Celebrating Science: Earthquakes Rock Our World
Grade: *9-12*

Description:

Earthquakes have been rocking our world for the last several billion years, and yet the study of seismology has only really started making advances in the last 50 years, with the theory of plate tectonics. We still can't predict earthquakes, but we know a lot more about how and why they happen. By participating in this Passports exploration, students will understand that earthquakes occur along plate boundaries, that there are three different types of boundaries, and that these boundaries govern the location and type of earthquake that occurs. They will also learn that while there are three different types of earthquakes they all generate waves and that these waves have properties that enabled us to learn about earth's interior. They will then explore the difficulties in predicting an earthquake.

Preparation for the Excursion
To ensure the most meaningful learning experience for your students, it is recommended that students engage in activities prior to the excursion. The additional resources and activities offer opportunities for curricular connections and integration within your larger unit of study. The excursion is intended to complement a comprehensive unit.

Challenge Questions:
- What patterns exist in the global distribution of seismicity? What physical processes can be causing these patterns?
- Using what you know about earthquakes waves, can earthquakes waves be heard? Which ones? Do you there might be a correlation with animals and their reactions to earthquakes?
- Compare and contrast the three different types of earthquakes.
- Some people think that there are patterns between when earthquakes happen and the time of day, or with different types of weather. Prove whether this is true or not.

Responses/Prompts:
- Patterns: Earthquakes happen in specific bands around the world. These bands are plate boundaries. This is because earthquakes are caused by motion along plate boundaries. Thin lines of earthquakes occur at divergent and transform boundaries, while thick zones of earthquakes can be observed at convergent boundaries. The shallowest earthquakes are at divergent plate boundaries and the deepest are at convergent plate boundaries. The earthquakes at convergent boundaries get deeper as they move inland. This is because divergent boundaries are usually in the ocean, and the oceanic crust is only 6-8 km thick. Transform boundary earthquakes occur along narrow zones, along vertical faults. Subduction zones are a type of convergent plate boundary. They pull oceanic

crust deep below earth's surface down as deep as 700km. The plate subducts at an angle, the earthquakes occur all along the plate's surface and so when they are projected onto the surface the earthquakes appear in a wide band.

  - Prompts: Where do you see the earthquakes happening? Everywhere? (no, along plate boundaries) Can you tell what types of plate boundaries there are by the earthquakes? (yes, see description above) What type of crust is needed for there to be earthquakes? (cold, if the crust is too hot the crust will flow instead of break) Where is there more crust? (at subduction zones) Use a map of global earthquakes as a visual aide.

- Theoretically, earthquakes can be heard. Earthquakes do generate sound waves. Sound waves are dilation-compression waves. They move the air in a direction parallel to the direction of wave propagation. Sound waves are the same type of waves as P-waves. But can humans hear them? Humans have a range of frequencies for which they can hear. If earthquake waves are in this frequency we can hear the earthquakes. Earthquakes do not tend to occur in the frequencies audible to humans. However, some people have amplified the frequencies of earthquakes so that we can hear them. The following website: http://quake.wr.usgs.gov/info/listen/ has recordings of different earthquakes.
  - Prompt: What kind of waves are sound waves? (compressional-dilational) What kind of waves are P-waves and S-waves? (compressional-dilational and transverse) Can humans hear all frequencies of sounds? (no – if they're not sure, ask Can humans hear the same as dogs? (no) think about the dog whistles)
- There are three types of earthquakes: normal, reverse and strike-slip. Strike-slip earthquakes tend to be the shallowest and usually don't happen below 20 km. The deepest earthquakes are reverse earthquakes, these happen in subduction zones and can happen at depths down to 700 km in some locations. Normal earthquakes cause crustal extension – more land. Reverse earthquakes cause crustal shortening – less land. Strike-slip earthquakes don't effect the amount of land. Land moves up and down in normal and reverse events and back and forth for strike-slip events. Almost all earthquakes are located along plate boundaries, others are located at hot spots, and a very few happen in the middle of plates. All earthquakes are caused by movement of ground on one side of the fault relative to land on the other side. All earthquakes generate waves. These waves differ in size depending on the earthquake, but each earthquake will have P-waves, S-waves and Surface waves. The bigger the earthquake, the longer the fault.
  - Prompts: Do all earthquakes make waves? (yes) Do all earthquakes happen in the ocean? (no) on land? (no) Do all earthquakes happen in the same place? (no) Do different types of plate boundaries cause different types of earthquakes? (yes) Are some earthquakes bigger than others? (yes)
- To make a useful earthquake prediction you need to know the time, place and magnitude of the earthquake. For example, if you know there is going to be a M8 earthquake in your city, but you don't know when it will be, the earthquake could be tomorrow or in 1000 years, it isn't a useful prediction. If you know there is going to be a M5 earthquake tomorrow, but you don't know where, it could be in

