ShakeAlert® activities for formal and informal learning settings

Earthquake Machine (Activity 2 of 2)

Investigating frequency and magnitude with a hands-on model

Version 12/9 /20

Activity modified from IRIS activity (Earthquake Machine 2—Developing Arguments About Earthquake Occurrence)

The Earthquake Machine (Figure 1) is a simple model that demonstrates earthquake mechanics. The parts of the Earthquake Machine represent the elements of an active fault. "*Earthquake Machine (Activity 1 of 2)*" introduced the model and used a qualitative approach to observe the stick-slip fault behavior that leads to earthquakes. In this second activity, learners take quantitative measurements to explore earthquake frequency and magnitude. Please review Activity 1 before proceeding.

The 5-, 15-, and 45- to 60- minute options provide opportunities to understand the unpredictability of earthquakes, in terms of magnitude or frequency (time between earthquakes). The 5-minute presentation explores how we can't predict the size (magnitude) of an earthquake, and why we can't predict when it will happen. The 15-minute activity builds on that, as learners collect data with the model to observe trends of earthquake magnitude, time, and frequency. In the 45- to 60-minute activity, learners collect evidence from the model to support claims made about earthquakes. A vocabulary list is provided in Appendix A.

Why is it important to learn about the unpredictable behavior of earthquakes? More than 143 million people are exposed to potential earthquake hazards in the U.S. that could cost thousands of lives and billions of dollars in damage. An understanding of earthquake magnitude and frequency of occurrence is fundamental to earthquake hazard mitigation. An important tool for mitigation is the ShakeAlert® Earthquake Early Warning system for the Western U.S. which detects significant earthquakes quickly so that alerts can be delivered to people and automated systems.

Beginner

5 min | 15 min | 45–60 min

Large Group | Small Group

Demo | Materials

Time: 5-, 15- and 45- to 60-minute guided activities that can be adapted for audience and venue.

Audience: This can be done with novice and experienced geoscience learning groups.

Subject: Natural Hazards, Earthquakes, Geoscience.

OBJECTIVES

For the 5- and 15-minute activities, learners should be able to:

- Explain the unpredictability of magnitude and timing (frequency) of earthquakes as a part of the natural Earth system.
- Describe the global trends for earthquakes.

For the 45- to 60-minute activity, learners should be able to:

- Critically analyze data generated by the Earthquake Machine and use the data to develop an evidence-based response to a provided claim statement.

TABLE OF CONTENTS

MATERIALS

- Earthquake Machine stations: one station to demonstrate with a group of learners for 5- and 15-minute activities. Optionally, enough stations for each small team of 3-4 learners for the 15-minute activity. The 45- to 60-minute activity requires one station per 4 person team of learners.
  - Earthquake Machine Model: The full list of materials, tools, construction, and set-up is provided in Appendix B. This is the same model used in the first Earthquake Machine (Activity 1 of 2).
- Two (2) metric measuring tapes for each Earthquake Machine model.
- Equipment to project data graphs (45- to 60-minute activity).
- Choice for the 15-minute activity: either use data sheets from the Learner Worksheets for Groups A and B (on pages 10 and 12) or use White board and markers.
- Learner Worksheets for Groups A and B (Pages 9-12) for the 45 to 60-minute activity.

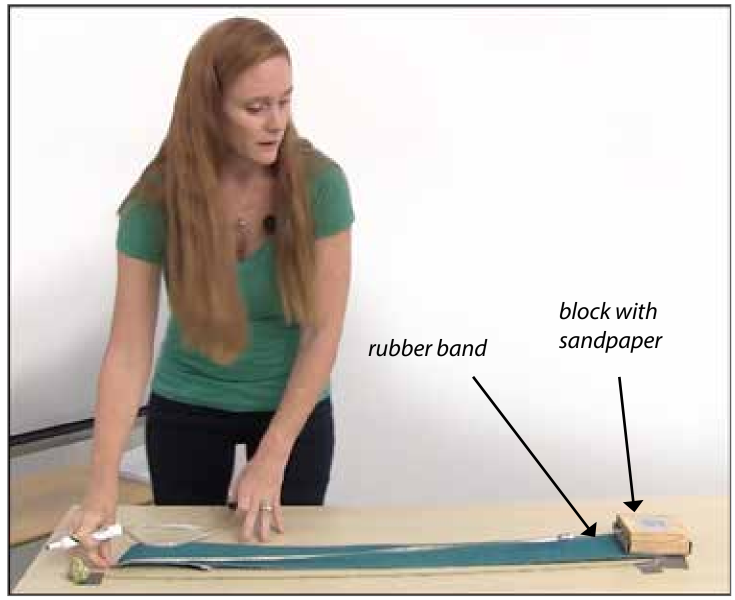


Figure 1: Dr. Wendy Bohon demonstrates the Earthquake Machine setup with sandpaper from a belt sander duct taped to the table. One tape measure is taped to the table adjacent to the duct tape. Groups collect data from opposite ends. Tape measure is tugged slowly and steadily.

RELEVANT MEDIA RESOURCES

Video:

- Earthquake Machine Model: Segments 1 and 2
  How can we demonstrate magnitude and frequency using a model?
- Earthquake Machine Model: Segments 3–6
  Investigating an earthquake's frequency and magnitude

Animation:

- Earthquake Machine: Basic one block & simple graph
  (Note: animation shows slightly different set up)

INSTRUCTOR PREPARATION

Students gain an understanding of earthquake mechanics, unpredictability, and patterns through the exploration of the Earthquake Machine model. Using the seismically active regions of the Western United States, the model allows us to see how the pull on the rubber bands attached to the block is analogous to slow, continuous plate motions, like the downward pull of a subducting slab along a convergent margin like the Cascadia Subduction Zone (CSZ). The CSZ extends from northern California to southern Canada.

The rubber band represents the elastic properties of the surrounding rocks, storing *potential energy* as they are deformed (yes, rocks bend elastically!). The sandpaper represents the contact between the sides of the fault. When the frictional forces between the block and sandpaper are overcome, the block lurches forward, which represents ground motion during an earthquake. The description of this entire process (that is, the slow accumulation of *strain* in an elastic material, followed by the release in a sudden slip event) is known as *elastic rebound* theory (Vocabulary, Appendix A).

The basic stick-slip behavior of the model has two main analogies to explore:

A. *magnitude*: slip distance (how far the block moves when *friction* is overcome) is proportional to, but not equivalent to, magnitude, and

B. *time between earthquakes* (*frequency*): how far the rubber band stretches between jumps of the block. The measuring tape is attached to the rubber band (which, in turn, represents the tectonic plate) and is moving at a constant rate of speed. The distance the rubber band stretches before the block moves represents the *"time" between earthquakes*. In this investigation, one cm = one year. The amount of time that elapses between earthquakes is known as earthquake *frequency*.

In this activity, learners discover patterns to earthquake magnitude and frequency, despite their unpredictability.

