Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2007 Volume IV: The Science of Natural Disasters

The New Madrid Earthquakes of 1811-1812: Shaking Our Misconceptions about Earthquakes in United States History

Curriculum Unit 07.04.09
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Rationale

Earthquakes are geological phenomena and thus, literally shake the earth irrespective of political borders. Yet the destruction of an earthquake can have far reaching political consequences to the United States or any nation that has to endure these natural disasters. Historically, earthquakes in North America predate the United States. However, since they are a part of our historical record and remain a viable threat to millions of Americans, a study of earthquakes in American history is a pertinent subject for high school students in United States History class. The study of earthquakes requires skills that students of history need to master. Reading or compiling data on maps, charts, and graphs is part of the Social Studies Curriculum. Moreover, examining the past as a means to prepare for the future essentially defines the rationale for any historical exploration. In this case, in the face of the devastating consequences posed by any potential earthquakes, there is much at stake for regions of the United States politically, economically, and socially. This unit will use the historical example of the New Madrid Earthquakes of 1811-1812 to expose students of high school history to the causes and effects of earthquakes. It should at the very least displace some common misconceptions about the nature of earthquakes in the United States.

Because the West Coast of the United States has experienced a number of infamous earthquakes, most Americans believe that earthquakes and their destructive forces occur primarily in California or on the Pacific Coast. Two of the most serious earthquakes in the history of the United States have helped shaped this popular perception. The San Francisco Earthquake of 1906 and the Good Friday Earthquake in Alaska in 1964 wrought havoc on the natural landscape and the built environment. More recently, the World Series Earthquake of 1989 reinforced the notion of California as "earthquake central". This seismic event was made famous by the fact that millions of people (including me) had their television sets tuned to the World Series game, between the Oakland A's and the San Francisco Giants, when an earthquake shook the ballpark along with the surrounding region. In the destruction caused by this quake, a section of elevated highway collapsed and killed a number of motorists. I remember watching the news reports of the game being disrupted and of the highway collapse. I could recall only once hearing of a tremor in the Northeast, so this televised event reinforced my wondering why anyone would want to live in a section of the country that could "fall into the ocean" at any time. Actually it is not due to ignorance that I haven't noticed an earthquake in Connecticut or the Northeast in my lifetime. Connecticut is one of only seven states that have not had an earthquake of magnitude 3.5 in the last 30 years (USGS, 2007, Regional Information-Last Earthquakes, Earthquakes Hazards Program). In contrast, Southern California has approximately 10,000 earthquakes per year. Several hundred are of magnitude 3.0 or higher (USGS, 2007, About Earthquakes- Earthquake Facts, Earthquakes Hazards Program). However, this does not mean that earthquakes only occur on the West Coast.

According to the United States Geological Survey, the largest earthquake in the history of the United States struck the Mississippi Valley Region, in the Midwestern United States, in the winter of 1811- 1812. Four major shocks of Modified Mercali intensity VI-VIII along with numerous and sizeable aftershocks appear to have originated from an epicenter below New Madrid Missouri, then a small frontier town along the Mississippi River between St Louis and Natchez Mississippi (USGS, 2006, Earthquake Center-Historic Earthquakes, Earthquakes Hazards Program). Scientists, Arch Johnston and Eugene Schweig (1996), concluded that at least six and possibly nine major events struck at moment magnitude M>7 and at least two events were at least M>8 (Johnston, A and Schweig, E. 1996 p.1). Most striking is the fact the principal quakes not only severely affected the grounds above the epicenter but they also shook the earth in cities on the East Coast. Damage was reported as far away as Charleston, South Carolina and Washington D.C. In Boston, 1000 miles away from the epicenter, the shock was severe enough to ring a church bell (Schweig, E, Gomberg, J, and Hendley II, J, 1995). Log cabins and chimneys fell in Cincinnati, Ohio and the ground shook in Quebec, Canada (Stover,C, and Cover, J.1993). Considering that earthquakes on the West Coast are felt rarely more than a few hundred miles from their epicenter, the New Madrid series of earthquakes are certainly significant . Unfortunately, the prevalence of more frequent and recent earthquake activity on the West Coast, coupled with the fact that no major earthquake of similar magnitude has occurred in the Midwest since the 1811-1812 events, has reinforced the notion of "earthquake central" on the West Coast while relegating the New Madrid events to a footnote in the national memory.

The severity of the New Madrid events should inspire a closer look at the geological profile of the United States and the history of seismic activity in the United States. Scientific investigations since the 1970's have brought to light that the New Madrid area rests on top of the most seismically active zone east of the Rocky Mountains (Schweig, E, Gomberg, J, and Hendley II, J, 1995). They reveal that earthquakes are a realistic natural disaster in the nation's interior and not only on the West Coast. The event raises questions about when, not if, a similar event or series of seismic events could occur again. Moreover it should raise concern as to whether or not similar events could occur in other regions of the country that escape being considered potential natural disaster sites. Study of the New Madrid Earthquakes of 1811-1812, as historical and geological events, should lead to a more comprehensive understanding of the geological profile of the United States. Subsequently, the unit will explore the history of earthquakes across the continental United States, the potential for future seismic events, and the implications for specific communities in areas subject to earthquakes.