the middle of the ocean where nobody has to worry about it, or under your house, where you and your neighbors have to worry about it, it isn't a useful prediction. If you know there is going to be an earthquake tomorrow in your neighborhood, you may want to evacuate the city, or you may have to do nothing, if it's a M8, you'd want to evacuate, but if it's only a M1, people won't even feel it. Therefore, all three factors, time, location and magnitude are necessary to make an effective earthquake prediction.

  - Prompt: What would you want to know about the next earthquake that is going to happen? (is it near me? Is it big? When will it be?) If you just know the size of the next earthquake is that useful? (no) How about location? (no) How about time? (no) Is a prediction useful if you don't know when it will be? (no) Where it will be? (no) How big it will be? (no)

- California cannot fall into the ocean. California is on two different tectonic plates. Most of California is on the North American plate, but a small sliver of it is on the Pacific Plate. The boundary between the two plates is a transform boundary. That means the two plates are sliding past each other. This does not open up any holes, therefore there is nowhere for California to fall. Secondly, California is attached to the ocean floor. They are on the same plate, which means they are connected. To say California would fall into the ocean is like saying that the shell on an M&M is going to fall into the chocolate. It can't – they're connected.
  - Prompt: Using the fault blocks model how land moves on opposing sides of a transform boundary. Show the students that there are no open spaces for California to fall into. Which part of California do people think will fall into the ocean? (southern) What plate is southern California on? (Pacific) What plate is the ocean on? (Pacific) So are the two on the same plate? (yes) So are the two connected? (yes) If two things are connected, can one fall into the other? (no) http://www.earthquakecountry.info/roots/socal-faults.html

- Earthquakes do not occur at a particular time of day or in a particular type of weather.
  - Prompt: Students can look up historical earthquakes on the internet and can then record the time of day and year that the earthquakes happened. They can then make a histogram with the number of earthquakes that happen at each time of day and time of year. They could also do more research online and look at newspapers from the day of the earthquake to find out what the weather was like that day.
  - http://www.earthquakecountry.info/roots/socal.html is a useful website with some information about times of historical earthquakes
  - http://www.earthquakecountry.info/roots/measuring.html is a useful website for "earthquake weather" Your students will have difficulty finding the exact weather on the day of the historical earthquakes, however, you can have them compare the time of year, for example, would the same weather occur in January as in July? How about the

amount of rain in Seattle compared to Southern California – they are both regions with earthquakes?

Lesson at a glance:
Students will plot earthquake epicenters on a world map and then correlate their locations with plate boundary locations. Students will look for patterns in earthquake data. They will model the different fault types and then explore particle motion as earthquake waves pass by.

Lesson Outcomes:

The students will:

- Discover correlation between earthquake epicenters and plate boundaries.
- Determine which variables correlate with earthquake locations.
- Determine which variables correlate with earthquake frequency, and relate these to earthquake prediction.
- Simulate motion across the three different types of earthquake faults.
- Model particle motion as earthquake waves pass through.
- Distinguish between different types of earthquake waves and subsequent particle motion.

Activities:

Plotting Earthquake Epicenters

Materials:
Internet – to get list of earthquake locations
Map of the world with latitude/longitude grid [master copy included, 1 page]
Colored pencils [5 per student, blue, green, yellow, red, black]
Map of plate boundaries [master copy included, 1 page]
Three overhead transparencies [not included, on one you will photocopy the map of the world with lat/lon on it, and on the other two you will photocopy the master of the plate boundary map and then color code the boundaries with overhead markers)

Activity:

- Prior to doing this activity you will need to go to http://earthquake.usgs.gov/regional/world/historical.php (this link should be used for the students plotting by month, depth and magnitude) and http://neic.usgs.gov/neis/qed/ (this link should be used for the students plotting by time of day) and download/print a list of recent global earthquakes. Photocopy this list, one for each student. If there are enough computers with internet access, you can have the students access and print these lists themselves. You will also need to make a photocopy of the world map with the latitude/longitude grid. Also copy the world map onto an overhead transparency.
- Hand out both the map (lat/lon map, not the plate boundary map) and list of earthquakes. Using the overhead transparency, model for the students how to use

the latitude and longitude of an earthquake to plot it on the world map. Have the students plot the point with you.