Small earthquakes are frequent and large earthquakes are infrequent. Earthquake history on known faults help us to better understand the need for earthquake preparedness. One dimension of preparedness is the information provided by the ShakeAlert® Earthquake Early Warning system along the West Coast of the United States.

To prepare the Earthquake Machine stations:

- Watch the video for Activity 1 for how to construct and use the model, starting at minute 3.
- Assemble the Earthquake Machine model. Tape one measuring tape flat alongside the long sandpaper belt, centimeter side up (Figure 2).
- Attach the other measuring tape to the rubber band (which is connected to the eyelet and block).

To prepare for the 5-minute activity:

- Watch the video that describes this activity
- Set up one Earthquake Machine station with model and measuring tapes to demonstrate the activity.

To prepare for the 15-minute activity:

- Watch the video that describes this activity
- Refer to instructions on how to take measurements before and after each "earthquake" event on page 8.
- Set up one Earthquake Machine station with model and measuring tapes to demonstrate with a group of learners. Alternatively, set-up enough Earthquake Machine stations for each team of 3-4 learners.
- White board and markers to write data collected or print the Data Sheets for Group A (page 10; Frequency) and for Group B (page 12; Magnitude).

To prepare for the 45- to 60-minute activity:

- Watch the video that describes this activity
- Refer to instructions on how to record measurements before and after each "earthquake" event for Groups A and B on page 8.
- Read the Instructor Background in Appendix C for claim statements for Groups A and B.
- Set up one Earthquake Machine station with model and measuring tapes for each team of 4 or more learners.
- Split the class into teams of 4 or more learners, one for each Earthquake Machine set-up. Each team splits into two groups (Group A and Group B) to work on their assigned claim statements.

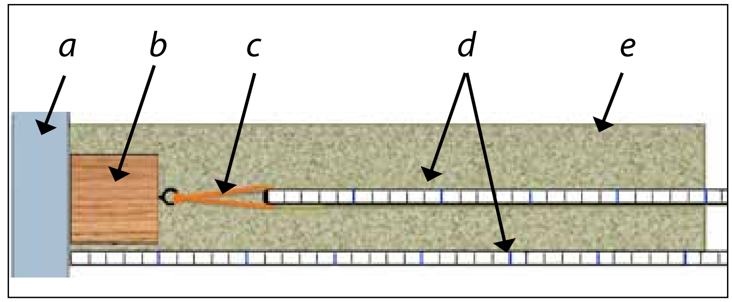


Figure 2: Earthquake Machine with parts labeled. a) duct tape taping the sandpaper (rough side up) to the table; b) block with sandpaper facing down; c) rubber band; d) two measuring tapes; e) strip of sanding belt.

- Print the Learner Worksheets for Groups A and B.

  Group A receives:

  a. Learner Worksheet Group A: Earthquake Frequency = Time with directions and data table (pages 9-10)

  b. Graph half-sheet: Group A Earthquake Frequency (page 13)

  Group B receives:

  a. Learner Worksheet Group B: Earthquake Magnitude with directions and data table (pages 11-12)

  b. Graph half-sheet: Group B Earthquake Magnitude (page 13)

ACTIVITIES AND DEMONSTRATIONS

IF YOU HAVE 5 MINUTES (Demo)

Do Question #1 or #2 (or both) as time permits.

Review the parts of the Earthquake Machine model, which has been set up on a table. What is:

a. The sandpaper belt taped to the table? (*one side of a fault, or on a larger scale, a plate tectonic boundary)*

b. The place where the two sandpaper surfaces, the sandpaper on the table and the block with sandpaper, are in contact? (*a fault, like the Cascadia Subduction Zone or the San Andreas Fault Zone*)

c. The rubber band? (*The materials found in rock that can deform elastically.*)

d. The block of wood and rubber band together? (*a single block of rock or tectonic plate including its elastic properties*)

e. The block, when it's not moving? (*the balanced forces of the fault when it is locked by friction*)

f. The nonmoving block (in part e) and the rubber band starting to stretch as it is being pulled? (*The pulling force stretching the rubber band portion of the rock/plate is stored as elastic potential energy in the rock.*)

g. The block and rubber band jumping or sliding forward? (*Stored elastic potential energy in the rock is released as it overcomes the force of friction holding the block and sandpaper together. The release of energy is an earthquake.*)

Question #1: Did you know we can't predict the size (magnitude) of an earthquake?

Let's investigate this statement with the Earthquake Machine model.

1. Ask learners to predict how far the sandpaper block will move (slip) when you begin to pull the measuring tape attached to the rubber band and block. For example, ask learners to raise their hands if it will be a small, medium or large slip, and/or have the learners pair up and ask each other to state what they think will happen. (For the purposes of this exercise, a small slip will move less than an inch, a medium slip will move an inch or a little more, and a large slip will move several inches. You could slide the block to demonstrate the size of slip before you begin.) Note the starting point of the block before pulling the measuring tape.
2. Pull the measuring tape and rubber band slowly and consistently until the block moves, no matter how far, then stop. Was the slip, small, medium or large? Repeat the pull several times creating different sized movements.

Questions for Discussion:

- Are all the slip distances the same? (*No, they are random.*)
- Can you tell if a specific slip distance would be large, medium or small? (*No, however, one might anticipate that if the elastic was stretched to an extreme, the slip might be large because of the large amount of stored potential energy. But this is not always the case. The slip might still be small, which means the system continues to store more energy for the next movement.*)

Question #2: Did you know that we can't predict when an earthquake will occur?

To see if this is a true statement, let's use the Earthquake Machine model to find out. The references to "time" below refer to how far the rubber band stretches before the block moves (Analogy B in the Instructor Preparation section). As a reminder, one cm = one year.

1. Hold the block, rubber band and measuring tape in two hands. Remind learners that the stretching rubber band in this model represents strain building along a fault. The longer the rubber band stretches, the larger amount of energy has accumulated along the fault and the longer amount of "time" has passed. Stretch the rubber band a little and ask, did you stretch the rubber band for a short or long "time"? (*short*) Repeat and stretch the rubber band further. Did you stretch the rubber band over a short or long "time"? (*longer time*)
2. Place the block on the long sandpaper strip. Ask learners to predict if an earthquake will happen in a short, medium or long period of "time" either by raising hands or telling a neighbor as before.
3. Pull on the measuring tape and rubber band until the block moves no matter how far, then stop. Did the rubber band stretch over a little, medium or a long period of "time" before movement occurred? Repeat the pull several times to create different sized stretches of the rubber band before movement occurs, to illustrate different sized earthquakes.

Questions for Discussion:

- Did the rubber band stretch the same amount before each movement in an "earthquake"? (*No, the length the rubber band stretches is random and can't be predicted.*)
- Could you tell if a specific stretch of the rubber band (or the amount of time that passes before an earthquake occurs) would be short, medium or long? (*No, the stretch represents time passing before an earthquake occurs. The length of the stretch is random and cannot be predicted.*)

IF YOU HAVE 15 MINUTES

Did You Know?

- Did you know that with data from many earthquakes, you can observe trends of earthquake magnitude and frequency?