Increased awareness of the history and potential threat of seismic activity in the United States can only help all of us. The cost of earthquakes in lives and dollars can be enormous. Approximately three-thousand people died in the San Francisco Earthquake of 1906 due to the earthquake and related fires. One hundred and twenty-five people died in the 1964 Alaska Earthquake from the earthquake and related tsunami. The earthquake killed 15 people in Alaska but the related tsunami killed 98 people in Alaska, 11 in California, and one person in Oregon. A 1946 earthquake unleashed a tsunami that killed 159 people in Hawaii, five in Alaska, and one person in California (USGS Earthquakes Hazards Program-Deaths from Earthquakes). The financial losses of earthquakes to the United States are projected to be approximately $4.4 billion annually. Los Angeles County has the highest projected losses at $1billion annually (Abbott 2006, p. 143).

Fortunately the United States has not suffered a devastating earthquake in the last decade. This has not been the case in other parts of the world. In December 2003, 41,000 people died and another 100,000 went homeless due to a strong quake that shook Iran (Abbott, 2006, p.4). Even more recently, an earthquake rocked Pakistan on October 8, 2005, killed at least 86,000 people, and wounded more than 69,000 people (USGS, 2006, Earthquake Center-Historic Earthquakes, Earthquakes Hazards Program).

Most earthquake casualties are due to construction that fails and collapses. Indeed, attention to how buildings are constructed in known earthquake zones can save much loss of life and destruction. Ignorance of or being unprepared for a natural disaster threat would be devastating. One has to look no farther than the examples of recent earthquakes in Iran and Pakistan cited above **.** Having students and adults in the United States acknowledge the potential dangers of earthquakes not only in the Pacific region but across the country is an important first step toward disaster preparedness.

New Madrid, Missouri is located more than a thousand miles from areas known for their earthquakes such as California and Alaska. Yet, between December 16, 1811 and March 15, 1812, an amateur seismologist named Jared Brooks reported 1,874 earthquakes (Abbott, 2006, p.157). Some of the quakes were of sufficient magnitude to reroute the Mississippi River, drown a forest, and form a new lake. How and why these events happened are essential questions I hope to answer in developing this unit. When these events occurred, New Madrid was a small frontier settlement that claimed to be the "Gateway to the West". The Louisiana Purchase was not even ten years old when these events occurred and the War of 1812 was but a few months away. The lack of development in this frontier area and the fact that this event happened in a bygone time shouldn't minimize the implications of these seismic events. Today, the region affected by the New Madrid quakes is well developed and populated. Moreover, the geological profile of the area prompts scientist to predict that future quakes there are probable. Important cities such as St. Louis and Memphis as well as other Mississippi Valley habitats would be very adversely affected.

Unlike the stereotypical 'West Coast quake' which occurs next to a plate-tectonic transform fault or subduction area, the New Madrid quakes occurred in a failed rift zone. I seek to explore with my students why this particular kind of quake can be just as dangerous or even more so than quakes that occur along known fault lines. Students should understand the principles that suggest that quakes on failed rift zones are felt over greater distances than those localized seismic events on known fault lines. Naturally this should lead students to compare various types of earthquakes that have occurred across the United States in the history of the United States. Essential questions for our study may include: How are the geological profile of a region and the probability of earthquakes related? How are the New Madrid earthquakes similar and different from other quakes in the history of the United States in regard to size, scale, location, and damage?

Earth Science as Basis for Understanding How Earthquakes Work

An in-depth comparison of earthquakes in United States history ultimately leads one to earth science. An exploration of plate tectonics and the thermodynamic cycle of convection in the layers below the earth's crust are fundamental to understanding how most earthquakes occur. How in-depth these phenomena can be studied will depend largely upon the prior knowledge and ability of my students. Since many of my students complete an earth science curriculum in ninth grade, most should have been exposed to some fundamental concepts about the composition and process of the earth's layers. An assessment of prior knowledge and review of earth science principles as they pertain to the composition and process of the earth's interior will be necessary. I plan on using on-line information hosted by the United States Geological Survey (USGS) to teach the scientific components. The USGS site is a comprehensive resource that students and I can repeatedly refer to in order to view data pertaining to geological processes and specific geological events. In some cases, study of earthquakes and history appears to offer an opportunity for interdisciplinary work between a science or math teacher and history teachers. I will explore this as a possibility should any of my students have an earth science or a science/ math elective. I will also share information from this unit with colleagues in my school who teach earth science and math.

Nevertheless, as teaching time permits, I should probe for prior knowledge and expose students to the fundamental composition of the earth's interior and the process of plate tectonics and mantle convection that recycles layers of rock. I will explore information from hardcover texts and on-line resources to reference the composition of the earth, the process of mantle convection and the behavior of plate tectonics. Most of the specific terms associated with earthquakes in regard to characterizing their origin, intensity, and magnitude were unfamiliar to me at the start of this seminar. The plethora of accessible resources made it realistic for me and I predict for students to get a basic grasp of the fundamental scientific principles of earthquakes. The United States Geological Survey (USGS), in particular, hosts online texts, maps, charts, diagrams, and videos that are particularly helpful in presenting key concepts.