- Break students into groups of four. Give half the class (including those within each group) them the same set of earthquakes to plot. Give the other half the list of earthquakes from the previous year. When they are done, they should share their maps with the rest of the group and with another group who had the other data set and then draw conclusions about whether or not there are patterns/correlations with earthquake locations and times. Each student within the group should be plotting the same earthquakes, but color-coding them differently. One student should color code the earthquakes by time of day, another by time of year, another by the earthquake depth, and the last by earthquake magnitude.
    - Time of Day: Group from midnight to 6am (blue), 6am to noon (green), noon to 6pm(yellow), and 6pm to midnight (red)
    - Time of Year: Group by winter (Dec to Feb - blue), spring (Mar to May - green), summer (Jun to Aug - yellow), and fall (Sep to Nov - red)
    - Depth: Group from 0-15 km (blue), 15 km to 100 km (green), 100km to 400 km (yellow), deeper than 400 km (red)
    - Magnitude: Group from less than M4 (blue), between M4 and M6.5 (green), between M6.5 and M7.9 (yellow), greater than M8 (red)
- The colors are important so that the maps can be compared with the two different data sets. You can choose other colors, but they should be consistent for the entire class.
- Make sure the students put a key on their map explaining what they are color coding (time of day, time of year, depth or magnitude).
- Are there correlations between earthquake location and the time of day that they happen? How about time of year? Magnitude? Depth? Why are these patterns there (or not there)? Do the maps from the different years look very different?
- Hand out the plate boundary map to the class. What do they notice about the location of the plate boundaries and the locations of the earthquake epicenters?
- Using the arrows on the maps, the students should color code the different types of plate boundaries; divergent should be blue, convergent in red, and transform in green.
    - The transform boundaries are harder to see, so you should point them out in advance: part of the boundary between the Pacific Plate and the North American Plate from the CA/Mexico boarder up to San Francisco, part of the plate boundary through New Zealand, and the boundary between the Nazca and Antarctic Plates. Other boundaries are messy and/or not well defined. The students should mark these with dotted/dashed black lines. These lines separate the Eurasian and African plate boundary, the South American and Antarctic plate boundary, the Australian and Pacific plate boundary, the Australian and Indian plate boundary, and the Saudi Arabia and the Indian plate boundary. I would recommend actually having two transparencies. One with all the answers, and the other with these particular boundaries so the students can copy them.
- Have an overhead transparency of this map with the boundaries color coded to show the class as an answer key for them to compare their answers. Ask the

students to observe patterns between the different variables they just plotted on the maps and the different types of plate boundaries. Which plate boundary are the deep earthquakes associated with? How about the large magnitude earthquakes?

- Make sure students keep their earthquake lists and maps because they will need them in future activities.

Graphing earthquake frequency and analyzing patterns

Materials:
The same earthquake list used in the epicenter plotting activity
Lead pencils [one per student]
Graph Paper [two pages per student]
Lined Paper [one per student]
Ruler [one per student]

Background:
Students should do the earthquake epicenter plotting activity first

Activity:
- Students should take out their earthquake lists and maps from the previous activity.
- Students will be given the same category that they had in the previous activity: (ie time of day, time of year, depth and magnitude).
- Students will go through the list of earthquakes again, but this time they will keep a tally of the number of earthquakes in each group. They will be using a smaller interval for the grouping than they used in the previous activity, as described below.
  - Time of Day: Group by hour: Midnight to 1am, 1am to 2am etc.
  - Time of Year: Group by month
  - Depth: Do intervals of 20 km depths, starting with 0 km
  - Magnitude: Group by integer values: less than M2, between M2 and M2.9, M3 and M3.9 etc.
- Students will take their tallies and graph them. The X-axis should be the variable they're plotting and the Y-axis should be the number of earthquakes. Make sure the students label their graphs with the year their data is from.
- Have the students get back together into their groups of four and then groups of eight (two groups each with a different year of data) and answer the following questions.
- Is there a correlation between the number of earthquakes and the time of day that they happen? How about the time of year? What about magnitude? What about depth?
- What would happen if the earthquakes were grouped the same way, but separated out into geographic regions? Would the graphs look the same? Why or why not? If you have enough time, or for your more advance students, you can have the students graph the earthquakes by regions and see if their hypotheses were correct. If they do graph it, the graph should be on one piece of paper and the regions should be plotted next to each other in different colors. How did the students determine where to make their geographic divisions?
- Which interval (either hour, month, depth or magnitude) has the most earthquakes? How many earthquakes does it have? Which interval has the least

