustal root uplifts the mountain range to greater average elevation
   o as the mountain belt gets smaller, isostasy pushes the mountain up to maintain equilibrium

17. High grade metamorphic rocks and intrusive igneous rocks are exposed and visible at the surface of the Caucasus Mountains. How can metamorphic and igneous rocks formed deep in the crust eventually be found at the surface?
   o erosion removes overlying material as rocks within the crust are uplifted
   o the crust is eroded away down to the mantle, exposing igneous rocks
   o the rocks decrease in density once cooled and rise to the surface
   o a drastic decrease in sea level exposed the rocks at the surface

18. The reason for my answer to Question 17 is because:
   o the rocks are uncovered as the water level decreases
   o rocks can buoyantly rise through the surrounding crust
   o deep crustal rocks erupt onto the surface through volcanoes
   o mass removal from the mountain allows the crust to move up

19. Marine sedimentary rocks containing fossils 10 million years in age have been found at elevations of 3500 m (11,500 feet) in the Caucasus Mountains. Which of the following is the most likely explanation for ocean sediments to be found at this elevation?
   o marine organisms have evolved to live in mountainous regions
   o sea level has dropped 4 kilometers in the last 10 million years
   o the crust where the sediment was deposited has been uplifted
   o dense ocean basins have sunk to a deeper elevation over time
20. The reason for my answer to Question 19 is because:
   - marine sediments are left on land as the ocean floor sinks lower
   - volcanism has uplifted the sedimentary rocks to high elevations
   - the sedimentary rocks are uncovered as the water level decreases
   - the seafloor sediment is pushed upwards as the continents collide

21. The Caucasus Mountains are one of Earth’s most rapidly growing mountain ranges. What does this imply about the relationship between erosion rates and uplift rates in this region?
   - uplift rates and erosion rates are approximately equal
   - uplift rates are greater than erosion rates
   - uplift rates are less than erosion rates

22. The reason for my answer to Question 21 is because:
   - erosion processes are very slow until after the mountain range reaches its maximum height
   - though erosion is ongoing, tectonic and isostatic forces combine to cause uplift
   - erosion does not begin until plate convergence ceases
   - isostasy prevents erosion from occurring
The Caucasus Mountains are located between the Black Sea and Caspian Sea, separating Europe from Asia. This 550-mile long mountain range lies between Russia to the north and the countries of Georgia, Azerbajian and Armenia to the south. With an average elevation of 6000-9000 feet (~1800-2700 meters), the Caucasus Mountains contain several 4000 meter (13,000 feet) peaks, including Mt. Elbrus at 5642 m (18,481 feet) in height. The western Caucasus Mountains, because of its proximity to the Black Sea, have a warm, humid and rainy climate with thick conifer and deciduous forests. The Central Caucasus Mountains are glaciated at high elevations with high, jagged peaks and 30 small glaciers. At lower elevations, the Central Caucasus consists of alpine meadows and pine forests in the valleys. The Eastern Caucasus has a drier, semi-desert climate and contains barren foothills with isolated peaks.

Instructions: Answer the following questions about the Caucasus Mountains based on the brief information given above and your knowledge of mountain building processes. YOU WILL NOT NEED ANY OTHER REFERENCES TO COMPLETE THIS ASSESSMENT. To earn maximum points for each short essay answer, please be sure to include each of the bulleted points as part of your answer, and explain your reasoning to the best of your ability. Your goal should be to explain your thoughts as briefly and clearly as possible.

Question 1:
How has the elevation of the Caucasus Mountains above sea level and thickness of the crust below the mountain range been affected by the convergence of the Eurasian and Arabian plates?

Be sure to include in your answer:
- Whether the elevation of the crust above sea level has increased, decreased, or remained the same as before the plates began to converge
- Whether the thickness of the crust below the mountain range has become thicker, become thinner, or remained the same
- Your reasoning for both of your observations about the continental crust
Question 2:
The position of Earth’s crust as it floats upon the mantle depends on isostasy. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

How is the position of Earth’s crust floating in the mantle affected by changes in mountain height or changes in crustal density? Specifically, a) how does the crustal root below the Caucasus Mountains most likely react to the loss of material at the top due to erosion?, and b) how does the position of the crust likely react to the intrusion of low-density molten magma that has formed granite plutons in the Caucasus Mountains?

Be sure to include in your answer:
- Whether the crustal root moves farther down into the mantle, moves up within the mantle, or remains the same size/position as material erodes from the Caucasus Mountain range?
- Whether the crust moves up, moves down or remains in the same position in the mantle as low-density magma intrudes into the crust
- Your reasoning for both of your observations about the continental crust

Question 3:
The Caucasus Mountain range contains regions with varied topographic relief, as well as a variety of climates. The mountain range has steep relief in areas of high peaks and deep valleys, moderate relief in the foothills, and gradual relief in the plains and plateaus. As is detailed in the introductory paragraph, the climate in the western portion of the range is warm, humid and rainy. In the central Caucasus, a glacial climate exists in higher elevations with temperate forests at lower elevations. The Eastern portion, furthest inland, is drier and semi-arid. Which climate and which degree of relief (steep, moderate or gradual) likely results in the lowest erosion rates in the Caucasus Mountains?

Be sure to include in your answer:
- Whether slower average erosion rates occur in regions with steep relief or regions with gradual relief (or whether erosion rates are unaffected by relief)
- Which of the climate regions above (western, central or eastern Caucasus) has the slowest average erosion rates (or whether erosion rates are unaffected by climate)
- Your reasoning for both of your observations about erosion rates

Question 4:
High grade metamorphic rocks and intrusive igneous rocks (granite and granodiorite plutons) are exposed and visible at the surface of the Caucasus Mountains. How can metamorphic and igneous rocks formed deep in the crust eventually be found at the surface?

Be sure to include in your answer:
- At least two processes associated with the formation and evolution of the Caucasus Mountains that are involved with exposing deep crustal rocks at the surface of the mountain range
- Your reasoning for both of the processes you observed that contributed to exposing deep crustal rocks
Rubrics for Essay Responses

Pre-test and Post-test questions were identical except that the Post-Test are in present rather than future (predictive) tense.

Predictions (Pre-Test) and Observations (Post-Test)
How will the elevation of the crust above sea level and thickness of the crust below the mountain range be affected by continued subduction of the oceanic plate and collision of a second continent?

Be sure to include in your answer:
- Whether the elevation of the crust above sea level will increase, decrease, or stay the same
- Whether the thickness of the crust below the mountain range will become thicker, become thinner, or remain the same
- Your reasoning for both of your predictions about the continental crust

RUBRIC for Question #1 (pre, post)
This question is graded on a 0-4 point scale. Each point can be earned as follows:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly states that the elevation of the crust above sea level will INCREASE</td>
<td>/1 pt</td>
</tr>
<tr>
<td>Includes reasoning for increase in elevation, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>- Upward movement of magma/mantle during subduction (resulting in thickening or volcanism)</td>
<td></td>
</tr>
<tr>
<td>- Addition of new material to the crust (accretionary wedge)</td>
<td></td>
</tr>
<tr>
<td>- Shortening/thickening due to compression or plate convergence</td>
<td></td>
</tr>
<tr>
<td>- Other scientifically accurate reasoning that is directly applicable to the question</td>
<td></td>
</tr>
<tr>
<td><strong>Uplift due to subducting plate pushing up continental plate is NOT acceptable</strong></td>
<td></td>
</tr>
<tr>
<td>Correctly states that the thickness of the continental crust below the mountain range will INCREASE</td>
<td>/1 pt</td>
</tr>
<tr>
<td>Includes reasoning for thickening of crust, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>- Upward movement of magma/mantle during subduction</td>
<td></td>
</tr>
<tr>
<td>- Addition of new material to the crust (accretionary wedge)</td>
<td></td>
</tr>
<tr>
<td>- Shortening/thickening due to compression or plate convergence</td>
<td></td>
</tr>
<tr>
<td>- Thickening occurs above and below surface to maintain balance</td>
<td></td>
</tr>
<tr>
<td>- Other scientifically accurate reasoning that is directly applicable to the question.</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL SCORE for Question #1 /4 pts

Notes:
- The elevation and thickness could potentially STAY THE SAME if student’s reasoning includes an explanation such as: If all factors (tectonic uplift, volcanism, erosion, etc.) are in balance, elevation maintains equilibrium
- Some responses show student confusion about the “crust below the mountain range”. Responses discuss the subducting oceanic crust will receive no credit for that portion of the response because the question asks for predictions or observations about the continental crust. Responses that refer to the continental crust as a whole, w/o making reference to “below the mountain range” are acceptable if they are scientifically correct.
Predictions (Pre-Test) and Observations (Post-Test)

The position of Earth’s crust as it floats upon the mantle depends on isostasy. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

How will the position of Earth’s crust floating in the mantle be affected by changes in mountain height or changes in crustal density? Specifically, a) what will happen to the size or position of the crustal root if the height of the mountain range is decreased by erosion? and b) how would the position of the crust be affected if the crustal density could increase to greater than 2700 kg/m³?

**Be sure to include in your answer:**
- Whether the crustal root will move farther down into the mantle, move up within the mantle, or remain the same size/position when the height of the mountain range is decreased by erosion
- Whether the crust would move up, move down or remain in the same position in the mantle if the crustal density increased
- Your reasoning for both of your predictions about the continental crust

RUBRIC for Question #2 (pre, post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly states that the crustal root will MOVE UP within the mantle when mountain height decreases due to erosion</td>
<td>/1 pt</td>
</tr>
</tbody>
</table>
| Includes reasoning for upward movement of root, which could include:  
  - Decreased downward force (crust is lighter)  
  - Less crustal root is necessary to compensate for weight of mt. range  
  - The crustal root responds by thinning to maintain isostatic equilibrium  
  - Other scientifically accurate reasoning that is directly applicable to the question. | /1 pt |
| Correctly states that the crust will MOVE DOWN or SINK INTO the mantle when crustal density increases | /1 pt |
| Includes reasoning for downward movement of crust, which could include:  
  - Increased downward force (crust is heavier, more affected by gravity)  
  - Decreased buoyancy  
  - Crust responds to maintain isostatic equilibrium  
  - Other scientifically accurate reasoning that is directly applicable to the question. | /1 pt |

**Crust completely sinking into mantle is not acceptable unless crust density > mantle density. “Heavy things sink” is not acceptable (e.g. battleships are heavy, but buoyant).**

**Total Score for Question #2 /4 pts**
Predictions (Pre-Test) and Observations (Post-Test)

Landforms on Earth are shaped and changed by erosion and other geologic processes. How will relief (the difference between the highest and lowest elevations in a region) and climate affect average erosion rates in a region?