The first key point to remind or teach students would be that the earthquakes are a natural by-product of the internal processes of the earth that include planetary convection and cooling. Heat from the interior of the earth, some of which is a by-product from the formation of the earth, fuels a cycle of convection that circulates more buoyant material toward the surface. Material closer to the surface cools and becomes denser and sinks back toward the earth's interior where the cycle of convection and cooling repeats. This process takes place over hundreds of millions of years. However, while the movement of plate material is remarkably slow it is measurable at key geographical locations around the globe. Areas where plate material is sinking such as the northwest Pacific Ocean have been identified (Abbott, 2006, p.62). Spreading centers, such as the Mid-Atlantic Ridge are areas where new and buoyant material is formed. Scientists can measure sea-floor spreading at spreading centers and analyze the movement of the earth's plate material.

The sinking of cooler and denser material pulls the earth's plates which collide and/or rub against each other. The regions between plates, called plate boundaries, become prone to earthquakes.

When two plates collide, the edge of the plate that is colder and denser is driven below the less dense plate with which it collides. The crust of the earth in these subduction zones bends and breaks according to these forces. Violent earthquakes often occur at subduction zones. Alternatively, when plates move sideways with respect to another, scientists refer to this as a transform fault (Abbott, 2006, p.62). The rocks in transform faults bend to the forces of plate tectonics and thus experience stress until snapping violently. The resulting movement of the crust indicates that an earthquake or seismic event has occurred. Areas where long transform faults exist include the northeastern Pacific (Queen Charlotte fault), the San Andreas Fault in California, and the southwestern edge of the Pacific Ocean (Abbott, 2006, p.62).

Students will need to become familiar with the scientific terms that describe geological characteristics of the earth. These terms include definitions that describe the earth's interior: the crust, mantle, and core. The mantle is important to understanding the earth's composition. Scientists point to the importance of the top two sections of the mantle, the lithosphere (solid) and the asthenosphere (plastic) (Abbott, 2006, p.30). In addition students will be able to define plate tectonics and the different types of faults: dip-slip faults (normal and reverse faults), strike slip and /or transform faults (right lateral fault or left lateral fault)(Abbott, 2006, p.86).

Since each of these topics might serve as a topic of extended study, I find that the biggest challenge might be condensing their fundamental meaning and relation to the topic of earthquakes. Using the USGS web site, I have begun summarizing some of the most fundamental topics and concepts. To help contextualize these topics I tried to list an essential question that might be worth exploring with my students.

Layers of the Earth

How does the interior of the earth impact what happens on the surface?

Discussion of the earth's interior involves knowing the layers of the earth's interior and what happens in each region. The USGS on-line publications *The Interior of the Earth* and *Inside the Earth* describe the layers of the earth's interior. The earth's interior can be divided into three primary layers: crust, mantle, and core. Each layer can be conceptualized as part of a hard boiled egg; the crust is compared to the thin and brittle egg shell, the mantle to the elastic egg white, and the core to the yolk. Each of the earth's layers has unique characteristics.

The characteristics of the core and mantle affect the crust, the thinnest and most brittle of the layers. The mantle is approximately 2,900 km thick and contains more iron, magnesium, and nickel, than the crust. The mantle is semi-solid rock and is subdivided into two layers: the lithosphere and the asthenosphere. The earth's core (approximately 3,400 km thick) consists of a solid inner core (1,250 km thick) and a liquid outer core (2,200 km thick). The liquid outer core creates the Earth's magnetic field due to its fluid motion. The characteristics of the mantle of the Earth have a profound affect on the crust. The upper layer of the mantle, called the lithosphere is where plate tectonics are at work (Watson, J.M. 1999, This Dynamic Earth, USGS).

Plate Tectonics

How does plate tectonics relate to earthquakes?

Alfred Wegener proposed in 1912 that the continents moved or drifted over time. Wegener developed his theory of continental drift to debunk a theory that land bridges were the media by which similar fossilized plants and animals could be found from the same time period on different continents. Central to Wegener's theory is the idea that the continents were once joined in a single landmass that Wegener named Pangaea. Wegener investigated what Abraham Ortelius had declared as far back as the late 16th century; the continents roughly fit together as if they were the pieces of a giant puzzle (Watson, J.M.,2007, Historical Perspective- This Dynamic Earth,USGS).

Unfortunately, Wegener's explanation that the rotation of the earth fueled the continental movement proved inaccurate. He believed that the continents plowed through the lithosphere. His contemporaries led by Harold Jeffereys, dismissed Wegener's idea. Jefferey's argued that the ocean lithosphere was too strong for continents to drift or plow through. Alfred Holmes (1929) proposed thermal convection as the correct causal mechanism that drives the movement of plates. However, the ideas linking the movement of plates with thermal convection were not given attention until the 1960's. Harry Hess (1962), R. Deitz (1961), and S. Keith Runcorn (1962) proposed that mantle convection currents caused sea floor magnetic anomalies, ocean trenches, mid ocean ridges, and island arcs. Sea floor spreading, as this concept came to be known, and plate subduction are two fundamental ideas of plate tectonics (Weil, Anne, 1997, Plate Tectonics: The Rocky History of an Idea).