earthquakes? How many earthquakes does it have? What is the difference between the number of earthquakes in the interval with the highest frequency of earthquakes and the interval with the lowest frequency of earthquakes? What fraction out of the total number of earthquakes is this? What percent? What is the average number of earthquakes per interval? Does this average represent the data well? Why or why not? How many more earthquakes happen in the interval with the highest frequency of earthquakes than the average? What fraction of the total number of earthquakes is this? What percent? How many less earthquakes happen in the interval with the lowest frequency than the average? What fraction of the total number of earthquakes is this? What percent?

- Have the students compare the different data from year one and year two. Do the same intervals have the most earthquakes? How about the least number of earthquakes? How do the averages from the two years compare? Does there appear to be large differences between the two years? Are the differences the same for all variables? What does this data tell you about earthquake positions in space and time? Does this give you any information about earthquake prediction?
- Have the students combine the data from the two years and re-graph for their variable. They should do this in partners with the person from the other group who had the same variable. If there isn't enough time, you can have the students do this as a thought exercise. Before doing the graph have the students predict what they think the graph will look like. Have them draw a rough sketch. Do they think it will look very different or pretty much the same? Why? How will it differ if they think it is going to change? Then have the student do the graph. Does the graph look much different from what they thought it would? How were they right? How were they wrong? Is the graph similar or different from the two separate graphs? How is it different? Why do they think the graph looks the way it does? Does this new graph make the correlations between earthquakes and the different variables more or less clear? Why?
- Have the group of eight get back together and discuss their findings. How do the answers change for the different variables? Why do they think this is? What does this tell them about the relationship between earthquakes and each of the different variables?

Fault Block Models

Materials:
Scissors
Crayons or pencils
Fault Block Paper (one per student) [master copy included, 1 page]
Tape
Blank piece of paper (one page)

Background:
No background necessary.   This is an easier activity than the others, good for a Friday lesson. If you will do all the activities great, if you are skipping one, because of lack of time or any other reason, skip this one.

Activity:

- The teacher should make an example of the model before the students do so that they can see what they are working towards.
- Explain to students that the different types of plate boundaries cause different types of earthquakes to happen. Today they are going to make a model where they can demonstrate the difference between these earthquake types. Show the students your model so they know what they are going to build.
- Have students color in the fault block paper. Layer one should be colored in brown, layer two should be colored in yellow and layer three should be colored in orange. The top should have a blue river, a black road and green for the grass.
- Students should then cut out the blocks along the bold black lines along the edges.
- Students should then fold along the remaining bold black edges and tape the sides together to make a three-dimensional model.
- For the younger students, the cutting and taping should ideally be done in small groups, with a parent volunteer if possible.
- Lead the students in modeling the different types of earthquakes: normal, reverse and strike-slip. For example: have the students match up the two Ns to show what the earth looks like after a normal earthquake; have the students match up the two Rs to show what the earth looks like after a reverse earthquake; have the students match up the two LLs to show what the earth looks like after a left-lateral strike-slip fault; have the students match up the RLs to show what the earth looks like after a right-lateral strike-slip fault.
- Call out the different types of earthquake faults and have the student demonstrate them using their models.
- Give the students blank pieces of paper and have them draw what they see after modeling each earthquake
- Ask the students which types of earthquakes are likely to occur at a divergent plate boundary? Which earthquakes are going to occur at a convergent plate boundary? Which earthquakes are going to occur at a transform plate boundary? Have them add these labels to their drawings of their fault block motions. How

do they know which type of earthquake occurs with which type of plate boundary? It's the same type of motion.

Slinky Earthquake Waves

Materials:
Slinkys – as many as possible, up to one for every two students
Table

Background:
No background necessary for this lesson.

Activity:
All earthquakes generate waves. They all generate the same types of waves. There are two main types of earthquake waves, each with two subgroups. The main groups are body waves and surface waves. The two types of body waves are Primary Waves (P-waves) and Secondary Waves (S-waves). The two types of surface waves are Love Waves and Rayleigh Waves. P-waves are the fastest, then S-waves, then Love waves, and Rayleigh waves are the slowest. Surface waves are larger than body waves, and P-waves are the smallest. Bigger earthquakes generate larger versions of these waves than smaller earthquakes. Earthquake waves are recorded on a seismometer. The picture of earthquake waves is a seismogram. This activity focuses mostly on body waves, but the slinky part of the lesson can also demonstrate Love waves.