Be sure to include in your answer:
- Whether faster average erosion rates will occur in regions with steep relief or regions with gradual relief (or whether erosion rates will be unaffected by relief)
- Which of the climates above (glacial, temperate or tropical) will have the fastest average erosion rates (or whether erosion rates will be unaffected by climate)
- Your reasoning for both of your predictions about erosion rates

RUBRIC for Question #3 (pre, post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly states that erosion rates are higher in regions with STEEP relief</td>
<td>1 pt</td>
</tr>
<tr>
<td>Includes reasoning for high erosion rates with steep relief, which could include:</td>
<td>1 pt</td>
</tr>
<tr>
<td>- Less slope stability (weathered material removed more easily)</td>
<td>1 pt</td>
</tr>
<tr>
<td>- More exposure to erosive agents</td>
<td>1 pt</td>
</tr>
<tr>
<td>- Stream velocities greater/greater driving forces</td>
<td>1 pt</td>
</tr>
<tr>
<td>- Other scientifically accurate reasoning that is directly applicable to the question.</td>
<td>1 pt</td>
</tr>
<tr>
<td>Correctly states that erosion rates are highest in GLACIAL climates</td>
<td>1 pt</td>
</tr>
<tr>
<td>Includes reasoning for high erosion rates in glacial climates, which could include:</td>
<td>1 pt</td>
</tr>
<tr>
<td>- Movement of heavy/massive glaciers is a strong erosive force</td>
<td>1 pt</td>
</tr>
<tr>
<td>- Combination of several erosive forces (water, ice, rockfall, etc.)</td>
<td>1 pt</td>
</tr>
<tr>
<td>- Other scientifically accurate reasoning that is directly applicable to the question.</td>
<td>1 pt</td>
</tr>
<tr>
<td>** if glacier is frozen to bedrock, erosion will be minimal, but not all glaciers are frozen to the bedrock, so overall, glacial climates still have fastest erosion</td>
<td>1 pt</td>
</tr>
</tbody>
</table>

TOTAL SCORE for Question #3 /4 pts

Notes:
- High erosion rates in TROPICAL climates are also acceptable, if sufficient explanation is included. Simple statements about climate such as high precipitation or high humidity and temperature are not acceptable without an explanation of WHY those climate conditions produce high weathering or erosion rates. The distinction between weathering rates and erosion rates is too subtle to be penalized at the Geology 101 level. “Heavy precipitation” or “more water” is not acceptable without references to water velocity or relief. More water does not necessarily = faster erosion rates.
Predictions (Pre-Test) and Observations (Post-Test)

Which processes that occur during mountain formation will be responsible for exposing intrusive igneous and metamorphic rocks, which form deep within the crust, at the surface of the mountain range?

Be sure to include in your answer:
- At least two processes associated with the formation and evolution of a mountain range that would be involved with exposing deep crustal rocks at the surface of the mountain range
- Your reasoning for both of your predictions about how deep rocks can be exposed

RUBRIC for Question #4 (pre, post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>One process related to mountain building that could expose deep rocks at the surface is identified, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>- Erosion</td>
<td></td>
</tr>
<tr>
<td>- Isostatic Uplift (upward movement of crust or crustal root)</td>
<td></td>
</tr>
<tr>
<td>- Crustal shortening/thickening (tectonic uplift due to convergence)</td>
<td></td>
</tr>
<tr>
<td>- Faulting/earthquakes</td>
<td></td>
</tr>
<tr>
<td>- Caldera formation</td>
<td></td>
</tr>
<tr>
<td>(volcanism in itself is not sufficient, unless xenoliths are specified**)</td>
<td></td>
</tr>
<tr>
<td>- Weathering (only if erosion is also included in answer)</td>
<td></td>
</tr>
<tr>
<td>- Folding/overturning (in association with erosion)</td>
<td></td>
</tr>
<tr>
<td>Reasoning consistent with the process listed above is included, which must be a “Scientifically Accurate” statement</td>
<td>/1 pt</td>
</tr>
<tr>
<td>(an explanation of WHY or HOW the above process contributes to the exposure of deep rocks must be included in order to receive this point)</td>
<td></td>
</tr>
<tr>
<td>A second process related to mountain building that could expose deep rocks at the surface is identified, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>- Erosion</td>
<td></td>
</tr>
<tr>
<td>- Isostatic Uplift (upward movement of crust or crustal root)</td>
<td></td>
</tr>
<tr>
<td>- Crustal shortening/thickening (tectonic uplift due to convergence)</td>
<td></td>
</tr>
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<td>- Faulting/earthquakes</td>
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<td>- Caldera formation</td>
<td></td>
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<tr>
<td>(volcanism in itself is not sufficient, unless xenoliths are specified**)</td>
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<tr>
<td>- Weathering (only if erosion is also included in answer)</td>
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<td></td>
</tr>
<tr>
<td>Reasoning consistent with the process listed above is included, which must be a “Scientifically Accurate” statement</td>
<td>/1 pt</td>
</tr>
<tr>
<td>(an explanation of WHY or HOW the above process contributes to the exposure of deep rocks must be included in order to receive this point)</td>
<td></td>
</tr>
<tr>
<td>TOTALSCORE for Question #4</td>
<td>/4 pts</td>
</tr>
</tbody>
</table>

**In order to receive full credit, one of the identified processes MUST be EROSION**
Delayed Post-Test

The Caucasus Mountains are located between the Black Sea and Caspian Sea, separating Europe from Asia. This 550-mile long mountain range lies between Russia to the north and the countries of Georgia, Azerbaijan and Armenia to the south. With an average elevation of 6000-9000 feet (~1800-2700 meters), the Caucasus Mountains contain several 4000 meter (13,000 feet) peaks, including Mt. Elbrus at 5642 m (18,481 feet) in height. The western Caucasus Mountains, because of its proximity to the Black Sea, have a warm, humid and rainy climate with thick conifer and deciduous forests. The Central Caucasus Mountains are glaciated at high elevations with high, jagged peaks and 30 small glaciers. At lower elevations, the Central Caucasus consists of alpine meadows and pine forests in the valleys. The Eastern Caucasus has a drier, semi-desert climate and contains barren foothills with isolated peaks.

TEST QUESTION INCLUDES SATELLITE IMAGE OF CAUCASUS MOUNTAINS

How has the elevation of the Caucasus Mountains above sea level and thickness of the crust below the mountain range been affected by the convergence of the Eurasian and Arabian plates?

Be sure to include in your answer:

- Whether the elevation of the crust above sea level has increased, decreased, or remained the same as before the plates began to converge
- Whether the thickness of the crust below the mountain range has become thicker, become thinner, or remained the same
- Your reasoning for both of your observations about the continental crust

RUBRIC for Question #1 (delayed post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly states that the elevation of the crust above sea level will INCREASE</td>
<td>1 pt</td>
</tr>
<tr>
<td>Includes reasoning for increase in elevation, which could include:</td>
<td></td>
</tr>
<tr>
<td>- Upward movement of magma/mantle during subduction (resulting in thickening or volcanism)</td>
<td>1 pt</td>
</tr>
<tr>
<td>- Addition of new material to the crust (accretionary wedge)</td>
<td></td>
</tr>
<tr>
<td>- Shortening/thickening due to compression or plate convergence</td>
<td></td>
</tr>
<tr>
<td>- Other scientifically accurate reasoning that is directly applicable to the question.</td>
<td></td>
</tr>
<tr>
<td><strong>Uplift due to subducting plate pushing up continental plate is NOT acceptable</strong></td>
<td></td>
</tr>
<tr>
<td>Correctly states that the thickness of the crust below the mountain range will INCREASE</td>
<td>1 pt</td>
</tr>
<tr>
<td>Includes reasoning for thickening of crust, which could include:</td>
<td></td>
</tr>
<tr>
<td>- Upward movement of magma/mantle during subduction</td>
<td>1 pt</td>
</tr>
<tr>
<td>- Addition of new material to the crust (accretionary wedge)</td>
<td></td>
</tr>
<tr>
<td>- Shortening/thickening due to compression or plate convergence</td>
<td></td>
</tr>
<tr>
<td>- Thickening occurs above and below surface to maintain balance</td>
<td></td>
</tr>
<tr>
<td>- Other scientifically accurate reasoning that is directly applicable to the question.</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL SCORE for Question #1 /4 pts

Notes: The elevation and thickness could potentially STAY THE SAME if student’s reasoning includes an explanation such as: If all factors (tectonic uplift, volcanism, erosion, etc.) are in balance, elevation maintains equilibrium
Delayed Post-Test

The position of Earth’s crust as it floats upon the mantle depends on isostasy. Isostatic equilibrium is achieved when the gravitational forces pulling down on the weight of the crust equals the buoyancy forces pushing up on the crust. If density or crustal thickness changes, the crust will slowly respond to regain equilibrium.

How is the position of Earth’s crust floating in the mantle affected by changes in mountain height or changes in crustal density? Specifically, a) how does the crustal root below the Caucasus Mountains most likely react to the loss of material at the top due to erosion?, and b) how does the position of the crust likely react to the intrusion of low-density molten magma that has formed granite plutons in the Caucasus Mountains?

Be sure to include in your answer:
- Whether the crustal root moves farther down into the mantle, moves up within the mantle, or remains the same size/position as material erodes from the Caucasus Mountain range?
- Whether the crust moves up, moves down or remains in the same position in the mantle as low-density magma intrudes into the crust
- Your reasoning for both of your observations about the continental crust

RUBRIC for Question #2 (delayed post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly states that the crustal root will MOVE UP within the mantle when mountain height decreases due to erosion</td>
<td>/1 pt</td>
</tr>
<tr>
<td>Includes reasoning for upward movement of root, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Decreased downward force (crust is lighter)</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Less crustal root is necessary to compensate for weight of mt. range</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• The crustal root responds by thinning to maintain isostatic equilibrium</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Other scientifically accurate reasoning that is directly applicable to the question.</td>
<td>/1 pt</td>
</tr>
<tr>
<td>Correctly states that crust will MOVE UP, STAY THE SAME, or MOVE DOWN when low-density magma intrudes into crust</td>
<td>/1 pt</td>
</tr>
<tr>
<td>Includes reasoning for movement of crust, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Increased buoyancy with the addition of low-density material (which increases volume more than it increases mass)</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Addition of molten magma decreases overall density of crust</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Addition of new material increases thickness (increases elevation)</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Other scientifically accurate reasoning that is directly applicable to the question.</td>
<td>/1 pt</td>
</tr>
</tbody>
</table>

**Does not move downward due to increased weight or increased mass because overall density decreases**

**Because of the complexity of this part of the question, accept any response that is internally consistent and scientifically reasonable**

| TOTAL SCORE for Question #2 | /4 pts |

Notes:
- The intruding magma could have no measurable effect on the crust because the amount of magma is very little compared to the size of the mountain (amount of magma isn’t specified in the question – so this is a good point)
- With a reasonable (scientifically accurate) explanation, the position of the crust could STAY THE SAME (ie. erosion and uplift rates are in balance)
- Accept the crustal ROOT moving downward when low-density magma intrudes (due to increased volume, crustal thickening)
The Caucasus Mountain range contains regions with varied topographic relief, as well as a variety of climates. The mountain range has steep relief in areas of high peaks and deep valleys, moderate relief in the foothills, and gradual relief in the plains and plateaus. As is detailed in the introductory paragraph, the climate in the western portion of the range is warm, humid and rainy. In the central Caucasus, a glacial climate exists in higher elevations with temperate forests at lower elevations. The Eastern portion, furthest inland, is drier and semi-arid. Which climate and which degree of relief (steep, moderate or gradual) likely results in the lowest erosion rates in the Caucasus Mountains?

Be sure to include in your answer:

- Whether slower average erosion rates occur in regions with steep relief or regions with gradual relief (or whether erosion rates are unaffected by relief)
- Which of the climate regions above (western, central or eastern Caucasus) has the slowest average erosion rates (or whether erosion rates are unaffected by climate)
- Your reasoning for both of your observations about erosion rates

RUBRIC for Question #3 (delayed post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly states that erosion rates are higher in regions with STEEP relief</td>
<td>/1 pt</td>
</tr>
<tr>
<td>Includes reasoning for high erosion rates with steep relief, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Less slope stability</td>
<td></td>
</tr>
<tr>
<td>• More exposure to erosive agents</td>
<td></td>
</tr>
<tr>
<td>• Stream velocities greater/greater driving forces</td>
<td></td>
</tr>
<tr>
<td>• Other scientifically accurate reasoning that is directly applicable to the question.</td>
<td></td>
</tr>
<tr>
<td>Correctly states that erosion rates will be slowest in the EASTERN Caucasus region</td>
<td>/1 pt</td>
</tr>
<tr>
<td>Includes reasoning for slow erosion rates in Eastern Caucasus, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• dry climate (dry = less moving water, less precipitation, no glaciation) <strong>no credit for just stating it is a dry climate w/o further explanation</strong></td>
<td></td>
</tr>
</tbody>
</table>

TOTAL SCORE for Question #3 /4 pts

Notes:
- The CENTRAL Caucasus region could also be acceptable because they are temperate forests if heavy vegetation is mentioned.
**Delayed Post-Test**

High grade metamorphic rocks and intrusive igneous rocks (granite and granodiorite plutons) are exposed and visible at the surface of the Caucasus Mountains. How can metamorphic and igneous rocks formed deep in the crust eventually be found at the surface?