Geologists have determined that the earth's surface is divided into 12 major plates and several smaller ones. The movement and subsequent collisions of these plates cause earthquakes in areas where plates collide and grind against each other.

(To view a diagram of the plates of the earth's surface visit USGS online http://pubs.usgs.gov/gip/dynamic/slabs.html). The United States (with the exception of Hawaii), Canada, and Greenland sit on the North American Plate. The North American Plate has relative contact with other plates on the West Coast of the United States. Subsequently this is an area of high earthquake activity. Hawaii is subject to earthquakes due to its being a chain of collapsing volcanic islands (Watson, J.M., 2003, dynamic slabs, USGS).

Spreading Centers or Divergent Boundaries

What is the role of spreading centers in causing earthquakes?

Spreading centers, or divergent boundaries, such as the Mid-Atlantic Ridge, in the earth's crust and lithosphere occur due to plate tectonics and the cycle of convection and cooling that drives plate tectonics. They are centers of seismic activity. However, earthquakes there are not as prominent as they are at transform boundaries or convergent boundaries (subduction zones). At transform boundaries, plates slide against each other causing seismic activity. At subduction zones, denser plate material sinks under lighter more bouyant plate material. The friction and grinding of one plate as it subducts under the other not only causes seismic activity but also generates heat and steam which manifests itself in volcanic activity over the subduction zone. Spreading centers occur where two plates move away from each other slowly but at a measurable pace. The East Pacific Rise, in the Southeastern Pacific Ocean and the Mid-Atlantic Ridge, in the Atlantic Ocean demonstrate a predictable and measurable rate of spreading. The range of spreading along the East Pacific Rise ranges from six centimeters per year in the south of the Pacific Ocean to 10 centimeters per year just west of Central America's Pacific West Coast. Spreading along the Mid Atlantic Ridge ranges from approximately two centimeters per year near Iceland to four centimeters per year in the south of the Atlantic Ocean. The Mid-Atlantic Ridge actually bisects Iceland. It is one of the few places in the world where a spreading center exists on land. The spreading center is causing Iceland to gain approximately four centimeters of land per year (Abbott, 2006, p. 52).

Spreading is caused as the older, cooler, and denser plate material sinks. This process pulls plate material behind it. Imagine a towel on a table top. As you pull the towel over the edge, the back end of the towel follows behind. At a certain point the weight of the towel would cause the towel to completely slide off of the table top. If you covered a table with two towels so that each covered one half of the table's surface and you pulled the towels in opposite directions, the space between the towels would spread and subsequently the space between the towels would increase. Scientists believe a similar process occurs in the world's spreading centers. The earth's plates cool and sink at their denser and cooler end. The remaining plate material is dragged behind.

Gary Smith and Aurora Pun in *How Does the Earth Work?* describe the process that occurs at divergent plate boundaries. One characteristic that occurs at a divergent plate boundary is having upwelling of asthenosphere fill the space between separating plates. In addition, submarine volcanic eruptions occur and the crystallization of magma forms oceanic crust. Earthquakes happen because normal faults also occur. These faults break the crust. As a result seismic activity occurs (Smith, G. and Pun, A., 2006, p. 316-317).

How might a new rift or spreading center form?

Imagine a single towel or tablecloth that hangs over opposing edges of the table. If you continued to add weight to opposite and hanging ends of the towel or tablecloth, eventually, the table cloth would tear and spread toward the edges of the table where the weights have been added. Rifts occur where plate material had been ripped apart. As the cooler and denser edges of plates sink, the plates are subject to stresses that eventually tear them. Before the stress in the plate can be relieved through a complete tear or rift, a number of smaller tears and rifts might occur. Tears or rifts that begin but subsequently stop due to stress release in other areas are referred to as failed rifts. These phenomena may remain stable and unknown over time. However, they may become points of relief as stress builds up from plate movement over time. This stress relief can result in small seismic activity or large earthquakes. Seismic activity in the Reelfoot Rift, a failed rift lying below the Mississippi Valley, is the probable cause of the New Madrid earthquakes.

Subduction Zones

What is the relationship between plate tectonics, subduction zones, and earthquakes?

The process by which a denser, cooler, and older plate collides and slips under a lighter and more buoyant plate and then sinks into the earth's mantle is referred to as subduction. The area where two plates collide and one is driven under the less dense plate is known as a subduction zone, or, convergent boundary. Earthquakes and volcanoes are prone to areas of the earth's crust in subduction zones. Due to the pressures that build up in the earth's crust above subduction zones, cracks or faults in the crust occur. In the case where two land masses collide, mountains are often the result. The Pacific Northwest coast of the United States is above a subduction zone where the Juan de Fuca Plate (a remnant of the Farralon Plate) is subducting under the North American plate. Earthquakes and volcanoes happen in this area because of subduction.