This is an exploratory activity that can be used to familiarize learners with taking measurements using the Earthquake Machine. A longer inquiry investigation follows in the 45- to 60-minute activity.

Directions:

1. Have one Earthquake Machine with measuring tapes to demonstrate with a group of learners.

Alternatively, set-up an Earthquake Machine with measuring tapes for each team of 3-4 learners.

2. Demonstrate how to measure the length the block slides. Note the placement of the leading edge of the block with the measuring tape alongside the long strip of sandpaper. Assign a student to record the measurements before and after the block slides on the whiteboard (Figure 3) or have students record data on the Data Sheet (Figure 4). The distance the block moves is analogous to the "magnitude" (or size) of an earthquake (see analogy A in the Instructor Preparation section) in this model. Repeat as often as possible in 5 minutes.
3. Demonstrate how to measure the length the rubber band stretches and how that represents the amount of time between earthquake events. Assign a student to record the number of centimeters before and after the block jumps for the measuring tape attached to the rubber band on the end of the long sandpaper strip either on the whiteboard or on the Data Sheet. Repeat as often as possible in 5 minutes.
4. Ask learners to look at their data and answer the following questions:

Questions for Discussion:

- Even with a small sample size, were you able to see a trend in the magnitude (length the sandpaper block moved) of the earthquakes you saw? (*more small earthquakes than large*)

Figure 3: Dr. Wendy Bohon records slip and pull data during the Earthquake Machine tests.

- Even with a small sample size, were you able to see a trend in the amount of "time" that passed (length the rubber band stretched) before another earthquake occurred? (*Most earthquakes are small and happen frequently, so there is a shorter duration of time between small earthquakes or when the rubber band does not stretch very far.*)

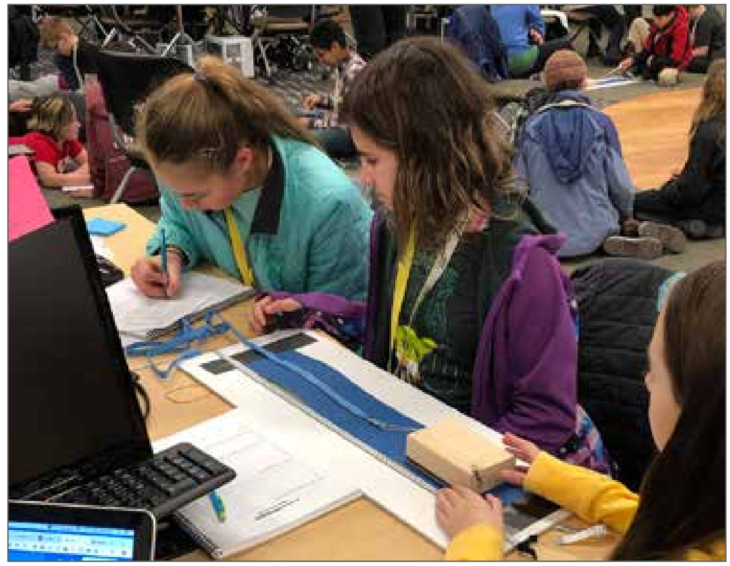


Figure 4: Students record data using the Earthquake Machine.

Optional explorations to become familiar with the Earthquake Machine model.

A. Ask learners to pull the measuring tape attached to the rubber band by one-inch increments, predicting what would happen to the block with each increasing pull. Did outcomes match prediction? Why or why not? (*Frequency and distance of movement is random.*)

B. Ask multiple groups to do the same activity as A at the same time? Did all the blocks move at the same time? What would account for the differences between models? What would the differences represent in nature? (*Differences in sandpaper grit relate to differences in rock types, differences in pulling rates relate to the rate of energy released rapidly or more slowly, different types of rubber bands relate to how strain accumulates and is stored on a fault surface.*)

IF YOU HAVE 45 TO 60 MINUTES

Did You Know?

- Did you know that we can collect evidence to support claims made about earthquakes?

In science, models are designed to replicate natural phenomena, which can then be tested to support or refute a claim.

In this longer investigation, learners will be given a "claim statement" about either earthquake "magnitude" (slip distance) or "time" (length of rubber band pull) that they will then either support or refute based on evidence they collect from creating at least 30 experimental earthquakes with the Earthquake Machine model. This larger sample size will give learners greater evidence to use in their responding argument to the claim statement.

Directions:

1. Demonstrate the model as you review the components of the Earthquake Machine Model:
   - The sandpaper represents the contact between one plate and another plate
   - The moving block represents an earthquake
   - The distance the block moves is analogous to the "earthquake magnitude"
   - The block of wood, rubber band and measuring tape that you pull represents a single tectonic plate
   - The wood block represents the edge of the plate that is locked
   - The rubber band represents the elastic material properties of rocks. Rocks store *potential energy* inside the Earth as *stress* is applied (Vocabulary, Appendix A).
   - Pulling the measuring tape represents the force that causes the plate to move
2. If this activity is used in a classroom, use existing lab table arrangements of student learners of 4 or more learners per table. Each lab table should have one Earthquake Machine model and measuring tape. Each table will have two groups, A and B. Both groups will use the same Earthquake Machine and record every earthquake that occurs.
3. With claim statement (Appendix C) on a data projector or board, discuss each claim statement.

   Statement A: "There are always long periods of quiet between earthquakes."

   Statement B: "Most earthquakes are huge, deadly, and destructive events."

   Learners at each table should discuss and determine which parameters they need to measure with the Earthquake Machine in order to test the statement for their Group (refer to the demonstration in Step 1). The Groups will need to work together to collect the data for both groups at the same time; for example, assigning one person to pull the rubber band.

   Group A will investigate Claim Statement A and will measure "Time" (length the rubber band is stretched) between events, which indicates earthquake frequency.

   Group B will investigate Claim Statement B and will measure the "Magnitude" (or slip distance) of the earthquake events.

   (Alternatively, the entire class can investigate both statements and discuss the findings together.)
4. Distribute group specific Learner Worksheets with blank data tables and graph to Groups A and B at each table. (See Instructor Preparation page 3.)
5. Have one learner from each team pick up the materials for the model. Teams will assemble their models. Review directions for supplies, assembling the Earthquake Machine, how to record measurements (page 8) and run the investigation.
6. Have learners run the experiment/investigation for 30 events (earthquakes) and record their data in the data table.
7. Learners bin/group the data as directed on the worksheets.
8. Learners plot the data into a graph on the half-sheet paper provided. Sample graphs are provided in Appendix C.
9. Present and discuss the outcomes. Some options to discuss findings about the two statements are:
   a) The entire class can discuss both statements and discuss the findings together.
   b) All Group A members of the teams can get together to discuss their findings and all Group B members can do the same. Then, learners assigned to each Group will present their response to their investigative question to the entire class with the graph of their investigation.

   Use a data projector to display learners' graphs as they present their findings.

   Note: The prepared graphs in Appendix D may also be used.
10. Lead a discussion with learners to place the Earthquake Machine model in a context of the real world using the following guiding questions.