**Be sure to include in your answer:**
- At least two processes associated with the formation and evolution of the Caucasus Mountains that are involved with exposing deep crustal rocks at the surface of the mountain range
- Your reasoning for both of the processes you observed that contributed to exposing deep crustal rocks

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### RUBRIC for Question #4 (delayed post)

This question is graded on a 0-4 point scale. Each point can be earned as follows:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>One process related to mountain building that could expose deep rocks at the surface is identified, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Erosion</td>
<td></td>
</tr>
<tr>
<td>• Isostatic Uplift (upward movement of crust or crustal root)</td>
<td></td>
</tr>
<tr>
<td>• Crustal shortening/thickening (tectonic uplift due to convergence)</td>
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<td>• Faulting/earthquakes</td>
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<td></td>
</tr>
<tr>
<td>(volcanism in itself is not sufficient, unless xenoliths are specified**)</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Weathering (only if erosion is also included in answer)</td>
<td></td>
</tr>
<tr>
<td>• Folding/overturning (in association with erosion)</td>
<td></td>
</tr>
<tr>
<td>Reasoning consistent with the process listed above is included, which must be a “Scientifically Accurate” statement (an explanation of WHY or HOW the above process contributes to the exposure of deep rocks must be included in order to receive this point)</td>
<td>/1 pt</td>
</tr>
<tr>
<td>A second process related to mountain building that could expose deep rocks at the surface is identified, which could include:</td>
<td>/1 pt</td>
</tr>
<tr>
<td>• Erosion</td>
<td></td>
</tr>
<tr>
<td>• Isostatic Uplift (upward movement of crust or crustal root)</td>
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<tr>
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</tr>
</tbody>
</table>

**TOTAL SCORE for Question #4 /4 pts**

**In order to receive full credit, one of the identified processes MUST be EROSION**
# APPENDIX V: Student Interviews

**Student:** _________________________  **Interview time:** with _________________________

The purpose of this interview is for me to talk to students one-on-one to better understand how you interacted with the web activity, and how your thinking was affected by using the web activity. Since this was an online activity that students completed on their own, these interviews will provide some insight into what the experience was like for students. Unless I indicate otherwise, the questions I will ask relate only to this Flash interactive web activity, not the assessments and questionnaires you completed on Blackboard. Though it would be helpful if you can answer all of the questions I ask to the best of your ability, feel free to pass on any question, and it is quite acceptable to indicate that you are unsure of the answer. Please keep in mind that there are no “right” answers to the questions I will ask. I would much rather hear your honest opinions, so please don’t worry about offending me or “saying the wrong thing”. Also, if a question I ask is unclear or doesn’t make sense, please feel free to ask me to rephrase the question. Remember, this interview is entirely voluntary, and you are welcome to terminate the interview at any time without penalty. Do you have any questions before we begin?

## General Questions:

In your opinion, what were the main ideas of the Mt. Building web activity as a whole?

<table>
<thead>
<tr>
<th>Animation #1: Plate Tectonics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the main ideas of this animation?</td>
</tr>
<tr>
<td>How is the continental crust affected as the plates converge at this subduction zone?</td>
</tr>
<tr>
<td>About how long does it take for a mountain range to form?</td>
</tr>
<tr>
<td>What do you predict would happen if this animation continued to show 50 million more years?</td>
</tr>
<tr>
<td>How much time did you spend reading the text on pages such as the intro, methods or summary sections? Did you find it useful or unnecessary?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Animation #2: Isostasy:</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the main ideas of this animation?</td>
</tr>
<tr>
<td>Why does a crustal root form below the mountain range?</td>
</tr>
<tr>
<td>How is the size of the crustal root affected by changes in height? Why does this occur?</td>
</tr>
<tr>
<td>How is the position of the crust affected by changes in crustal density? Why does this occur?</td>
</tr>
<tr>
<td>How is the position of the crust affected by changes in mantle density? Why does this occur?</td>
</tr>
<tr>
<td>How do you define isostasy?</td>
</tr>
<tr>
<td>Did you read the Instructions or Helpful Information boxes? Where the instructions written clearly? How helpful was the text in helping you understand the reasons behind your observations during the animations?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Animation #3: Erosion rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the main ideas of this animation?</td>
</tr>
<tr>
<td>What is meant by the term “relief”?</td>
</tr>
<tr>
<td>How does the amount of relief affect erosion rates? Can you explain why this occurs?</td>
</tr>
<tr>
<td>Which climate has the highest erosion rates? Why do you think that is the case?</td>
</tr>
<tr>
<td>To what degree, if any, did the Predictions questions on the Blackboard site influence how you interacted with the Flash web activity?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Animation #4: Rock Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the main ideas of this animation?</td>
</tr>
<tr>
<td>Explain how igneous, sedimentary and metamorphic rocks are formed during mountain building.</td>
</tr>
<tr>
<td>How can the rocks that form deep within the crust be found at the surface of mountain ranges such as the Cascades?</td>
</tr>
<tr>
<td>How user-friendly is the web activity? Were you able to navigate through it easily, or was it confusing at times?</td>
</tr>
</tbody>
</table>

FINALLY.......

Do you have any suggestions about how this learning activity could be improved so that students would find it more useful and enjoyable?
FEMALE 1 (essay)

I: Um... so, just sort of as a refresher here to () what the learning activity looked like, and in your opinion, what were some of the main ideas of the learning activity as you interacted with it?

F1: Ummm...like the four different categories? Is that what you’re talking about?

I: Yeah. Mmm hmmm.

F1: Um...Let’s see. They tell you about erosion and the differing climate and relating them? And there was also one about isostasy=

I: =mmm hmmm=

F1: =as far as how much it floats and sinks into the lava depending on the density of it and erosion and there’s like how rocks from deep in the Earth are, like, uplifted or how you see them, how you see things like that. And there’s one on... I think there’s one on colliding......

I: Yeah, you have a good memory for the first one. Uh, for all of them actually. I’m just going to go ahead and, um, go through the individual different ones, starting with plate tectonics. Can you tell me the main ideas you got out of this particular animation.

((introduction to Scott Linneman as he comes in and turns off phone))

F1: In this one, it shows what the plates look like together with the ocean crust subducts underneath the uplifted continental crust making the crust thicker, and like, making mountains?

I: OK.

F1: Yeah.
I: Great. Um, and if we were to continue with the animation and basically went through with the succession of pictures, what do you predict would happen if we got to the end and we had the plates continue to converge for another 50 million years?

F1: (1.0) Um, let's see. I think there would be a big earthquake. Too much pressure building up.

I: OK. So, just as kind of a general question about all of the, um, animations and the learning object as a whole, did you spend much time looking at the text on these first “Intro”, “Models” and “Summary” pages, and did you find it helpful at all?

F1: Um, when I didn’t quite get exactly what it was showing me, the, uh (1.0), the animation=

I: =mmm hmmm=

F1: then I would like, go back and reread over ().

I: Good. And kind of along with that, actually, did you find yourself using the “Helpful Information” boxes at all?

F1: I did on a couple of ’em ‘cause I didn’t get what we were supposed to do.

I: Okay. But when you felt like you understood it clearly, you didn’t.

F1: Yeah.

I: Okay, great. Alright, well let’s go ahead and move on to the second one then. Um ((pause while bringing up the second animation activity)) So, what do you feel like the main ideas of this particular animation were?

F1: Um, it was basically just showing the relationship between um, like, the....amount of crust above the mantle and the density of the crust and the density of the mantle=

I: =mmm hmmm=

F1: and showing, like, how if any of those things changed, then whether the crust sinks in the mantle.

I: Okay, so, speaking of some of those changes, how did the amount of crust in the mantle change when you increased the height of the mountain?

F1: When you increased the height of the mountain, um, let’s see, it would sink a little bit lower because there was more mass to be held up.

I: Alright, so why do you think that crustal root or that part that’s down in the crust ((oops, meant down in the mantle)) is there in the first place?

F1: Um (5.0). I don’t really know.
I: That's okay. How about when we changed the density of the crust. How did that affect the position of the crust in the mantle?

F1: Well, if you increase the density, then it would have to sink lower because it would take more to hold it up, and if you do decrease the density then it would, um, rise above ()

((interruption due to a knock on the door))

I: So what would happen if we, um, instead of manipulating the crust density, if you changed the mantle density instead?

F1: Umm... let's see (1.0) If the mantle was less dense, I would think that it wouldn't be able to hold up as much, and so um, the crust would sink lower. And if it was more dense, the crust would move up.

I: Okay. And, you know, you talked about isostasy, and used the word, but if you had to define it in your own words, how would you do that?

F1: Um... (1.0) I guess I would call it (4.0), like what the relationship would be between like the height of the crust sticking above the mantle and the density of the crust and the mantle.

I: Okay, good. Alright, so let's go ahead and move on to this third one, which you remembered was about erosion. So, what would you say were the main ideas of this animation?

F1: Um, basically it was showing you when you looked at different climates, like which one eroded the most. Um, (1.0) and also the difference, like, when you looked at glacial or temperate or whatever climate, like the difference between a gradual or a steep relief?= mmm hmmm, mmm hummm=

F1: and like, how, if it was gradual, that there is not as much erosion and if it were steep relief there was significantly more.

I: Okay. What do you mean by relief?

F1: Um, like the, like if it's really mountainous or if it's just a meadow.

I: Okay. And then, do you remember which had the highest erosion rates?

F1: It was the glacial one on the steep.

I: So, yeah. Why do you think that was the case?

F1: Uhh... because of like, the ice of the glacier would just, like, it like rips away the rock, and because it's, like, jutting out at different angles it can take off more from the top instead of just, like, the thin layer on the gradual.

I: Okay. Do you remember in your predictions questions, um, when you first did the Blackboard assessment, do you remember which of the three climates, temperate, tropical or glacial that you chose that you thought would have had the most erosion?
F1: I said the tropical.
I: Okay. What was your reasoning for that?

F1: Um...because we had gone over in class (), of what type of climate (.5), I don’t remember exactly, but it was like a warm, wet climate was more.

I: Um, and speaking of those predictions questions, did they impact in any way the way that you interacted with the animation?

F1: Like the questions that were asked before we went through it?
I: Yeah, on the Blackboard site.

F1: Um...those ones, it made me look for things to know to reanswer the questions.
I: Okay. Alright, and then just the final one, you probably recall, is the rock one. So, what did you feel like the main ideas of this animation were?

F1: Um, basically it was just showing you how different rocks were, like how different rocks were formed and how they were exposed at the surface.
I: Okay. So, can you explain how the three main different rock types, igneous, sedimentary, and metamorphic, fit into the rock cycle during mountain building?
F1: Well, let’s see. The igneous comes from volcanic activity.

I: =Okay.=
F1: =And then, the sedimentary is from, like, uh particles of rock being eroded away anad then, like, all gathering in an area and then, like, cemented and lithified together.=
I: =Okay.=
F1: =And then the metamorphic is, like, from either sedimentary or other metamorphic or igneous rocks that were either put under pressure or temperature and change with them.
I: Okay. Great. Um, so how do those rocks, such as the, um, deep igneous and metamorphic rocks eventually get exposed?
F1: Um, well part of it is, like, if a volcano erupts and part of the mountain is gone, then you can like see underneath it. And also, like, erosion will strip away the top layers until you can see down to the bottom.
I: Okay. So does the erosion continually erode down, down down, until we get to really deep levels or (.5) can you explain more of what you’re meaning there?
F1: Um, ((clears throat)) (2.0) I guess, well, it probably like (4.0), the way it erodes, like more jagged it is, the more it will be taking off and then like the less steep it is, the less it will be taking off?
I: Okay. Yeah. So how does eroding material from the top affect the mountain range as a whole?