Faults

How do faults reflect the type of plate activity that occurs in a region?

Faults are the cracks in the crust that form mostly in plate boundaries under forces of plate tectonics. The land above a fault often deforms due to the relative movement of plates. Geological observations show that changes in elevation relative to the faults may cause pieces of land to rise or fall away from each other or move laterally in relation to each other. These can be characterized or defined as normal faults/reverse faults, strike slip faults, and transform faults.

Plate Tectonics and the United States

How do Plate Tectonics apply to areas of the United States?

The United States is subject to the same geological phenomena as any other continent riding on a plate or plates. Parts of the West Coast have been and are currently experiencing the effects of the subduction of plates below the crust. The Juan de Fuca Plate continues to dive under the Pacific Northwest. In parts of California, the northwestern movement of the Pacific plate continues to cause sliding between plate edges. Faults such as the San Andreas Fault are the result of this plate movement. Some of the most damaging earthquakes can be associated with fault activity.

Why are failed rifts an earthquake risk?

While failed rifts may go unnoticed for hundreds, if not thousands, of years (compared to active faults at subduction zones, where seismic activity is more common) they still pose earthquake risks. Failed rifts are vulnerable to the changing stresses caused by plate movements. While they may not completely tear, they may move. The end result may be the subtle or violent movement of the material above the failed rift. The latter appears to be the case in New Madrid as the ground shifted at times radically in reaction to seismic activity on the underlying failed rift.

The New Madrid earthquakes are an example of seismic activity in an area of failed rifts. Due to the integrity of the earth's crust and lithosphere in these areas any seismic activity potentially poses wider ranging risks than in areas of localized fault lines. Quite simply, the solid material will transfer the disturbance over a much larger area than where a heavily faulted and broken-up region will dampen or scatter the waves. Such was the case in the New Madrid episodes which appear to have been felt from New Madrid to Cincinnati and as far east as Washington and Boston. West Coast quakes are rarely noticed beyond the West Coast. A significant seismic event in the central or eastern United States could resonate throughout much of the central and eastern regions.

A comprehensive study of the New Madrid Earthquake events determined that significant land fissuring and deformation occurred. In addition, sunken lands became new lakes. New lakes were formed in Tennessee (Reelfoot Lake) and Arkansas (St. Francis Lake and Big Lake). Most importantly, paleoliquefaction studies showed that at least two major earthquakes hit the same region in a 1500 year period prior to the 1811. Of primary interest is the assessment that further major seismic events are probable (Jonhston, Arch and Schweig, Eugene, 1996). If the New Madrid Earthquakes are indicative of future probable events, people from the nation's interior particularly from the Mississippi Valley above the Reelfoot Rift will have to be prepared. Municipalities could significantly lessen the destruction of a major event by focusing on the earthquake-compatible types of construction and plans for disaster readiness. The New Madrid events could provide valuable history lessons for our future.

Objectives

I imagine that the following objectives will drive the activities of this unit. First, I would like students to be able to understand the geological profile of the United States that contributes to disasters such as earthquakes. This will involve learning about plate tectonics, subduction, strike-slip or transform faults, and rift zones. Secondly, I would like students to be able to distinguish between different types of earthquakes. Earthquakes along subduction zones are different from earthquakes on ancient rift zones and on strike-slip zones. Thirdly, I would like my students to be able to name and categorize the potential earthquake zones in the United States. Subsequently this should lead to the identification and analysis of the destructive implications of earthquakes on the landscape and built environments. I imagine this would also extend toward examining city planning, construction, and political response in areas subject to earthquake activity. Specifically, it will lead to case studies in which students will synthesize information about famous earthquakes in American history. My preparing a case study of the New Madrid Earthquakes will provide the anchor set by which students can research, organize, synthesize, and present information about other famous earthquakes. Developing an informed perspective on earthquakes in United States history, the natural processes that bring them about, and the political responses to those earthquakes should serve students well in their thinking about future responses to earthquakes as they occur in our future.

Lastly, working on the above objectives should result in students being able to demonstrate an understanding of key terms and concepts regarding geology and earthquakes: plate tectonics, subduction, rift zones, failed rift zones, fracture zones, fault lines, and earthquake magnitude.

Alignment with the Curriculum

Occurring within ten years of the Louisiana Purchase and Lewis and Clarks Exploration of the Northwest, the New Madrid Earthquakes align with the district unit on Westward Expansion/Manifest Destiny in the New Haven Public School Curriculum. Additionally, the rumblings of the ground metaphorically foreshadow the War of 1812 and the countless troubles in securing the westward lands from Native Americans. Indeed, the curriculum and most textbooks rarely explore the link between natural disasters and United States history. I hope that by introducing a connection with natural disasters, I will be able to help students see relationships between how natural events occur and what citizens can do to minimize the natural disaster risk.