Guiding Questions:

- How frequently do earthquakes occur? (*On average, magnitude 2 and smaller earthquakes occur several hundred times a day worldwide*.)
- Are all earthquakes large events? (*No, not all earthquakes are large events*.)
- How frequently do large events occur? (O*n average, major earthquakes, magnitude 7 or greater, happen around once per month (Appendix E). "Great earthquakes", magnitude 8 and higher, occur about once a year. Appendix F provides context for earthquakes on the West Coast of the United States*.)
- Can earthquakes be predicted? (*No, earthquakes cannot be predicted*.)
- How does the Earthquake Machine model compare to global data? (*To compare with global data, share this interactive website with learners:* IRIS Earthquake Browser. *Learners should observe that more small earthquakes occur worldwide than large ones.*)
- What challenges do scientists and emergency managers face when trying to prepare for and recover from earthquakes? (*Scientists and emergency managers cannot predict when an earthquake will occur. They must wait for an earthquake to happen and provide as much warning as possible. Scientists and emergency managers must communicate and collaborate with each other to best support communities after an earthquake. An issue with larger earthquakes is that aftershocks can last for days, weeks, and even months to years after a major earthquake. Providing accurate and timely information to communities who need to recover can be a challenge in the face of aftershocks*.)

Optional Extension

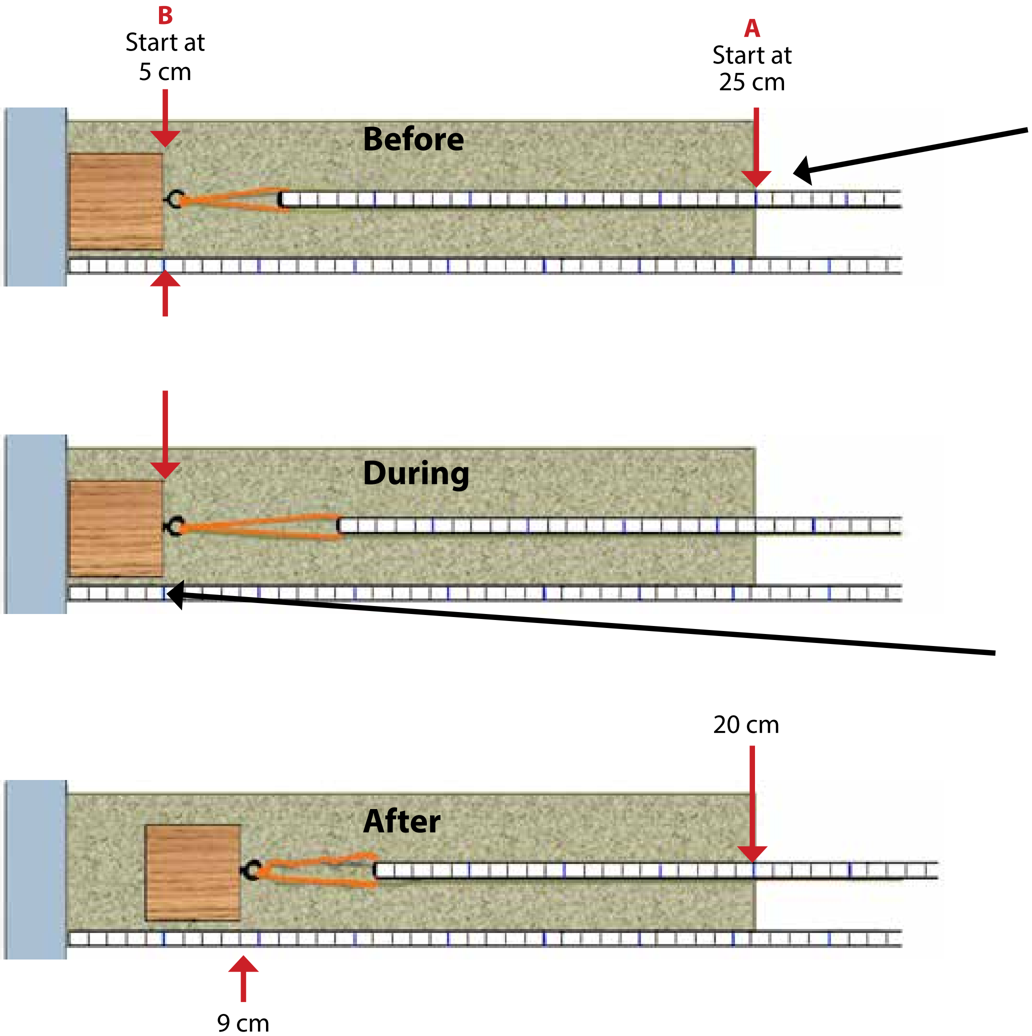
Claim Statement for Discussion:

1. Display the claim statement: "There hasn't been an earthquake in a long time, therefore the next one will be huge."
   Note: This question is asked at 7min 55sec into the Earthquake Machine Segments 3-6 demo video.
2. To respond to this claim, learners will need to discover how often large earthquakes occur. Since Group A and Group B of each team collected data on the same earthquakes, learners combine their binned data tables from the earthquake frequency and magnitude groups into one new graph.
3. Learners begin by plotting on the blank graph found on page 14:
   - Group A's X-axis frequency data: time between earthquakes (# of cm rubber band stretched from Column C from the "Data Table for Earthquake Frequency") against
   - Group B's Y-axis magnitude data: slip in cm (# of cm block traveled for this event from Column C from the "Data Table for Earthquake Magnitude").
4. Discuss the claim statement. Ask learners if the graphed data does or does not support the claim statement. Have learners explain why. (*By analyzing the graph, learners can see that small earthquakes are frequent and large earthquakes are infrequent. It is also important to note that earthquake history helps us understand the need for earthquake preparedness, such as earthquake early warning*.)

Instructions: How to take measurements before and after each "earthquake" event for Groups A and B

See these measurements in the sample data tables below.

Graphs for a 30-sample investigation are in **Appendix B**



Using the *Earthquake Machine*

Group A Data:

Measure "**Time**" by measuring how far the tape is pulled. In the model, we assume that the measuring tape or plate, is moving at a constant rate of speed. Thus distance can be converted into time. For simplicity 1 cm = 1 year is a good rate to use. In this case it translates to 5 years.

A moved 5 cm (X = 25 – 20)

Group B data:

Measure **"Magnitude"** of the block by noting the position of the block before and after an event occurs. In this model distance of slip is proportional to the magnitude of the event. Thus, if 1 cm = **M1**, then 4 cm = **M4,** or a magnitude of **4.**

B moved 4 cm (X = 9 – 5)

NOTE: Events are recorded on the data tables each time the block moves, even it is only a little bit.