F1: Um, it reduces the height, and... um....

I: And then, thinking back to one of the previous animations, when you reduced the height of the mountain, what occurred?

F1: It would rise higher in the mantle.

I: Yep, so, um, ((clears throat)), when stuff gets taken off the top by erosion ((interviewer is pointing to animation on computer screen)) and then the whole thing moves up in the mantle, what does that do to the deep crustal rocks?

F1: It brings them closer to the surface.

I: Yep. Okay. So, if you were to design the activity such as this, or if you could give me suggestions on how to make it more user-friendly or informative or useful to students, do you have any suggestions?

F1: Animation #2... was unsure what to do with the “+” and “-“ buttons until she clicked them and saw changes, would have liked directions on the screen with the animation activity. The formula was unclear and intimidating. Thought it was unfair that she had to answer essay questions when her friend had multiple choice questions (they did have the same animation activity).

MALE 1: (essay)

I: First we’ll start with the, uh, general overview of the learning activity. So in, what, what in your opinion were some the main ideas of the activity? What did you get out of using this activity?

M1: Uh, well, the activity helped me to better understand, um, isostasy, and isostatic rebound, as well, um, a few reasons why rocks deep within the Earth’s crust were extruded to the surface and erosion. Um, so one questions that was asked, ‘why is it that billion year old rocks are on the surface’, that sort of thing. Before, I was kind of, like, ‘well, I don’t really know’ ((both I and M1 chuckle)), they’re pretty far down there, it made more sense, so that did help. Other things, I had a pretty general to good understanding of, those were the main ones that helped me.

I: Okay. Great. Um, so what I’ll do is kind of go with you, with you through the four animations activities themselves. You already described in general what you saw, but, um, the first one that you looked at, well, I guess one thing I should ask is, when you used the activity, did you use it in any sort of sequential order or was it just kind of a [random order.

M1: No, I followed it sequentially.
I: Okay, so this first activity was related to plate tectonics. So did you feel like we were the main ideas of this particular animation?

M1: Well, it gave an understanding of, um, the ocean's crust and how it, uh, how the processes come that it subducts. I'm not sure, does it go into the explanation island arc accretion?

I: Not, well, kind of. But, um, what are the effects of the, um, subduction or convergence of the plates on the continental crust?

M1: Aside from volcanism?

I: Sure.

M1: Okay.

I: So that's one thing. Did you notice, I mean, what were some of the other effects?

M1: Um, subduction in general creates metamorphic rocks that we've investigated in labs and stuff like that, as well as, um, mountain ranges...I guess along the coast. And, um, and as mountains increase, so does the overall thickness of the crust.

I: Okay. Great. Um, now that this subduction zone has become active, how long do you think it takes for mountain range to form?

M1: Millions of years?

I: Yeah.

M1: Sure.

I: That's kind of a ballpark figure. And why does it, does it take such a long time?

M1: Because the rate at which the crust is inching along and subducting varies but if you were to give an average, maybe an inch a year. It's really quite small.

I: Okay, great. So, if I continued, you know, we looked at several million years or several hundred millions of years of, um, plate convergence, what do you predict would happen if we allowed that to continue for another 50 million years? (I is showing M1 slides in Animation #1).

M1: Uh, as far as the Earth is concerned?

I: Yeah, or about that mountain range in particular.

M1: Um, depending on when the startings of the plate and it was subducting, like at the end there you have the land mass actually coming together and then forming mountain ranges when the, when it subducts, like uh, in the Himalayas or if, uh, new crust was being formed instead of you just having constant mountain range being built and then eroded over time, and so you have variances in the overall thickness of the crust that would, um, increase and decrease depending on erosion and how much is going through.
I: Okay, great. Um, let's move on to the next animation. And, in this one, what do you feel like were the main ideas that were conveyed?

M1: Um, short and sweet, the larger the mountains are on top, the thicker the crust is on the bottom. And um, it has to be that way to displace the, uh, mantle, and keep the uh, keep everything in equilibrium.

I: Okay. That was going to be the next question, 'why is that root down there?' So, what would happen if we increased, say, the density of the crust?

M1: Uh, it would (2.0) sink.

I: Okay.

M1: It would sink some. ((hand motions downward))

I: And how about if hypothetically on Earth we could increase the density of the mantle?

M1: Then, um, according to displacement it would raise the crust some.

I: And what, okay, you answered that one well. So, how would you define the word isostasy?

M1: Um, an equilibrium that exists between the sort of liquid mantle and the crust on the surface. It's a lot like, uh, an oil tanker on the ocean kind of a thing.

I: [so, what...

M1: Displacement.

I: Okay. Is the mantle, I mean, liquid in the sense that water in the ocean is a liquid?

M1: Not nearly as liquid, much more viscous.

I: Alright. (3.0) Alright, so just kind of some logistical questions about the activity itself. Did you spend any time reading the instructions, or helpful information or the text here on these pages ((intro, methods, summary)) at all?

M1: Uh, I'm pretty sure I read it all.

I: And did you find it useful at all, or was it...

M1: Um, some of it helped me, like a lot with the isostasy, and some of it was just going over things that I already knew so some of it I skimmed.

I: Okay, so in the third activity, we looked at several situations, um, of climate and relief. What do you suppose the main ideas that were conveyed in this activity were?

M1: Um... the steeper the relief, uh, the more potential there was for erosion and that really depended on the weather and if there were a lot of rainfall and well, of course if there was a lot of water running over the surface and eroding=
I: =mmm hmmm=

M1: =much more quickly than if there were a gradient, a very shallow, not steep relief.?

I: Okay. And, so when you looked at the three variations of climate types, 'cause you’ve pretty well explained the effects of relief, there was temperate, tropical and glacial. Do you recall which had the greatest erosion rate?

M1: Tropical?

I: Okay, and why was that? Why do you think that’s the case?

M1: More rain.

I: Okay. So, in looking at a glacial situation where you’ve got alpine glaciers, what is going to control the erosion rate?

M1: (2.0) Um, alpine being in the mountains.=

I: =yes=

M1: Um, again I would say whether the amount of rainfall that the area receives and temperature. If it stays cold enough to keep everything frozen, you wouldn’t have as much erosion. Whereas if, for some reason, global warming or what-have-you, the temperature rose and it started melting, you could have glaciation taking place

I: [okay

M1: [and it would carve out the surrounding area.

I: (1.0) Okay. Great. And, um, before you started the activity, you answered some predictions questions=

M1: =mmm hmmm=

I: =on the Blackboard site. Would you that answering those questions had any effect on the way that you used the actual interactive activity after that?

M1: Ummmm...for something like the erosion rates and the gradient of the land when I think I kind of answered similar before and after=

I: =uh huh=.

M1: =I’d known it, so I didn’t spend a whole lot of time going over them when I went back to the end.

I: Got to the observations questions [on the next step?

M1: [Yeah.
I: All right. So this final animation that you looked at, was, as you said earlier, related to the rock cycle and exhumation of rocks. Um. Do you have anything else to add about the main ideas of the activity?

M1: (2.0) How do you mean?

I: Well, I think you pretty well covered it, like, in that first ((question)) when I asked you the main ideas of the whole [main activity, you talked about this one quite a bit in particular.

M1: [Okay.

I: So, can you explain to me, um, how each of the four main rock types, specifically sedimentary and metamorphic, are formed within a mountain belt?

M1: (1.0) Three main?

I: Yeah, well I mean there's four main here because we have both volcanic and plutonic.

M1: And so the question again was?

I: How are, say, igneous rocks formed within a mountain belt.

M1: Strictly from the heat of the mantle melting whatever rock you might have melting, whether its igneous or sedimentary when it gets that hot and gets to the liquid state and then recrystallizes you have an igneous rock.

I: Okay. And how about sedimentary rocks?

M1: Uh, well, over time eroded igneous or metamorphic rocks and as they’re carried away from the mountain environment, the further that they get from that, uh, depositional environment, the rounder the grains get, the smaller they get and uh, over time, they all lithify into the rocks.

I: Great. And, uh, how about metamorphic?

M1: Metamorphic. Not as hot that the rocks melt, but it changes, um (2.0) a lot of pressure’s included in that so aligns a lot of the minerals and the crystals, so you have foliation and it recrystallizes some of the minerals within igneous rocks so it gets larger crystals visible on the surface, especially in schists.

I: Good. You have a really good memory. So, how much new information did you learned from this activity as opposed to from lecture and lab if you can sort that out?

M1: Um...(2.0) As far as, probably just going back to the way that rocks came up from deep within. Um, lab was good for a lot of, um, a lot of things like rocks and identification, and being able to get a grasp on basic ideas and then lecture kind of went into more detail about things. The lab helped round out the whole ideas of geology, but at least it seems like the general idea was there but there was a lot more details when it comes to uh, actual in lecture and when tests are given, it goes into more detail than it seems from the lab, but at least it gives you a better understanding of the whole thing.
I: Okay, great. So, going back to, then, the idea of deep rocks, like the metamorphic rocks and the intrusive igneous rocks coming to the surface, how does that happen?

M1: Um, a lot of it’s erosion and when, uh, what is it, uh, when the magma flows from under it can push large plutons and stuff like that towards the surface where and then over millions of years the erosion finishes it off.

I: Okay. So, is it a matter of the erosion continually eroding down (pointing to images on screen)) to this depth where these guys ((referring to intrusive and metamorphic rocks)) are uncovered?

M1: Um, not necessarily. Some of them can come out of the side of the mountain as well, if I remember right.

I: Okay. So, let’s go to these illustrations where that process started to happen. Um, I think maybe this is where you’re getting the idea of them coming out of the side=

M1: =Yeah.=

I: =What is allowing that motion to occur?

M1: Heat? Sort of like convection?

I: Okay. And if we go back to the animation where you played with isostasy.=

M1: =mmm hmmm=

I: = What were the effects of erosion, when we decreased the height of the mountain, what happened to the whole crust?

M1: The crust got thinner and um, and, yeah, the crust basically got thinner on top and underneath and uh, equilibrium was pretty well maintained since the density was still the same for the most part.

I: So as we erode the mountains down and the crust underneath, the crustal root gets thinner, what effects do you think that has on the individual packages of metamorphic or igneous rocks that were formed deep in the crust?

M1: Um (3.0) Maybe relieving pressure on some of the things, so I don’t know if there was still a lot of heat on some of the rocks and pressure were released, they would alter its state, maybe the type of rock that were formed?

I: Okay, great. Um, basically that’s all the questions I have. What I was wondering is if you were to create something like this, or if you could make any changes to make it more user-friendly and informative to students, what would you do?

M1: More MC questions, essays were daunting (combinations). Can’t think of any changes to learning object.
FEMALE 2: (M/C)

I: Well, let's just start at the beginning, um, just talking about the general mountain building web activity as a whole. What do you feel like were the main ideas of this learning activity?

F2: The main ideas that I got from it?

I: Yeah.

F2: Um, how mountains are formed and volcanoes, and, um, which rocks are deposited where. Oh, how the buoyancy is affected.

I: Okay. Great. Those were kind of the key ideas and now let's kind of go through some of these "explore" animations, starting with this first one that you saw, which was related to plate tectonics. What were some of the main things that you learned from doing this part of the activity?

F2: Um...what happens when the oceanic plate converges with continental one. And the density, how that was, the density of the oceanic plate.

I: Okay, cool. Let's talk about the continental crust a little bit. What happens to the continental crust as the oceanic crust subducts underneath it?

F2: It, um, raised in elevation.

I: Okay. Um, then how about as you stepped through the activity, eventually another continent collided into the continental crust.

F2: Oh yeah.

I: So, what happened at that point?