Strategies

I imagine strategies for the unit will include reading for information, cooperative learning, researching, and persuasive writing. Students will complete background reading that defines basic earthquake terminology. In addition, students will read and discuss primary and secondary accounts of the New Madrid Earthquakes. I imagine students viewing some film clips of earthquakes. I have some footage of the 1964 Alaskan quake. In addition the USGS has a number of photographs, documentaries, and correspondence about earthquakes in the United States and abroad.

Students will also complete a significant task for the unit. The significant task would be to write a persuasive letter to FEMA that recommends a course of disaster prevention action that will help prepare a defined and populated area for future earthquakes. The letter will take into account the history of earthquake activity in the New Madrid region, the potential for future quakes in the region, an assessment of risk if no preparedness is undertaken and concrete steps that could be done to significantly reduce the potential damage of earthquake activity in the region.

Classroom Activities

The following classroom activities will be conducted using our school computer labs. Students will complete a web-based earthquake scavenger hunt to explore some of the fundamental concepts of earthquake science. The scavenger hunt will involve exploring a number of predetermined reliable web sites such as those sponsored by the USGS. In addition, students will complete a group project on the study of an earthquake in United States history. Students will then prepare a 12 slide (minimum) presentation of their findings according to a rubric (see appendix)

Earthquake Scavenger Hunt

Students will view a slide show posted by USGS and complete a note page for each of the following. Following the slide show they will explore a number of sites and complete a couple of experiments.

The slide show is hosted at USGS and is free to duplicate and show to students. The site is http://earthquake.usgs.gov/learning/eq101/EQ101.htm

Terms to define and identify include:

Plate Tectonics

Plate Boundaries

Three Types of Faults

- Strike/Slip
- Thrust
- Normal

Scavenger Hunt Activities:

Students will tour a number of websites and then chose from a number of experiments to learn about characteristics of earthquakes.

The earth's interior:

1. Find a website, list the url, and list the layers of the earth's interior from the core to the crust. 5pts
2. Describe the composition of the earth's core. 5pts
3. Find a site that describes the process of convection that occurs in the earth's interior. Write the url and define convection. 5pts

Plate tectonics

4. Find a site that shows the major plates. Name the plates that relate to the United States. 5pts
5. Find a site that describes plate boundaries. List and define different types of plate boundaries. 5pts

Fault types

6. Find sites that show examples of the three types of faults seen in the slide show: strike/slip, normal, thrust fault. List the sites and where the faults are located. 5pts each.
Total 40pts

An alternative activity is to conduct a fault demonstration experiment such as the one listed below

http://earthquake.usgs.gov/learning/teachers/FaultFeatures.pdf

Investigating Earthquakes in United States History

Groups of students will be assigned one of a number of notable earthquakes in United States History. Students will construct a Power Point presentation after they research the event to identify a number of factors. These include:

Time, Place and Location

Historical reference points

Earthquake science points

Intensity
Magnitude
Damage
Subduction
Faults
Other:

Damages and casualties

Community and government response (see Preparedness and Response see USGS site http://earthquake.usgs.gov/learning/preparedness.php)

List of Earthquakes and source material

San Francisco Earthquake 1906

http://earthquake.usgs.gov/regional/nca/virtualtour/earthquake.php

http://earthquake.usgs.gov/regional/nca/virtualtour/photos.php
http://earthquake.usgs.gov/regional/nca/virtualtour/global.php
http://earthquake.usgs.gov/regional/nca/1906/simulations/
http://earthquake.usgs.gov/regional/nca/1906/shockwaves/
http://pubs.usgs.gov/gip/2006/31/

1964 Alaska Earthquake

http://neic.usgs.gov/neis/eq_depot/usa/1964_03_28.html
http://wcatwc.arh.noaa.gov/64quake.htm
http://wcatwc.arh.noaa.gov/web_tsus/19640328/19640328.htm

Seattle Earthquake February 28, 2001

http://www.pbs.org/newshour/bb/science/jan-june01/seattle_2-28.html
http://www.seattle.gov/fire/photoGallery/misc/miscMenu.htm
http://archives.cnn.com/2001/US/02/28/northwest.quake.05/
http://www.geophys.washington.edu/SEIS/EQ_Special/WEBDIR_01022818543p/welcome.html

Loma Prieta Earthquake 1989

http://pubs.usgs.gov/dds/dds-29/
http://earthquake.usgs.gov/regional/nca/1989/
http://seismo.berkeley.edu/seismo/faq/1989_0.html

Six Point Rubric for Earthquake Presentation

Each of the following criteria will be assessed according to the six points outlined below.

Criteria

A. Presentation includes 12 slide minimum

B. Presentation sufficiently includes time, place, and location of the event.

C. Presentation includes at least one other significant news/historical event that takes place in United States history at the time of this earthquake.