Data Table A (Measuring time):

	A	B	C
EQ Event	Starting cm of the rubber band *before* block moves	Ending cm of the rubber band *after* block moves	# of cm rubber band stretched = years
1	Ex: 25 cm	Ex: 20 cm	5 cm
2	20 cm		
3			

Data Table B (Measuring magnitude):

	A	B	C
EQ Event	Starting cm before block moves	Ending cm after block stops	# of cm block traveled for this event = magnitude
1	Ex: 5 cm	9 cm	4 cm
2	9 cm		
3			
4			

Learner Worksheet Group A: Earthquake Frequency = Time

Directions:

Group A: The time between earthquakes indicates earthquake frequency

(Time is analogous to the distance the rubber band stretches)

Run the investigation:

- Set up the Earthquake Machine by taping the sandpaper strip to the table. Tape a measuring tape next to the sandpaper strip. Place the block on the end of the sandpaper strip.
- Hold the end of the measuring tape attached to the rubber band. Extend the measuring tape flat alongside the sandpaper so that the rubber band is fully extended, but not stretched out at all. Record the distance (in cm) between the rubber band and the end of the sandpaper (data table Column A). (Refer to the directions for measuring on page 9).
- Slowly pull the measuring tape attached to the rubber band until the friction of the sandpaper block is overcome by the force you have exerted on the rubber band, which results in movement (or an "earthquake").
- Record the new distance between the rubber band and the end of the sandpaper. Your new distance should be smaller, since the block slid towards the end. (Data table column B.)
- Continue pulling and recording until you have completed 30 tests.
- Column C indicates the number of cm the rubber band stretched. Subtract cm in column B from A (A – B = C) to find the distance the measuring tape and rubber band stretched (1 cm = 1 year, time between events) before the block moved in an "earthquake". (Option: have students calculate C after each measurement).

Group the data:

The data from column C indicates the "time" between earthquakes (or frequency), where the distance (in cm) the rubber band and measuring tape stretched is equivalent to years. Bin or group the data by two-year intervals. For example, there might be 10 events that moved 0 to 2 years.

Graph the data:

Make a bar graph that displays the data you just binned or grouped. The number of earthquakes is on the y axis, and time between earthquakes is on the x axis of the graph.

Analyze the data and prepare a response:

Study the bar graph. How often do most earthquakes occur? Prepare a response to the original investigative statement: "There are always long periods of quiet between earthquakes." Be prepared to make an informal presentation to the group with your graph.

Group A

Data Table for Earthquake Frequency (How far the rubber band stretches before the block moves indicating an earthquake event). Note: Each cm represents 1 year.

	A	B	C
EQ Event	Starting cm of the rubber band *before* the block moves	Ending cm of the rubber band *after* the block moves	Number of cm rubber band stretched = years
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
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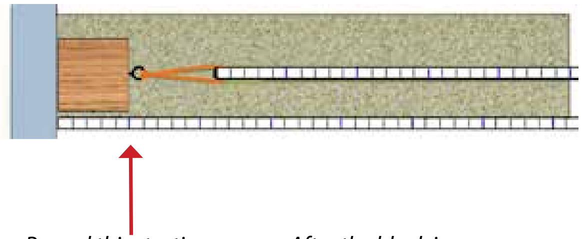


Record this starting measurement in Column A of the ***Data Table***

After the block jumps, record the new cm in Column B of the ***Data Table***

Bin/Group Frequency data (Column C from Data Table) into 2 cm/yr categories.

Time between EQ events (distance rubber band stretched in cm/yrs)	Number of EQ events in this category
0-2	
3-4	
5-6	
7-8	
9-10	
11-12	
13-14	
15-16	
17-18	
19-20	
21-22	
22-23	
23-24	

Graph your data

Title: **Earthquake Frequency**

y axis label: Number of Earthquakes

x axis label: Time between Earthquake

Directions:

Run the experiment/ investigation:

- Set up the Earthquake Machine by taping the sandpaper strip to the table. Tape a measuring tape next to the sandpaper strip. Place the block on the end of the sandpaper strip.
- Note where the leading edge of the block aligns with the measuring tape. Record this as your starting cm (data table column A).
- Slowly pull the measuring tape attached to the rubber band until the friction of the sandpaper block is overcome by the force you have imposed on the rubber band, which results in movement (or an "earthquake").
  NOTE: Record all events including very small movements of the block.
- After the block has moved, note where the leading edge of the block aligns with the measuring tape now. Record this as your ending cm (data table column B).
- Continue pulling and recording until you have completed 30 tests.
- Column C is the number of cm the block traveled for this event. Subtract cm in column B from A (A – B = C) to find the distance the block moved (slip in cm = magnitude) during the "earthquake". (Option: have students calculate C after each measurement.)

Group the data:

With the data from column C, which indicates how far the sandpaper block moved (the sandpaper block's slip distance, or the "magnitude" of an "earthquake"), bin or group the data by 2 cm intervals. For example, there might be 10 events that moved 0 – 1.99 cm.

Graph the data:

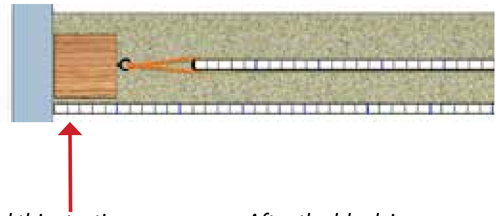
Make a bar graph displaying the data you just binned or grouped. The number of earthquakes is on the y-axis, and the distance between earthquakes is on the x-axis of the graph.

Analyze the data and prepare a response:

Study the bar graph. In what group do most of the earthquakes occur? Prepare a response to the original investigative statement: "Most earthquakes are huge, deadly, and destructive events." Be prepared to make a presentation to the entire group with your graph.

Group B

Data Table for Earthquake Magnitude (how far the block moves)



Record this starting measurement in Column A of the ***Data Table***

After the block jumps, record the new cm in Column B of the ***Data Table***

	A	B	C
EQ Event	Starting cm *before* the block moves	Ending cm *after* the block stops	Number of cm block traveled for this event = magnitude
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
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25			
26			
27			
28			
29			
30			