F2: Um, I think it, did it form a lake, or a body of water?

I: Okay. So, if we continue a couple more steps here, now we have an active subduction zone forming. How long do you think it takes a mountain range to form? Just kind of a ballpark figure, um, from the time that we have an active subduction zone.

F2: I don't know. (2.0) Does it say a hundred million years right there?

I: Yeah, a hundred million from the start of the, you know, (())

F2: [So, how long does it take ()=

I: =Yeah.

F2: I don't know.

I: =Okay.
F2: Probably millions of years would be my guess.

I: Okay. So why would you guess it would take that long?

F2: Because, I don’t know, it seems like it would.

I: Okay. That’s cool. So if we continue to step through this, and actually while I’m running through this, when you were using this activity yourself, did you find yourself paying attention to the text.

F2: Yeah.

I: And how about this information up here ((Pointing to the dynamic text at the top of Animation #1))

F2: I didn’t really look at that much.

I: That’s kind of what I thought. I tried to put a colored background behind it ((F2 chuckles)) to attract attention but it is still very easy to ignore. Okay, so from this point, let’s say we continue to have the plates move towards each other for another 50 million years, what do you think would happen?

F2: The, um, both continental ones?

I: mmm hmmm

F2: I think that they would just, uh, keep, uh, the base of it would going into the mantle and it would keep raising the elevation.

I: Okay, yeah. And how much higher do you think those mountains could get?

F2: I don’t know. Like, uh (3.0)

I: Or is there anything that would prevent them from getting infinitely tall?

F2: Um, (2.0) Well, doesn’t it want to stay in, like, equilibrium with, like, say it ran out of …..I don’t know.

I: Okay. Well, I mean you’re expressing some good ideas there. Um, so let’s go ahead and move on to the next one, and what were some of the main ideas of this activity?

F2: Um, basically that it wanted to stay in balance, the mountain and the, what it called, the (crustal range??)

I: mmm hmmm. The crustal root.

F2: Yeah. The root.

I: So what were some of the things that affect its balance within the mantle?
F2: Like, erosion would decrease the height and that would make it, the root, retract. And then if the height, elevation, was increased, the root would go deeper into the mantle.

I: And....

F2: And the density?

I: mmm hmmm

F2: I don't really remember about that.

I: So, let’s say that we could, hypothetically on Earth, increase the density of the crust. How would the crust react to that?

F2: How would the root react?

I: Yeah, or yeah. The root or the crust as a whole. How would the equilibrium be affected?

F2: If the density on top decreased than the density on the bottom would have to increase=

I: =okay=  

F2: =to stay, equal=  

I: mmmm hmmm, and if you kept the mantle density constant and only increased the density of the crust, what would happen?

F2: Oh, it would go deeper into the mantle?

I: Okay, and how come?

F2: Because dense things go, it would be more dense than the mantle and it would, I don’t know go ((chuckles))

I: Yep, you’re on the right track, have confidence in yourself. So, let’s go another route. Let’s keep the density of the crust, just, constant, and increase the density of the mantle, if we could hypothetically do that on Earth. How would that affect the crust?

F2: I think it would, um, (1.5) make the, make it rise, the root, and all of it maybe. I don’t really know.

I: Okay, so why would that happen?

F2: Because (.5) of dense... Mass = Density over Volume usually.

I: So just sort of a mathematical relationship? Alright. So, the whole concept that we’re dealing with here is isostasy, is the word. So if you had to define that word in your own words, how would you do that.
F2: Um, something about equilibrium and, like, they want to stay balanced on top and bottom 'cause, this is a convergent boundary, right?=

I: = mmm hmmm =

F2: So if they keep com, if they stop then it will, like, even out, since it keeps converging ()

I: Okay, just kind of a general question about the parts of the learning activity like the Intro, Models, Summary pages, and, um, the Instructions and Helpful Information, how much time would you say, or did you spending much time reading those text and were they very helpful at?

F2: I did go back to the introduction to read how (), 'cause I skipped right to the Explore part =

I: =Oh. Okay.=

F2: and I'm like, 'okay, I need to go back and read what I need to do here".

I: ((laughs))

F2: So yeah, I did spend time with that. The Summary, I spent definite time reading.

I: Did you feel like you got anything out of it?

F2: Yeah. ()

I: Okay. Did you use the Helpful Information buttons at all?

F2: Nope.

I: Okay. This is just some text that explains what you just went through and what isostasy is all about and that kind of thing, but because it doesn't force you to use it, I expected that not everybody would, so.

F2: Oh, I guess I didn't know.

I: Okay, well that's good to know. ((F2 laughs)) That's why I'm asking these questions, because I couldn't stand and look over your guy's shoulders while you were using it, so. Alright. Let's go ahead and move on to the third one. And, what were some of the main ideas of this one?

F2: ((laughs)) Oh, I did not get this one at all.

I: Okay, okay.

F2: I think that there wasn't enough text, so I just kind of like, I don't know, I did that and like, didn't spend much time with it.

I: Just pointing around and clicking and it didn't really mean much?

F2: Yeah.
I: Um, well, just kind of what I'm thinking the main ideas were. You can choose different climate types and relief. You could choose temperate, tropical, and glacial climates and you could also choose steep or gradual relief. So what do you think 'relief' means?

F2: Like, slope?

I: Yeah, so would you expect the erosion rate to be higher on a steep slope or a gradual slope.

F2: Uh, steep.

I: Okay. How come?

F2: Because, gravity?

I: Yeah, pretty much. Um, it affects that way that water and ice and wind and all that sort of stuff will affect it. So, between the temperate, like, kind of this continent, tropical and glacial, what of those three climates would you expect to have the highest erosion rate.

F2: Probably glacial because it all comes out in like an avalanche or, like. Oh yeah, I think so. Unless there's a lot of rain, that could do it. But I would guess glacial.

I: And, thinking back to when you used this for the first time, before you started using this interactive activity on Flash, you answered some prediction questions. I'm assuming multiple choice questions that had you predict, does that ring a bell at all?

F2: No....

I: One of the six steps that you had to take.

F2: Oh yeah, oh yeah. OK.

I: So, thinking back to those, did answering those questions affect the way that you used this at all?

F2: Affect the way that I used it, like, spent more time with it?

I: Yeah.

F2: Um....

I: Or did you just kind of think it was disconnected.

F2: I guess I kind of found this disconnected. Were there a lot of them? Because if there were a lot of them, then I probably didn’t spend as much time on this part.

I: Yeah, there were actually. They were a big part of the deal. There were like 28 questions.

F2: Yeah, 'cause I remember totally being at this one and just skipping over it because I was like uh....I've been here for awhile. And wasn't there still one more thing to do?
I: Yeah, I know. It was kind of too much for one sitting, I think.

F2: It was actually really helpful though.

I: Um, okay. I'll ask you about this last one and then think of some suggestions that you might have for improvement.

F2: And you want to know something else?

I: =Yeah.=

F2: =I reviewed this before I um, I went to this before my last test because I thought it was helpful.

I: Oh, did you? Cool. Well, that is good to know, actually. And did you see any of these themes on your test at all?

F2: Yeah. Definitely.

I: Great. Well, that is probably a good motivation, to help, you know, have students as a review for tests or whatever. But basically what I'm trying to figure out is what is a suitable activity use for this activity, like is it better in class? is it better as a prelab?

F2: I liked it on my computer, because a lot of times you have a lot of free time to spend on a computer, and like that was the only thing, like my professor didn't have anything posted.

I: Okay, great. Glad to hear that. So, let's just talk about this one last activity. What were some of the main ideas of this one?

F2: Um, where the rocks deposit or end up, and how they're formed, where they're formed.

I: How, for example, do metamorphic rocks form in a mountain belt?

F2: Pressure and heat, like, underneath the volcano.

I: Okay, and how about, there's two different types of igneous rocks, you got the volcanic ones, how does the other type form in the mountain belt?

F2: The extrusive ones that are formed on the side of the volcano.

I: Yep. Well, extrusive and volcanic are kinda synonymous. So then you also have the plutonic or intrusive rocks. So how do those guys form?

F2: Um...(1.0) I don't know.

I: Okay. So here's a little review for your final, then. Um, if you've got magma coming to the surface, it can either go all the way through to the surface and erupt as a volcano, or it can cool. If it cools before it makes it to the surface, then it will form what's called a pluton or batholith, or dikes and sills, those words might be familiar, and would you expect them to be coarse-grained or fine-grained?
F2: Fine-grained?
I: They cooled slowly below the surface, so
F2: They'd be coarse-grained ((chuckles))
I: So how can a sedimentary rock within this situation?
F2: Within the volcano.
I: Oh yeah, just within the mountain belt there.
F2: Don't they form from deposits of other rocks, like, erosion?
I: Okay, so, are all mountains volcanic?
F2: I don't know! I was wondering that in class! I don't think so.
I: What is another way a mountain can form if it's not all volcanic peaks?
F2: Um (2.5). Well, if it's a convergent boundary that makes a volcano, right?
I: Yeah, but what else would happen to the crust at that convergent boundary?
F2: Besides raising?
I: Mmmm hmmm. So why though? You've talked about the elevation increasing quite a bit, but why does that happen?
F2: Because (1.0) the rocks down there ((pointing to deep crustal rocks on the diagram on the screen)) are pushed up?
I: = mmm hmmm=
F2: Underneath it?
I: Yep.
F2: So are they all volcanic?
I: No, they're not all volcanic.
F2: But why, not?
I: So you've got the situation where you do have magma coming to the surface and forming volcanic peaks like Mt. Baker, Mt. Rainier and stuff like that, but if you think of the other mountains in the Cascade Range, they're not all those nice conical volcanic peaks, right?
F2: Yeah. Are they the erosion from the first ones?
I: Erosion has a lot to do with the way that they’re shaped, yeah, but if you have two plates coming together, you’ve got stresses that are squeezing the crust and pushing some of it up, and increasing the elevation like you said, and pushing some of it down to form this crustal root. So, when you squeeze that crust, it reacts by folding and faulting and all that sort of thing.
F2: =Ohhhh....=

I: So that’s what forms the mountains that you drive across that aren’t just volcanoes. That was one of the reasons why I wanted to do this activity in particular because I got out of Geology 101 and didn’t necessarily understand that all mountains weren’t volcanoes.
F2: ((laughs)) That is a definitely a question that should be, like, blatantly answered. Because I think a lot of people have it. My lab partner asked me too. And I said, “I don’t know, that’s a good question”.

I: So let’s talk about how these rocks that formed deep within the crust could possible get up to the surface. In the Cascades, you can see metamorphic rocks at the surface, and you can see coarse-grained igneous rocks at the surface.

F2: An eruption? Or the top erodes down and then, like, it comes up because it wants to stay balanced.

I: So yeah, as the top erodes down and we go back to that isostasy idea, the crustal root comes up to maintain equilibrium. So, it sort of looks like this idea ((points to animation on the computer screen)) where you’ve got erosion occurring at the top, and the blocks representing the deep rocks rising up because the crustal root coming up. So that’s how a lot of the deep rocks come to the surface.

F2: Okay.

I: So just as a general question, um, how user-friendly is this activity? Is it hard to navigate through? Or do you have any suggestions?
F2: It’s really easy. And you can go back ().....

FEMALE 3: (M/C)

I: Let’s just go ahead and start with kind of the main idea of the whole learning activity, the whole web activity. What, in your opinion, were some of the main ideas? What did you get out of it?
F3: Like what I learned from it?
I: Yeah, exactly.

F3: Um, generally, how plate tectonics works together and how mountains are formed, I guess, from either different, uh, like, whether the () slide past each other or move together or move apart. Or how weather had to do with it or what kinds of effects there were.
I: Okay, great. So, um, let's just start by going through each of the individual animations you worked with, starting with the plate tectonics one. You might remember this activity.

F3: ()

I: That's fine, that's absolutely fine. So what were the main things you learned from the plate tectonics one in particular?