D. The presentation addresses at least five of the following earthquake science components.

Faulting Magnitude Intensity Subduction Spreading Centers

Other: _________

E. The presentation includes an assessment of estimated monetary damages and casualties

F. The presentation describes community and government responses to the event

G. The presentation cites at least five reliable sources.

Six Points

6. Outstanding: Work exceeds the minimum standards. Mastery is evident.

5. Above average. Work exceeds the minimum standards.

4. Proficient: Student demonstrates the ability to fulfill criteria.

3. Acceptable. Work adheres to the criteria. There is room for improvement.

2. Work is incomplete or inaccurate

1. Work is incomplete or there are gross inaccuracies

Resources

Bibliography for Teachers

"The Awful Visitor" Ohio Geology. A Quarterly Publication of the Division of Geological Survey. Michael Hansen. Winter 1998

This is a concise report on the New Madrid Earthquakes that scientifically describes the events and includes excerpts from a variety of eyewitness accounts. It includes a map of Modified Mercali intensities for the events. Overall a readable account that can be used as background reading or as assigned reading for higher level students. Excerpts of the article are readable for mid to lower level readers.

"The Enigma of the New Madrid Earthquakes of 1811-1812" Annual Review of the Earth and Planetary Sciences. Arch Johnston and Eugene Schweig. Vol.24:339-384 May 1996.

This is a comprehensive scientific study of the seismic activity known as the New Madrid Earthquakes. It is written in scientific language. I recommend that those unfamiliar with earthquake vocabulary read a primer first. The source includes many charts of data and scientific illustrations.

How Does the Earth Work? Physical Geology and the Process of Science. Gary A. Smith and Aurora Pun. Pearson Prentice Hall. New Jersey. 2006.

This is a college level primer for Physical Geology. The sections in each chapter are organized in a question and answer format. While the book is a comprehensive account of geological process, I found Part II Earth's Internal Processes and Part III Earth Deformation to be the most helpful for the study of earthquakes. In particular, I found Chapter 12 Global Tectonics: Plates and Plumes helpful in understanding what happens at convergent and divergent boundaries.

Natural Disasters. Fifth Edition. Patrick Abbott. McGraw Hill. Boston. 2006

Our seminar used this as a text for weekly readings. Each chapter had charts of data, illustrations, content narrative, and a chapter summary. Exercises at the end of each chapter include Terms, Questions for Review, and Questions for Further Thought.

The Changing Land. Leonard Bernstein, Martin Schachter, Alan Winkler, Stanley Wolfe

Globe Fearon. New Jersey. 2006

I found this supplemental text about Earth Science in my high school book room. It has excellent readability for most all high school students. The following sections of Chapter One are particularly useful to the study of earthquakes:

Section 7 What are Earthquakes?

Section 8 What are the different kinds of seismic waves?

Section 9 How do earthquakes cause damage?

Section 10 What is the Ring of Fire?

Online Resources

http://archives.cnn.com/2001/US/02/28/northwest.quake.05/

Seattle Tries to Get Back to Normal. This is a CNN archive story of the Seattle Earthquake of February 28, 2001.

http://education.usgs.gov/common/video_animation.htm#earthquakes

USGS Education. This is a listing of videos and animations. Click on earthquake in the search field and a number of resources will appear. There are 12 earthquake related videos and animations. The most applicable are When the Bay Area Quakes (a 22 minute documentary of the 1989 Loma Prieta Earthquake), Parkfield Earthquake Video (2004 Parkfield Quake), Bay Area Earthquake Ground Motion Simulation (for 1906 San Francisco Earthquake and the 1989 Loma Prieta Earthquake), High Quality Earthquake Animations (show ruptures along different types of faults), Fault Interactions and Large Complex Earthquakes in the Los Angeles Area: San Jacinto fault (interaction of the San Andreas, San Jacinto and the Sierra Madre Cucamonga fault systems), Alaska Earthquake

Seismic Waves (animation from a 2002 quake), The Northern California Earthquake, April 18, 2006, (animation of the epicenter rupture speeds and intensity of the 1906 San Francisco Earthquake).

http://www.geophys.washington.edu/SEIS/EQ_Special/WEBDIR_01022818543p/welcome.html

The Pacific Northwest Seismic Report hosted by the University of Washington has data on the Seattle Earthquake's magnitude and intensity.

http://www.pbs.org/newshour/bb/science/jan-june01/seattle_2-28.html

Hosted by the PBS website, this segment from the Jim Lehrer News Hour is an interview with Randall Updike, chief scientist for the geologic hazards team at the U.S. Geological Survey in Colorado.

http://www.pbs.org/newshour/extra/teachers/lessonplans/science/earthquakes.html

"You Don't Need a Seismograph to Study Earthquakes" is an online lesson hosted by PBS and the Jim Lehrer News Hour. It contains demonstrations that can be done with a slinky and a rope to teach earthquake students about p waves and s waves. There are also activities to teach about lithospheric boundaries and plate behavior.

http://pubs.usgs.gov/dds/dds-29/

This USGS site has many photographs of the damage caused by the Loma Prieta Earthquake.

http://seismo.berkeley.edu/seismo/faq/1989_0.html

Hosted by the University of Berkeley, this site gives factual data and reference to additional resources for the Loma Prieta Earthquake

http://wcatwc.arh.noaa.gov/64quake.htm

The Great Alaska Earthquake and Tsunamis or 1964. Thomas Sokolowski hosted by NOAA. The site describes the destruction caused by the 1964 quake and tsunami.