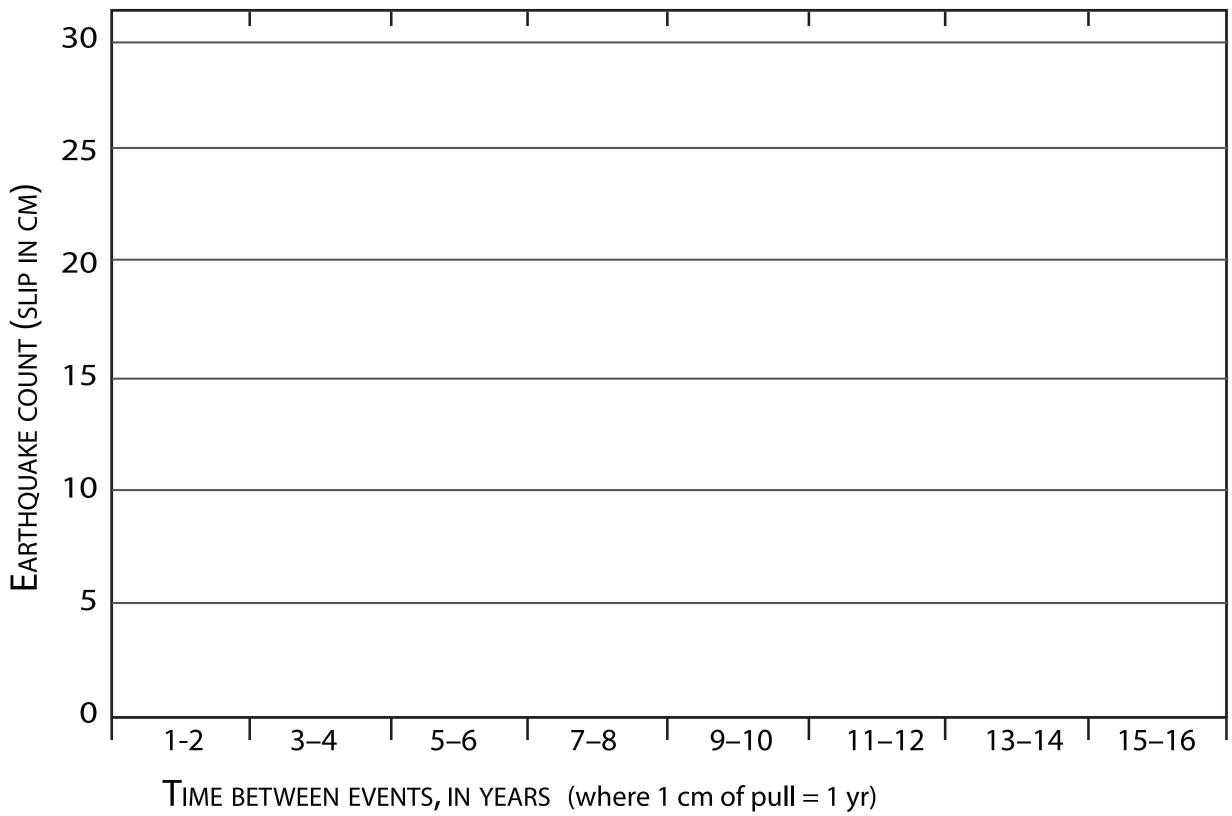
Bin/Group Magnitude data (Column C from Data Table) into 2-cm categories.

Distance traveled for this event in cm	Number of earthquake events in this category
0 – 1.99	
2 – 3.99	
4 – 5.99	
6 – 7.99	
8 – 9.99	
10 – 11.99	
12 – 13.99	
14 – 15.99	
16 – 17.99	
18 – 19.99	
20 – 21.99	
22 – 23.99	
24 – 25.99	
26 – 27.99	
28 – 29.99	

Graph your data

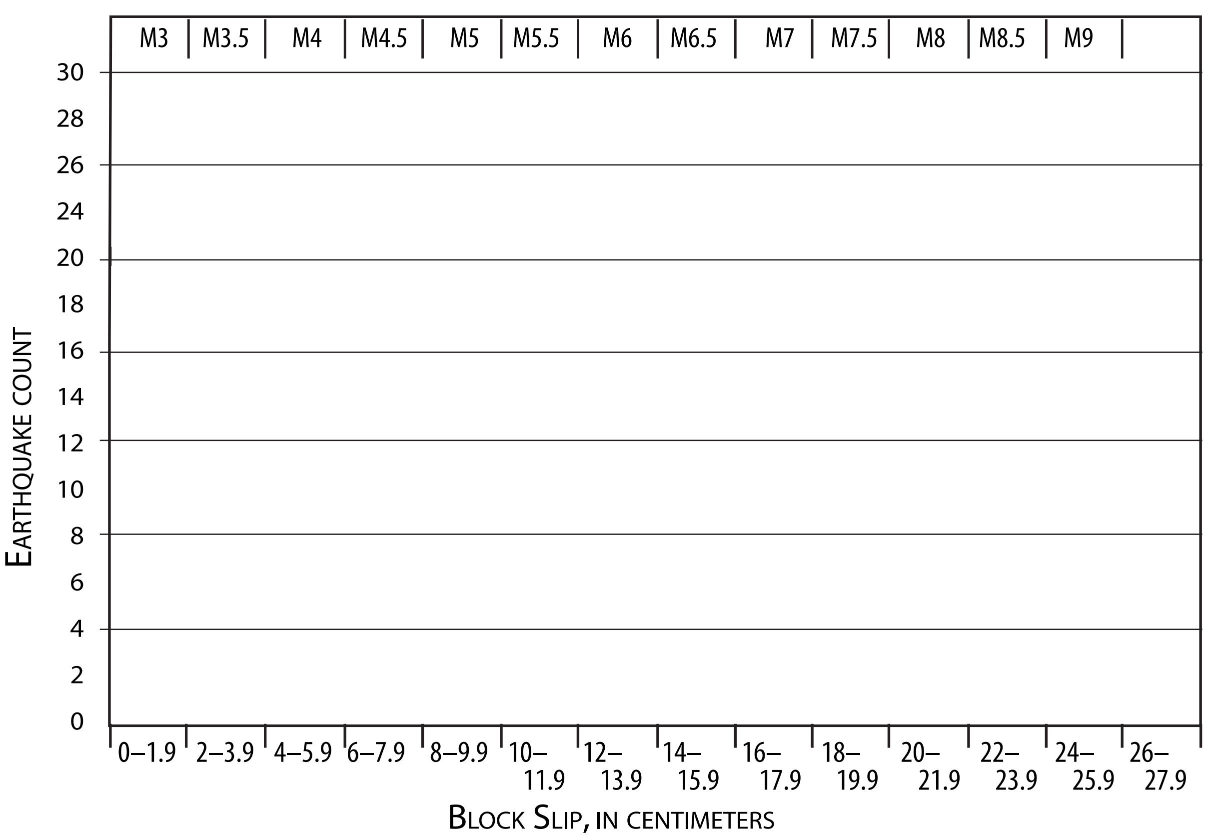
Graph title: **Earthquake Magnitude**
y axis label: Number of Earthquakes
x axis label: Magnitude (movement in cm)