F3: Um, most of plate tectonics we'd already gone over, like, in our main lecture class and it wasn't difficult for me to comprehend, but which one slides under which one and where the volcanoes occur?

I: mmm hmmm

F3: I guess that the age thing was in there, like how long how big the volcano gets and how long its been subsiding or whatever?

I: So, let's go with that question. How long after this, um, plate boundary becomes an active subduction zone do you think it takes for a mountain to form?

F3: Um ((laughs)) 6 million years?

I: Okay, just a ballpark figure is absolutely fine. Alright, and why do you think it takes that long?

F3: Well, they only move, I mean, centimeters into the sea per year unless it's a big earthquake, so it takes a really long time.

I: So, by "they", are you meaning the plates, or the crust, or....

F3: Yes, the plates. It takes a really long time for them to move.

I: Okay, great. Um, so how is the continental crust affected as the oceanic crust subducts underneath it?

F3: It gets pushed up or further...uh ((laughs)) this one goes down ((using hand motions to demonstrate plate convergence)) and then it builds up the lava and whatnot, and then it comes up to the surface further down, it can be miles down or over, and finally it comes up it becomes a volcano? So, it gets squished and forms a mountain?

I: Okay, so what's getting squished?

F3: The continental plate, er, yeah, the continental plate overriding the oceanic crust.

I: Okay, great. Are all of the mountains that are created volcanoes? Or is there....

F3: With this one ((pointing to a diagram of a oceanic-continental convergent boundary on the computer screen)), with the subduction zone, yes. But when they, they also come together and then, just like bow up, and then it's not necessarily a volcano?
I: So, yeah, when they actually collide. That's something that we saw as we stepped through. As you stepped through, how much time were you spending reading the stuff or looking up here (pointing to the dynamic text at the top of the screen)? Did that attract your attention at all?

F3: For the volcano, I mean, for the plate tectonics, not much because we had talked about it a lot in class. But the stuff above it, um were, I didn't pay nearly as much attention. Obviously since that was 50 million years ago and I said 6, it didn't exactly hit too hard.

I: Okay, well anyway, yeah, I can seen where that would be the case. If we took a look at this last picture, and if this plate continued to move toward, if the plates continued towards each other for 50 million years, what do you predict would happen?

F3: Um, the same thing continuing? I mean, it's going to continue to push up, or once it pushes all the way and like once they're, like, they're pushing ((using hand motions to demonstrate plate convergence)) and once they push to far it seems like they would stop ((laughs)).

I: And can the mountain range get bigger than it already has? Or...

F3: Yeah.

I: How much bigger, do you think?

F3: As big as it, well, not wants to, but as long as it continues to push it's going to keep getting larger.

I: Okay, alright, so um let's going ahead and move on to this next animation, which will be this one. What do you feel like were the main ideas of this particular activity?

F3: Um, like the balance of if the mountain is larger, than the, like, the root thing, but I know they're not called roots ((laughs)). It has to get larger too to balance out how it sits in the, like, liquid=

I: =Okay=

F3: = ()

I: Okay, so it the mantle liquid in the sense that the ocean is liquid?

F3: No, it's not solid, I mean it's not water but things can float on it, kind of? I figure its more viscous, I guess? ((laughs))

I: Good memory of that word. So, actually we do call this part a crustal root. And you mentioned it had to balance, so what is it balancing?

F3: Like, the bigger the mountain gets, the more the roots have to go down so it can, I mean if you have a really big mountain and just a really little root, it's not going to be able to support a really huge mountain.
I: Okay, great. So what would happen if we changed the density of the crust? If we could somehow increase the density of the crust?

F3: Then you’d have to increase the density of the root, er wait, of the crust, like the mountain comes up? Yeah, you have to increase the density or make the root go further down?

I: Okay, great. And if, hypothetically, since we can’t really do this on Earth, if we could increase the density of the mantle, how would the crust react to that?

F3: Well, I don’t really know if you can make the crust grow based on that. It would seem like it would either (1.0) I guess it would go up because the mantle would be bigger so therefore it would float up higher so therefore the mountain would be higher? ((laughs))

I: (1.0) And the word isostasy came up quite a bit, related to this? Do you have an idea of what the definition is? Or what does that word mean to you?

F3: Just like the general idea that it has to balance, I mean that, yeah. Basically, they need to be, not even, but in equilibrium.

I: Okay, and what do you mean by “they”? 

F3: The crust and root.

I: Okay, so when you were going through the activities, just as kind of a general question, did you read, did you pay attention to the instructions, or the “helpful information” or the text that was associated with the Intro, Models, or Summary sections?

F3: I generally read through it, and if I didn’t understand a word I didn’t necessarily go back, I figured it would be explained more later. But I read over all of it.

I: Okay, great. I’m just trying to get an idea of what was a useful part of the activity and what was unnecessary. Um, great. So, this third activity animation, do you recall what you learned from this one?

F3: Um, just like if the wea, either the weather or, like, how big the mountain, or like the height are different on different versions, like the steepness?

I: Yeah.

F3: Yeah, so just like the higher the mountain, the steeper, then they’re going to erode quicker because there’s more to erode, kind of?

I: Okay, sure. So why is steepness, the word we used there was ‘relief’ and it sounds like you have a good handle on what it is, just how steep the mountains are, and that steeper slopes erode more quickly. How about the climate though? How did the climates affect the erosion rate?

F3: I was a little more confused about those, sorry. I just, like, I assumed that glaciers in a mountain area are going to erode it. It seems like the more mild climate would have less of an effect because it wouldn’t have the extremities? I mean, it seems like mild climates would have erosion as well, but extremities would have some more erosion?
I: Okay, so extreme temperatures, extreme hot and cold, or?

F3: Yeah, I mean like either glaciers or an extreme heat with lots of humidity and whatnot would cause more erosion.

I: Okay, great. Um, and thinking back on the predictions questions from the Blackboard assessment that you did, did you have multiple choice questions or essay?

F3: Multiple choice.

I: Multiple choice, okay. So, did answering those questions affect the way that you used the learning activity at all?

F3: Well, kind of because I already knew most of the plate tectonics stuff, so when I answered those ones and I realized that I knew the answers to them, I went quicker through it. And, like, the stuff that I really didn’t have any idea about, I didn’t know, so I tried to figure out what, I mean, like the iso...

I: Isostasy?

F3: Yeah, I didn’t know what that meant, so I tried to figure out what the word meant.

I: Okay, great. Alright, so moving on to this last animation, um, what were the main points of this activity?

F3: Um, to figure out what rocks form where, that’s based on how deep they are, or where the volcano is or that metamorphic form where there’s like pressure and (1.0), uh.

I: Okay, so you mentioned how metamorphic rocks form in mountain belts, um, how about sedimentary rocks?

F3: They don’t form with the mountain, they form from sedimentary deposits, so I guess on the shore that they form? Or, I think.

I: Okay, and where do those sediments come from that are eventually deposited?

F3: Well, they’re from, like, I mean, the water, from, like, the current brings up sediments and they eventually get compiled ()

I: Okay, great, and how about igneous rocks?

F3: They’re from, like, um, the magma and all the lava stuff from the mountains. They’re purely from melting.

I: Okay. Um, so some of these rocks, metamorphic rocks, for example, or plutons, which are a general term for batholiths or any of the intrusive igneous rocks can form pretty deep within the crust, right?

F3: Mmmm hmmm.
I: So, when we go over the Cascades, or some other mountain range, we can actually see those rocks exposed that the surface.

F3: =Right.=

I: =So, how does that happen?

F3: Well, when the mountain erodes away over time, they’re exposed, or, um, through an explosion. The plutonics ones, I guess, they get exploded and they, um, get outside and they’re no longer a batholith.

I: Okay, by exploded, do you mean they become volcanic, or what do you mean?

F3: Well, I guess then that would make them extrusive, not intrusive anymore. Yeah, basically just the erosion.

I: Okay, and when the mountain erodes down, does it just continue to erode away these layers ((showing “erosion” on the diagram on the computer screen)) until these guys ((referring to blocks of metamorphic and intrusive rocks)) are exposed, or is there something else going on to help expose those rocks?

F3: Also the other crust is pushing, pushing up from, like, the bottom, kind of. So they’re being pushed up as it’s being eroded, so it’s kind of going together.

I: Okay, both of those processes are working together?

F3: Yeah.

I: Great. Um, so I want to show you just some of the later parts of this activity. Um, after you completed this, you might remember that there was three different screens that showed the process of erosion. Can you describe what this looks like to you? What do you see going on?

F3: The rocks being pushed up with the lava? I don’t know whether it’s lava interactive, if it’s extrusive? Or if it’s just plutonic rocks being pushed up to the surface.

I: Okay. Yeah, this one here’s supposed to represent the plutonic rock that you put there ((pointing to a second computer screen with the original “drag and drop” activity)) and the metamorphic rock that you put there. So they’re coming up to the surface. Um, and what’s allowing them to get up there?

F3: Well, when the subducting one goes under, then it’s pushing lava, or stuff ((laughs)), and pushing up the rocks to the surface with the lava.

I: On the whole, when you used this learning object, how user-friendly did you feel it was?

F3: Um, I thought that it would have been a lot more helpful if we would have talked about it in class first. A lot of stuff I had no idea of the balance of isostasy, I had no idea about that. We talked about the rocks and we talked about the plate tectonics, but the other ones I had no idea
what it was about to begin with, so it made it a lot harder to, kind of, like, navigate your way through if you haven’t ever even heard of what it was.

I: Sure, sure. So the concepts that didn’t already know were more difficult.

F3: Yeah, even though you have it on there and it makes sense, it is a lot easier sometimes to be told what it is and then to go, kinda, figure it out.

I: Okay, that makes sense. As far as finding your way around, do you have any suggestions that would improve that part of it at all?

F3: Um, well, for a class, if you had to learn all of it, or it was just, like, alright, let’s go through this, and you can skip it all if you want to, I mean you don’t have to look at it. So therefore, if it’s required that people need to go through it, I think it’s probably better if you had to go through a sequence of every one before you were finished.

I: Okay.

F3: But if it’s just like, for help, like if you need extra help and you want to look at it, then that makes more sense how it was, that you could just look at what you needed to.

I: I gotcha. Yeah, it was pretty non-linear.

F3: Yeah, however you want. If you want to look at it, that’s fine, if you don’t, then don’t.

Better in class? No, learn about it first in class, but this kind of thing is just kind of a waste of class time and is very individual.

FEMALE 4: (M/C)

I: So let’s just start at the beginning, um, thinking about the general mountain building web activity as a whole. What do you feel like were some of the main ideas that were conveyed? Or what did you learn by using it?

F4: I remembered isostatic rebound.=

I: =mmm hmmm=

F4: = and um (2.0) and I remember, I can’t even remember what they were about now, but the diagrams with the order of the things in it?

I: Okay, let’s just go ahead and just jump into looking at the different animations to kind of remind you, because it probably has been 4 or 5 weeks since you used it.

F4: Yeah.

I: Okay, so this first one, I think you were referring to, is related to plate tectonics and the order that things go in.=

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F4: =Yeah.=

I: So, what do you think were some of the main things that this activity was trying to teach?

F4: (1.0) Um. (1.0) ((laughs))

I: Okay, let me maybe ask you some more specific questions. Like, um, as you go through, and this plate boundary becomes an active subduction zone, what happens to the continental crust over time?

F4: Do you mean when another one is subsiding under?

I: Mmm hmm. Mmm hmmm.

F4: Well, I guess it's more affected by the earthquakes as it goes under, and it gets pushed up.

I: Yeah, okay, so why does it get pushed up?

F4: Um, because the other land mass, or the ocean crust is coming under it and pushing it up.

I: And how long do you think it takes for a mountain range to form, once the subduction zone becomes active like this?

F4: A long time. ((laughs))

I: Just a ballpark estimate?