http://wcatwc.arh.noaa.gov/web_tsus/19640328/19640328.htm

The site describes the tsunami that accompanied the 1964 Alaska earthquake.

http://www.pbs.org/wgbh/aso/tryit/tectonics/

This is a plate tectonic activity that has demonstrations of a Divergent Boundary, Convergent Boundary, Collisional Boundary, and a Transform Boundary.

http://www.ucmp.berkeley.edu/geology/techist.html

"Plate Tectonics The Rocky History of an Idea" is a narrative of the history of the theory of plate tectonics.

http://www.ucmp.berkeley.edu/geology/anim1.html

This animated display of the movement of the continents over time from over 700million years ago to the present. It has descriptions of each geological time periods (Cenozoic, the Mesozoic, the Paleozoic, and Precambrian) www.usgs.gov/hazards/earthquakes

The earthquake hazards page hosted by the USGS contains facts on earthquake hazards as a national threat.

http://www2.wwnorton.com/college/geo/egeo/animations/ch2.htm

This companion site for the Essentials of Geology textbook has a number of interactive features for each chapter. These include animations feature articles, crossword puzzle, self test, key terms, and a guide to reading. I found the information in Chapter Two: The Way the Earth Works: Plate Tectonics and Chapter 8: A Violent Pulse: Earthquakes useful as instructional reading. The animations are useful teaching tools.

Reading List for Students

"The Awful Visitor" Ohio Geology. A Quarterly Publication of the Division of Geological Survey. Michael Hansen. Winter 1998

This is a readable account of the New Madrid Earthquakes. It contains some eyewitness accounts and some scientific terminology.

"The Enigma of the New Madrid Earthquakes of 1811-1812" Annual Review of the Earth and Planetary Sciences. Arch Johnston and Eugene Schweig. Vol.24:339-384 May 1996.

Students will struggle with this so I intend to use only a few passages or charts.

Natural Disasters. Fifth Edition. Patrick Abbott. McGraw Hill. Boston. 2006

Students should be able to understand some of the reading charts and photographs.

The Changing Land. Leonard Bernstein, Martin Schachter, Alan Winkler, Stanley Wolfe

Globe Fearon. New Jersey. 2006

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Seattle Tries to Get Back to Normal. This is a CNN archive story of the Seattle Earthquake of February 28, 2001. This is an option for students to use as source material

For their research project.

http://education.usgs.gov/common/video_animation.htm#earthquakes

USGS Education. Students will use to learn about earthquake concepts and to research their earthquake topic. Information about the Loma Prieta Quake, Parkfield Earthquake, and the 1906 San Francisco Earthquakes are here.

http://www.geophys.washington.edu/SEIS/EQ_Special/WEBDIR_01022818543p/welcome.html

Students will use as a source option for the Seattle Earthquake of 2001. The Pacific Northwest Seismic Report hosted by the University of Washington has data on the Seattle Earthquake's magnitude and intensity.

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Hosted by the PBS website, this segment from the Jim Lehrer News Hour is an interview with Randall Updike, chief scientist for the geologic hazards team at the U.S. Geological Survey in Colorado. Students will use this as source material for the Seattle Earthquake of 2001.

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"You Don't Need a Seismograph to Study Earthquakes" is an online lesson hosted by PBS and the Jim Lehrer News Hour. It contains demonstrations that can be done with a slinky and a rope to teach earthquake students about p waves and s waves. There are also activities to teach about lithospheric boundaries and plate behavior. I may have students complete one or more of these activities.

http://pubs.usgs.gov/dds/dds-29/

This USGS site has many photographs of the damage caused by the Loma Prieta Earthquake. Students will use as source material for the Loma Prieta Earthquake.

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Hosted by the University of Berkeley, this site gives factual data and reference to additional resources for the Loma Prieta Earthquake. Students can use as source material for researching the Loma Prieta Earthquake.

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http://www.ucmp.berkeley.edu/geology/anim1.html

This animated display of the movement of the continents over time from over 700million years ago to the present. It has descriptions of each geological time periods (Cenozoic, the Mesozoic, the Paleozoic, and Precambrian). Students will navigate this site to observe the movement of continents over time.

www.usgs.gov/hazards/earthquakes

The earthquake hazards page hosted by the USGS contains facts on earthquake hazards as a national threat. Students will reference this page to appreciate the significant threat that earthquakes play in the United States today.

http://www2.wwnorton.com/college/geo/egeo/animations/ch2.htm

This companion site for the Essentials of Geology textbook has a number of interactive features for each chapter. These include animations, feature articles, crossword puzzle, self test, key terms, and a guide to reading. I found the information in Chapter Two: The Way the Earth Works: Plate Tectonics and Chapter 8: A Violent Pulse: Earthquakes useful as instructional reading. The animations are useful teaching tools for students.

Materials List

- Copies of pertinent articles
- A list of web resources
- Copies of activity rubric
- On-line access