Group A Earthquake Frequency Graph

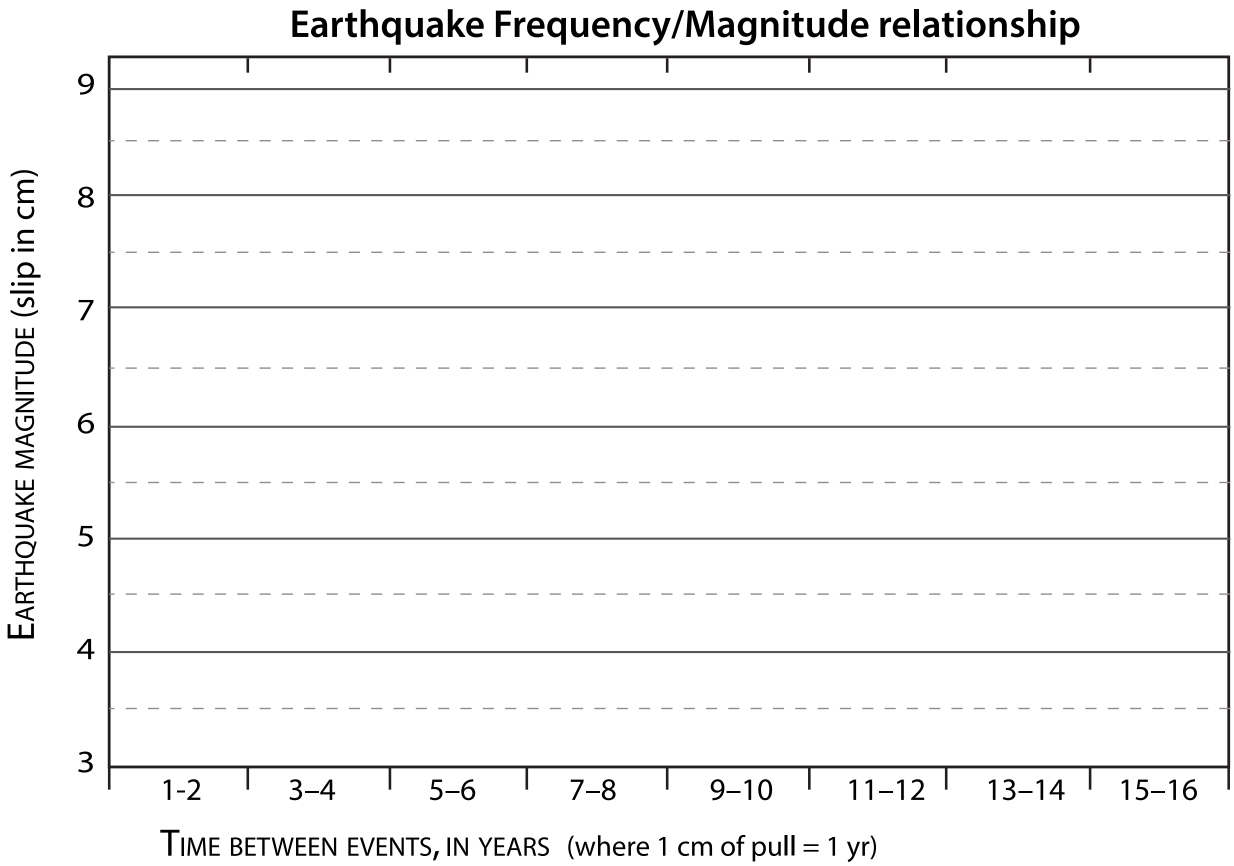


--*cut sheet in half*--

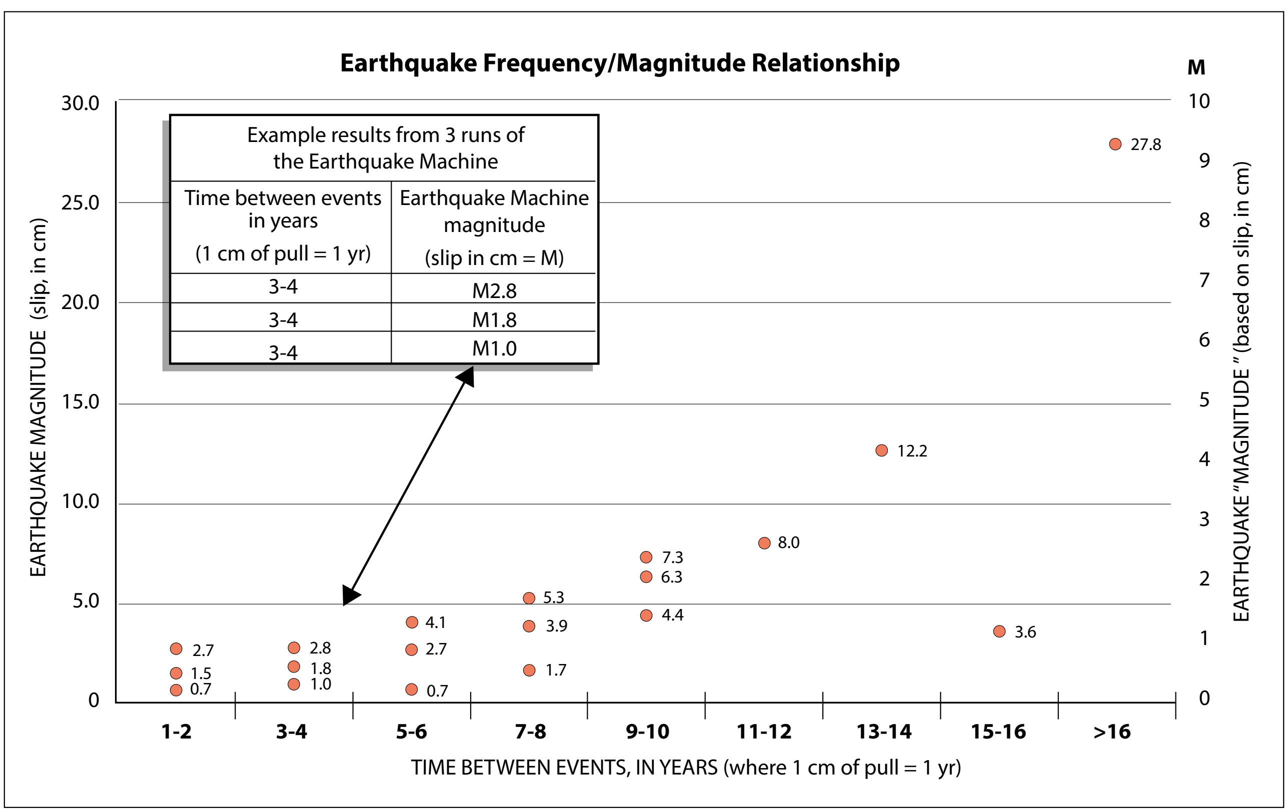
Group B Earthquake Magnitude Graph



Blank Graph for "Optional Extension", page 14 . Group A, time between events (X-Axis); Group B, magnitude (slip in cm, Y-axis). Example of a completed graph below.



Example graph of Frequency vs Magnitude using sample binned data. Frequency in Years (Group A, time between events) on X-axis; Magnitude (Group B, slip in cm) on the Y-axis (slip on left; "magnitude" on right)..



APPENDIX A — VOCABULARY

Earthquake—the release of stored elastic energy caused by sudden fracture and movement of rocks inside the Earth.

Elastic Rebound—an object's ability to return to its original shape after being broken apart.

Elastic Strain—a form of strain that, when the deforming force is removed, the distorted body returns to its original shape and size.

Kinetic Energy—the energy an object possesses due to its motion.

Fault—A fault is a fracture or zone of fractures between two blocks of rock. Faults allow the blocks to move relative to each other.

Friction—the resistance that one surface or object encounters when moving over another.