F4: Um, thousands of years?

I: And why do you think, you know, why does it take thousands of years for a mountain to form?

F4: Um, I would guess just because everything in geology ((laughs)) takes a really long time. I remember reading that it takes a long time.

I: As you continued through the order of this activity, as you were talking about, how much attention did you pay to the text and this information in the yellow bar up at the top?

F4: Um, I definitely looked at more of the pictures. And the bar, I did notice that they changed ((referring to the dynamic text such as ages)), but I thought that the pictures were more useful.

I: Yeah. That's kind of what I figured. ((both laughed)) And it's definitely the common response of most students. Alright, so if we continued to have these two plates come together for another 50 million years beyond this picture, what do you predict would happen?

F4: You mean, what would the mountains look like? Is that was you are referring to?

I: Yeah, it looks like there's already kind of a mountain there. I mean, what...

F4: If a mountain has already formed, what would happen if they keep going?
I: Yeah.

F4: Um, they would get bigger maybe?

I: How much bigger do you think it could get?

F4: Um, they don’t look very big right there, so probably a lot bigger, based off of that.

I: And, uh, is there anything that would prevent it from getting infinitely tall?

F4: Yeah, I’m sure there is ((laughs)). It seems like if you’ve got a land mass, it just seems like it wouldn’t be able to stay up as high once it got up to a certain height. I don’t know the reason.

I: That’s alright. Let’s move on to the second one, and this is the one that you remembered. What were some of the main ideas of this activity?

F4: Isostatic rebound?

I: Yep, so what does that mean?

F4: Um, well, I just remember it from there’s a glacier over it, the glacier will compress it, and then it will pop back up after the glacier melts after a long time.

I: Okay, so that’s what somebody talked about in lecture?

F4: Yeah, I think so. But I remember doing it on here because I remember it in lecture, but I remember the pictures here. But I remember the example of a glacier better.

I: Yeah, it’s a similar concept, for sure. Um, this particular one doesn’t have glaciers involved in it, but it the isostasy idea.

F4: I think maybe I first heard the word on this, and then maybe I learned it in class, and then was like, oh yeah, I remember that.

I: Cool. You made some connections. So, um, why does, when you have a mountain range up here, why does the crustal root form (.2) in the crust?

F4: Um. (3.0) Grounds it, maybe. Gives it more, like, I mean, obviously it has to go down to give it a stable base.

I: Okay. And what do you predict would happen if we increased the height of the mountain?

F4: Um, I remember these. These were the questions that were on the....

I: Yeah, pretty similar. ((both laugh))

F4: I did really bad on this. I think that was the one were it came back up, right?

I: Okay. Do you have any idea why that would happen?
F4: Um (3.0) Well, I guess maybe just because the mountain is forming, it would be harder for it to grow both ways.

I: Alright. Um, how about if we could hypothetically on Earth increase the density of the crust. How would the position of the crust be affected?

F4: It would increase. I think. It moves more down, no, it would sink wouldn’t it?

I: Okay.

F4: I’m just saying that because I know that continental is more buoyant =

I: =mmm hmmm=

F4: =and that’s why the ocean subducts, but maybe it if it was more dense, than it would go further down.

I: Okay, and how about if, instead of playing with the crustal density, we could manipulate the mantle density? How would that affect the crust, or would it?

F4: Um, I think that it would pop it back up, would elevate it.

I: Okay, and how come?

F4: If that were more dense, then that would make the crust in a different proportion to it? So it would be less dense now, it would be more buoyant.

I: Okay, you are on the right track with that. Good. Anyway, just kind of a general about the usability of the learning activity, um, did you read or take a look at any of the “helpful information” boxes?

F4: I did, but, with, like, computers, I don’t know about you, but when I read stuff off computers I don’t really retain it that well. All my essays I always print out to read, so I just should have printed it out to read it. I did read it on the screen, but you know, it’s kind of like when you read a book and you have to re-read it again because you don’t know what you just read.

I: I know. We were asked to read a few papers on the computer because they were too long to print out, and I didn’t retain it at all.

F4: I don’t know what it is, maybe it’s the screen or something, but I don’t retain it, I guess. It’s harder to read it.

I: Well, that’s important to know, for sure. And then, same with the instructions, or the Intro. Models and Summary pages?

F4: Yeah, I read them all. Even if didn’t necessarily......

I: Alright, so let’s so ahead and move on to the third activity. Would you say that the activities stuck more than the text?
F4: Yeah, the diagrams are helpful.

I: Do you feel like it’s the visuals or the actual, the interactivity of you playing with it that is more effective.

F4: I think it really depended on the activity. On this one, I think the visuals were more helpful than the actual interactivity.

I: Huh. Alright, so on this one, what were some of the main ideas that you got out of it?

F4: Um, I think that was the one that we changed the climate or the erosion rate, and it told you the difference and the isostatic effect. So, I think that one was mostly trying to convey the idea that what temperate areas, versus, like, cold glacial areas had different erosional rates.

I: Okay. So which of the climates (temperate, tropical or glacial), which would have had the greatest erosion rates?

F4: Tropical.

I: Okay. Why is that? Why do you think tropical has the highest erosion rates?

F4: Because it’s gonna get the most precipitation that increases.....oh, wait, it is glacier

I: Okay, so why does could glacial be the right one?

F4: Um, I don’t remember now.((laughs)) Um, well I know what has a big part to do with it, I know glaciers are big erosional factors when they melt, probably more than rain.

I: Okay. It was actually glacial on here, but tropical because of the precipitation, like you said, erodes more quickly as well. And then the other thing that you could choose from is steep or gradual relief. So what does ‘relief’ mean?

F4: Um, that’s the same as slope, right?

I: Okay.

F4: I remember that steep moves faster than the gradual, just because it’s got the incline. It’s harder for material to stay condensed.

I: Okay, right on. So, thinking of the predictions questions that you answered, I assume, did you have multiple choice questions or did you have essay?

F4: Oh, multiple choice.

I: Okay. Did answering those predictions questions before using the interactive activity affect the way that you used this at all?

F4: Um, (1.0) kind of, I mean, some of them I, like, I remember some of the predictions questions and I didn’t know what they were talking about ((laughs)), so then when I got to it, I was like “oh, that’s what they were talking about”. But maybe, I guess, only the things I didn’t
get, didn’t know what they were referring to, those are the things that I really paid attention to once I got there.

I: Okay, sure. That makes sense. Alright, um, finally, this last one. What were some of the main ideas of this activity?

F4: Um, hmmm (4.0). Relating what different areas are eroded:

I: Yeah, uh, kind of you had different rock types to choose from and different processes and you filled those in here. So, how can an igneous rock, for example, form in a mountain belt?

F4: Um, the lava, that came from the mantle?

I: Okay, how about sedimentary rocks?

F4: That can form by maybe being compacted under all of the material, maybe piled on the mountain and slowly building up.

I: Okay, and what about metamorphic rocks?

F4: Um, chemical change, right? Or I think probably in the oceans where there is...I remember that there are chemical and oceans happen together =

I: =yeah, hydrothermal alteration=

F4: =and classic is pressure and temperature changes, so maybe it got condensed in there somewhere and there was a lot of pressure

I: So, the metamorphic rocks (unless they’re that ocean type that you talked about) and plutonic or intrusive igneous rocks form really deep within the crust =

F4: =mmm hmmm=

I: =but yet, we can go to the Cascade mountains and see them there. =

F4: =mmm hmmm=

I: =How is that possible.

F4: Over a lot of time ((laughs)), geologic time again, things just move. ((laughs)) I don’t remember why, but, I know that it has something to do with, well I just remember that limestone, this is from lecture, but he said that you could find it in the Himalayas because it was pushed up from the oceans. I don’t know how (related that is??)

I: Well, it actually is.

F4: Okay, so maybe some of those rocks came out of the ocean and got push, well, maybe not out of the ocean, but got pushed up to higher elevations.
I: So if they get pushed up as the mountain gets higher, or whatever, how is it that we can see
they at the surface? Because if they just get pushed up, we can't see them at the surface, right?

F4: Would it be from erosion, like it exposed over time?

I: You got it, that's exactly it. So, kind of the combination of the erosion from the top and the
uplift due to the compression and squeezing and also the isostasy idea. All of those things in
combination is how we can get these deep rocks exposed at the surface. And they are really cool
looking if you ever drive up on Highway 20 or Highway 2 or something. Anyway, so when you
used this, how user-friendly do you feel like the activity is?

F4: Well, a specific....?

I: The whole thing. Not including the questions.

F4: I thought it was really user-friendly and explanatory.

No suggestions, I liked it. Better than a normal reading, more helpful than a normal reading.

FEMALE 5: (M/C)

I: So let’s just start with a general overview of the whole web activity. What do you feel were
the main ideas that the web activity was trying to convey?

F5: It was probably trying to convey how, um, mountains are created () and how climate change
effects erosion, and, yeah, that’s pretty much it.

I: Okay, um, I’m going to have you look at some of the animations in particular to look at some
of the details. You might remember that this first one was related to plate tectonics, so what do
you think the main ideas of that one were?

F5: I honestly can’t remember that one incredibly a lot.

I: Maybe I’ll ask you a more specific question, then.

F5: Yeah.

I: So, as, um, this plate boundary becomes an active subduction zone, what happens over time to
the continental crust?

F5: The continental crust will shorten so that the base builds up and becomes thicker and then
eventually volcanism occurs at convergent boundaries which eventually pushes it up

I: Okay, so what do you mean by pushing it up?

F5: Well, let me see for a second, I suppose (we get convection or something like that?) which
eventually forces magma to rise and therefore pushes the crust up.
I: Okay, good. And how long does it take for a mountain range to form at a subduction zone?

F5: Quite a while. Um, like millions of years.

I: Why does it take such a long time?

F5: Because they, um, basically move millimeters or centimeters per year.

I: If you were to continue through this all the way to the end and you can kind of see some of the changes, and I'm going to do that, how much attention did you pay to the text on the screen when you were using this yourself and also this information up here at the top?

F5: I think I paid a decent amount of attention to the text, yeah, to see what was going on. It was interesting to see how much it shortened, and I didn't realize that before, so that was important to see how it kind of got fatter, and the visualness of it was good.

I: Okay, great. So if we were to continue this for another 50 million years, um, from here, what do you predict would happen?

F5: There would probably be a volcano, or, never mind, there would probably be a volcano, actually.

I: Okay.

F5: And the continent would move further to the east.

I: Okay. And (3.0), so, moving on to the second animation, what was the main idea of this one?

F5: Is that the isostasy thing?

I: Yeah.

F5: That's the strange thing, because I haven't either read or really known about a lot about that beforehand. Everything else I kind of had a general knowledge of before I started. So, it was a new concept, and it was pretty well illustrated.

I: Okay, so what does isostasy mean to you?

F5: Um, just sort of the balance of the, I don't know, I kind of think of it as the, like, pulling down of the mountain, so when it erodes, it doesn't erode as fast because of the roots, or the bottom of it, makes up for it.

I: So, in what way does the root make up for the erosion?

F5: I think that it make the erosion slower because the root kind of goes up to compensate? And so the root kind of pushes the rock up a little bit as it's eroding.

I: Okay, great. So what effect would increasing the height of the mountain have on the size of the crustal root or the position within the mantle?
F5: The crust is going to (), grow larger to make up for the size of the, um, if the mountain grows higher because it needs to balance it out.

I: Great, and if, hypothetically, we could increase the density of the crust, what affect would that have?

F5: I think that the density, um, pushes it down more, so the effect, oh, I can’t remember.

I: Pushing it down more is kind of an effect, so that’s cool. How about if we could do, instead of increasing the crust density, we could hypothetically increase the mantle density?

F5: Um, the mantle density would also push down more, I think.

I: Okay, like, so, increasing the mantle density would push the crust down more?

F5: Mmmm hmmm.