- For the first part of the activity, you will be demonstrating P,S and Love waves with a slinky. You will need a student to help you by holding one end of the slinky still. You will need a horizontal surface to rest the slinky on. A table works best, but the edge of the blackboard will work too.
- First you will model the P-wave. Have the student stand on the opposite side of the table, and have the slinky parallel to the front of the room. Gently push the slinky towards the student, creating a P-wave. Repeat this several times. Ask the students what direction does the wave travel? (towards the student). Does the slinky travel too?(no, the slinky stays put, but the rings of the slinky move) How do the rings of the slinky move? (they move parallel to the direction of wave propagation/motion, or back and forth) Do they return to where they started from? (yes, they return to their original location) To make this point more obvious, you can put a piece of tape on one of the rings or even tape a pen or pencil to one of the rings and have it write on paper when it moves. The P-wave is a compressional wave and is created by all three types of earthquakes at all three different plate boundaries.
- Second you will model the S-wave. Move the slinky back and forth so it makes an S on the table. Then, hold the slinky off the table and make an up and down S. Repeat this several times. Ask the students what direction does the wave travel (towards the student). Does the slinky travel too?(no, the slinky stays put, but the rings of the slinky move) How do the rings of the slinky move? (they move perpendicular to the direction of wave propagation/motion, or side to side and up and down) Do they return to where they started from? (yes, they return to their

original location) The S-wave is a transverse wave and is created by all three types of earthquakes at all three different plate boundaries.

- Third you will model the Love wave. The Love wave looks exactly the same as the S-wave except it is only in the horizontal direction.
- Break the students up into as many groups as you have slinkys for and give them a chance to make the different types of earthquake waves.
- For the second part of the activity I like taking the students outside, but this isn't necessary if it isn't feasible/practical.
- For this part of the activity, you get to be the earthquake and the students are particles in the ground, and you are going to send waves through them.
- Have the students line up in two parallel lines facing each other. Make sure they stand with their feet shoulder width apart, and their shoulders should be touching the people on either side.
- Tell them that they are particles and you are an earthquake sending waves through them. Remind them that particles don't have eyes and they only move based upon what they feel from the particle next to them.
- The students are first going to be solid particles. They need to put their arms around the shoulders of the people next to them. In solids, the particles are closer together than in liquids or gases. By putting their arms around each other students are simulating how solids are joined together and limited in their movement.
- First send a P-wave through the students. Do this by pushing on the shoulders of the first student in the line so that the student rocks side to side. Then do this for the other line. It is important to do this in two lines so that the students can experience and see the wave propagation. Ask the following questions:
    - What direction did the wave propagate? (down the line)
    - Did the particles (the students) move? (yes) Permanently? (no)
    - How did the students move? (side to side, parallel to the direction of wave propagation, they returned to their original position)
- Then send an S-wave through the students. Do this by bending the first student at the waist. Then repeat for the other line.
    - What direction did the wave propagate? (down the line)
    - Did the particles (students) move? (yes) Permanently? (no)
    - How did the students move? (bending at the waist, perpendicular to the direction of wave propagation, they returned to their original position)
- Then have the students become particles in a liquid. Particles in a liquid are more free moving, but they are not as free as particles in a gas, so have the students still stand shoulder to shoulder, just not with their arms around each other. Make sure they stand with their feet shoulder width apart. Remind the students that particles don't have eyes and that they only move when they feel something from the particle next to them.
- Then send a P-wave through the two lines. Push them the same way you did when they were solids. The wave will propagate down the line. Ask the students the same questions.
- The send an S-wave through the two lines. Push them the same way you did when they were solids. The wave should NOT propagate through the line. Although the second students and then the rest of the line may copy the first

person. This is very common, most students forget that particles can't see what the particle next to them is doing and they think that the wave should propagate down the line so they move. Try again with the second line, reminding the students that they should only move if they feel compelled to by the particle next to them. This demonstrates that S-waves cannot propagate through liquids. Ask the students the same questions.

- The fact that S-waves cannot travel through liquids enabled scientists to determine that the outer core is liquid and not solid.