I: Okay. Um, so why do you think that would occur?

F5: Um, because the denser object is heavier, basically?

I: Alright. So when you were interacting with the web activity, did you read the Helpful Information, the Instructions, and the text on the Intro, Models and Summary pages at all?

F5: I did. One comment that I had was that, um, I wanted to be able to see the text and the visual at the same time.

I: Okay, so you mean the Helpful Information and visuals?

F5: Yeah, I had to go back to look at it so that you kind of.... It would have been more helpful if I could use the information and the simulation because you get the actual what’s happening and the explanation.

I: Okay, that’s a good suggestion. Alright, so the third animation was this one here where you could choose combinations of climate and relief. So what were some of the main ideas of this one?

F5: Um, that in harsher climates, erosions occurs a greater rate, and that more tropical erodes a bit slower, except for when things are excessively rainy, than that has sort of an effect on erosion.

I: So, what do you mean by climate, I mean, harsher climate?

F5: Harsher being like, um, if it’s like a mountain range, or if it’s really cold or something like that, the frost wedging will make the mountain erode faster.

I: Alright, so between tropical, temperate and glacial, which had the greatest erosion rate?

F5: Um, the glacial.

I: Okay. Um, and then the other idea, other than climate, was the relief. So does ‘relief’ mean?
F5: The relief within the mountain ranges, with respect to the flat valley. The mountain ranges eroded more than the valley did. The mountain ranges eroded more than the valley did, because, um, I think it kind of has to do with the amount of area that is exposed to agents of erosion.

I: Okay, great. Um, so before you started interacting with this Flash animation, you answered a series of multiple choice questions?

F5: Mmmm hmm.

I: Those were the predictions questions, so, in what way did those affect the way that you interacted with the activity, or did they?

F5: Yeah, it did. Um, it made me sort of relate it back to those questions and ask what it was talking about. Because of the format of the course, where we take a test online every week, um, with Blackboard, um, I thought this was more like, uh, I mean I thought I was supposed to look the answers up in the book.

I: =Ohhh, gotcha.=

F5: =So that had an influence too. Stuff that I didn’t have before, I looked the whole isostasy thing up=

I: =I see, okay.=

F5: =to interact with the test in the first place.

I: That’s good to know, that might have affected some students pretest scores.

F5: Yeah.

I: Definitely. Alright. Um, so let’s go ahead and move on to this final animation that you looked at. So, what were some of the main ideas of this one?

F5: Um, this one was just volcanism in general.

I: Okay, um...[okay

F5: [() into like plates where the rocks would occur.

I: Can you explain how an igneous rock, for example, would form in a mountain belt?

F5: Yeah, an igneous rock forms when the magma cools, so it forms at different rates. Like, the plutonic, um, the plutonic? Yeah, the plutonic would occur on the outside, and are finer-grained?, um the volcanic ones that have a longer time to cool.

I: The terms are just the opposite. You got it about the cooling times, but the volcanic cools on the outside []

F5: [yeah, comes out of the volcano
I: Yeah, exactly. But the concepts are absolutely right. Okay, so about sedimentary rocks?

F5: Sedimentary rocks, um, occur when there's some weathering and erosion, stuff like that, that breaks down rocks and lays them down in layers basically and () lithify with pressure.

I: And how is that different than with metamorphic rocks?

F5: Um, metamorphic rocks, um, pressure and heat is added, so things kind of get, um, partially melted, not all the way because then they would become an igneous rock. So, its just, aligned against different things to make a metamorphic rock.

I: And, you know, in the illustration here, it shows that metamorphic rocks and plutonic, or intrusive igneous rocks form deep within the crust.

F5: Mmmm hmmm.

I: So how can we see these today, on top of the Cascade range?

F5: Um, because of uplift and erosion.

I: So, how does that work?

F5: The crust on the bottom gets uplifted in areas () and then erosion on top occurs through weathering and stuff like that, so you see more inner layers of the mountain.

I: Was there any causal relationship between the uplift and the erosion?

F5: Maybe because of the whole isostasy thing, because that it uplifts to counteract the erosion that's occurred.

I: Okay, great. In general, how user-friendly would you say that this web activity was? Do you have any suggestions of how it could be more easily navigated, or how it could be improved?

F5: Not really, except the text and images together.

FEMALE 6: (M/C)

I: What, in your opinion, were some of the main, overall ideas in this web activity?

F6: Um, you mean the whole mountain building?

I: Yeah.

F6: Um, I guess just, uh, just figuring out what the main processes and how they happen and what they can cause, and how things affect mountain building in general.

I: Okay, so what were those processes that you saw?
F6: Oh, uh, you know, weathering, plate tectonics, um, uh, just yeah, things associated with plate tectonics, earthquakes and volcanic activity.

I: Okay, great, okay. So, I'll show you each of the animations themselves and ask you a little about each. Um, so for this first animation that you looked at, plate tectonics, um, what was the main idea behind this animation? What did you get out of it?

F6: Um, (4.0) basically just how oceanic crust interacts with continental crust.

I: So, how was the continental crust affected when the plates came together at this plate boundary?

F6: Um, usually there would be earthquakes happening at the subduction zone, and possibly some forming of volcanic landforms.

I: So as far as the shape of the crust itself, what happens as the plates continue to come together?

F6: Um, well, the oceanic crust subducts underneath and (1.0) and, you know, pushes up the continental crust on that side of the plate boundary.

I: How much time would you expect it would take for a mountain range to form once this plate boundary becomes active?

F6: Um, gosh, uh, =

I: = just a ballpark figure is fine=

F6: Oh, yeah, I'm trying to remember if it's in the 10s or the 100s of millions. (1.0) Millions ((both laugh))

I: Alright. Why do you suppose it takes that amount of time?

F6: Um, well, it's just so slow, it just takes forever, and also the erosion counteracts some of the movement of the plates.

I: Alright, if we continue to move through this, as you did when you looked at it, um, and you got to the end, what would you predict would happen if we let it go for another 50 million years after this last slide?

F6: (3.0) Another 50 millions years, um, (1.0) well I think the mountain would just keep building up, it would just become higher. I don't know how fast that happens because of the erosion, you know, it's counteracting. Yeah, it would just keep growing.

I: Any guesses on how high it could get?

F6: Oh, god, um, ((laughs)), in another 50 million years, I don't know, about double as high?

I: Okay, Alright, so let's talk next about the second animation. Um, so were the main ideas behind this one? What did you get out of it?
F6: Oh, um, I think this is referring to the relationship between, um, I can't remember that word, but uh, the gravity pulling, um, you know, how buoyant the mantle is, in terms of, you know, how high the mountain is, or how high the landform is above it, or whether it's being eroded or how it kind of balances out in equilibrium. ((uses hand motions to show upward and downward movement))

I: Okay, that's a good definition of isostasy.

F6: Yeah, that's it.

I: That's the word you were looking for. Okay, why do you think we get this crustal root below the mountain range.

F6: Well, let's see, mountain range, well, I don't know if that's affected by the subduction zone or what, but um, it's just uh, I guess being grounded so that if it keeps growing, it has to have a similar weight underneath it to hold it in the mantle.

I: Okay. So what do you suppose would happen if we increased the density of the crust.

F6: Um, the density of the crust, um (2.0). The mantle would have to balance out to adjust to it.

I: Okay, and how about if we increased the height of the mountain?

F6: We would have to increase the density of the mantle to support the weight, to keep it balanced.

I: Okay, well let's say that we can't change the mantle density.

F6: =mmm hmmm=

I: Because on Earth =

F6: =we can't change it=

I: And mountain heights do change, right? So, is there any other way that this could react to come to that equilibrium you were talking about?

F6: It would sink.

I: Okay, yeah. Just kind of in general, how helpful was this Helpful Information? Did you look at this stuff at all?

F6: Yeah, you know I did, and I was kind of surprised that when I went back and did the very last ones that we had to do? I mean, the first time that I did it, I don't remember what lab that was for, but um, I kind of just like breezed through it and I did okay, but um, I was surprised at how much I remembered on the last activity.

I: Great. You know, that was the purpose of that=
F6: Yeah (laughs)

I: Because they say, that you can maybe remember something right afterwards, but whether or not you retain that...so, did you actually go through and read those sections?

F6: Yeah.

I: Okay, great, because I don’t know how helpful that really is. So, in this third activity, what were some of the main ideas behind this one?

F6: Um, (3.0) I can’t remember this one.

I: Okay. Maybe just as a reminder, you got to pick some sort of combination of climate and relief?

F6: Uh huh.

I: And then....

F6: It’s just showing how erosion happens, you know whether it’s fastest in temperate zones, or it’s in a colder zone it will go slower.

I: Okay. So, which climate, glacial, temperate or tropical, did end up having the highest erosion rates.

F6: Oh, um, tropical.

I: Do you remember why that was? What is your explanation for that?

F6: Well, it’s warmer and wetter and things will, sort of flow down faster, it will pull soil and, you know, rock down faster than if it’s dry.

I: And the other thing, as well as climate, was the relief. So does that mean?

F6: ((laughs)) I still don’t remember what this is.

I: Just as a reminder, you got to choose between a gradual, so here’s a steep relief, and here’s gradual =

F6: Uh huh, so it’s just kind of the slope and how fast things are eroding?

I: Exactly, it’s the difference in elevation between the low points and the high points.

F6: Right.

I: So, based on that, does steep relief or gradual relief have faster erosion?

F6: I think that the steeper has faster erosion.

I: Okay, and how come?
F6: It had a higher elevation and um, it uh, there's some kind of, if there's bigger rocks and things like that, the elements, water and erosion can seep through faster and push it down.

I: Okay, great. And the last one we looked at was this guy here. So, what was the point of this activity?

F6: Oh, um, I guess just showing the different effects of um, of uh, what happens with erosion and metamorphic rocks and volcanism.

I: Okay, so can you explain how each of the three major rocks types, igneous sedimentary and metamorphic, form within a mountain range?

F6: Um, I think, that with the igneous rocks it's uh, contact metamorphism, so it's closer to the surface, and metamorphic is uh, much further down in the mountain ((shows subduction with her hands)), I guess that sedimentary would be somewhere in the middle ((laughs))

I: And, so how do these, because here we've got the intrusive igneous rocks and metamorphic rocks, kind of deepish, um, how do they get to the top where we can see them where we can see them on top of the Cascades?

F6: Um, well, erosion can break down the rock that's on the surface, you know, uncovering what's below. Also, you know, volcanic activity, you know, pyroclastic rocks could be exploded from lava that's further down.

I: Great, so going back to the erosion idea, um, would the mountain range, if we watched this progress over time, just cut down, down, down, until you get to these deep rocks, or how do they get up there to form mountains?

F6: Um (2.0) I think there's some areas that would erode down closer to the base, sometimes, enough so that you can get the low ones exposed.

I: So, to skip ahead, what does it look like is going on in this picture?

F6: It looks like the lava is being pushed up to the surface, pushing up rock with it.

I: Is it clear what these little blocks are supposed to represent?

F6: Um, well, () the different kinds of rocks.

I: Yeah, I wasn't sure how clear that was. So, these are our intrusive igneous and metamorphic rocks moving up to the top. Why do they do that?

F6: Um, (6.0) Well, actually it looks like volcanic activity, the plutons are being forced up, so yeah, I'm not.....

I: That's fine. I can see how this picture is confusing so I wanted to see what people actually thought.

F6: Yeah.
I: So, just kind of on the whole, how user-friendly do you think this activity was? Do you have any suggestions for improvement?

F6: Um, for the most part it was really user-friendly, just questions were not fun to go through, but I can see why it was helpful.

I: Did the predictions questions influence the way you used the activity at all?

F6: Yeah, you know, it got me thinking about things I might not have thought about, and that I’ll remember.

I: Okay, as far as the Flash activity, do you have anything you would change about it?

F6: Occasionally the descriptions next to the animations could be more clear.....