Potential Energy—the stored energy of an object due to its position or condition.

Strain—change in the shape or volume of a material, often recorded in three dimensions. Strain is defined as the amount of deformation an object experiences compared to its original size and shape.

Stress—a measure of forces acting on a body. Stress is defined as force per unit area.

APPENDIX B—MATERIALS, TOOLS, CONSTRUCTION, & SET-UP

For each Earthquake Machine:

Materials:

- 1 – 4" block cut from 2x4" lumber
- 1 – 4"x36" Sanding belt (50-60 Grit; coarse grit)
- 1 – Sheet of sandpaper, with the coarse grit (e.g. 60 Grit)
- 1 – Screw eye 12x1-3/16" (or similar)
- 2 – Rubber bands (size 19 is best)
- 1 – 16" strip of Duct Tape

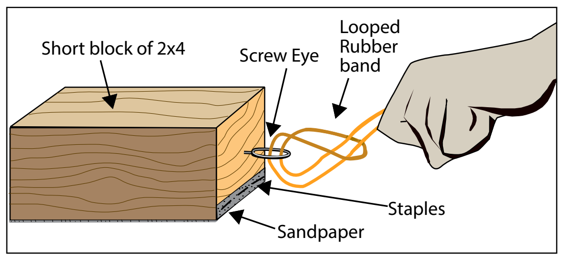
Tools:

- Saw
- Scissors
- Drill
- Heavy-duty staple gun & staples

Watch a video of the construction and use of the model

Construction of the Earthquake Machine:

1) Trace one of the 4" wood blocks on the back of a sheet of sandpaper, adding one inch to the length.
2) Place the sandpaper over the bottom of the block and fold the long edges up on to the ends of the block. Staple the sandpaper to the edges. (Figure 2)
3) Screw one 12x1-3/16" screw eye into the cut end of the block about 1/2 inch from the base at the edge of the sandpaper. It helps to make a small pilot hole either with a nail or a drill so the screw eye is more easily attached.



Parts of the Earthquake Machine.

4) Feed a rubber band through the screw eye and loop to secure.
5) If one rubber band does not provide enough pull, loop a second rubber band through the first to create a chain of 2 rubber bands.
6) Use scissors to cut the sanding belt so it is no longer a loop.

Setting up the Earthquake Machine for use:

1) Smooth the sanding belt out on the lab table, grit side up, so that there are no waves in it. It helps to roll it backwards on itself to help flatten it.
2) Use duct tape to secure each end to the table.
3) Place the block on one end of the sanding belt (Figure 1).

Group A:

"There are always long periods of quiet between earthquakes."

When you summarize the data for this question, begin by discussing the ambiguous phrase "long periods of quiet" and note that long is a relative term. This makes the statement open to lots of different interpretations and allows many answers to be potentially correct depending on your perspective. It may be helpful to point out that pets' lives are often much shorter than ours. For example, one year is ~1% of our lives (assuming 80 years or more), but for a dog that lives to be 10, this is 10% of its life.

When we look at the frequency data generated from the Earthquake Machine to examine this statement, we see a clear trend that suggests that for the majority of the events, a relatively small period of time passes between events. In fact, it is rather rare that a longer period of 13+ years should pass without another event. Remember, the distance that the tape is pulled is converted into time (1 cm = 1 yr).

Like global earthquakes, the majority of learner-generated earthquakes occur with a relatively short time interval between events.

Group B:

"Most earthquakes are huge, deadly, and destructive events."

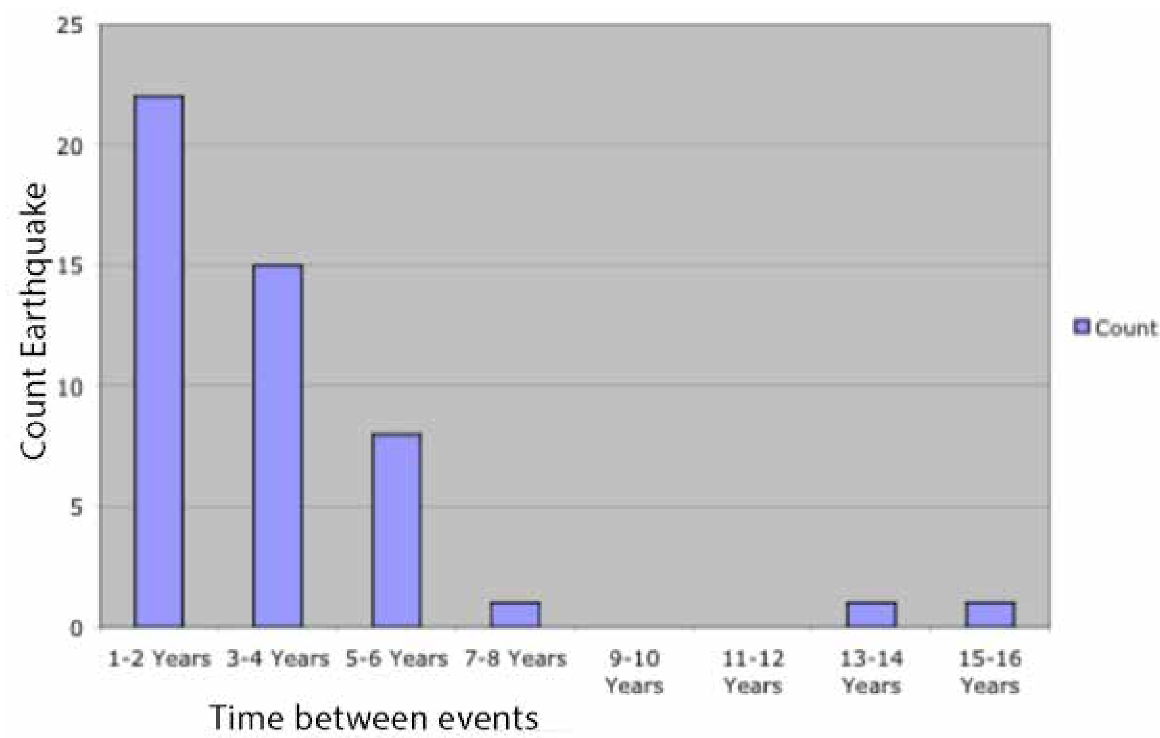
Begin this discussion by asking learners to identify ambiguous terms that may affect the discussion. In this case, the qualifying terms like deadly and destructive are dependent on other factors that are controlled by people and building codes. For example, a magnitude 6 earthquake near Los Angeles may cause some damage and injure some people. If this same earthquake were to occur in Turkey along the North Anatolian fault where building codes are much looser and/or less likely to be enforced, loss of life and property could be much greater.

When we examine the size (or "magnitude") data generated by the Earthquake Machine, we see that the majority of events that occurred are small. This should be put in perspective for learners by discussing what types of earthquakes learners hear about. Most often learners only hear about the large magnitude events that cause damage because of the nature of newscasts. The regularly occurring magnitude 2s are rarely newsworthy.

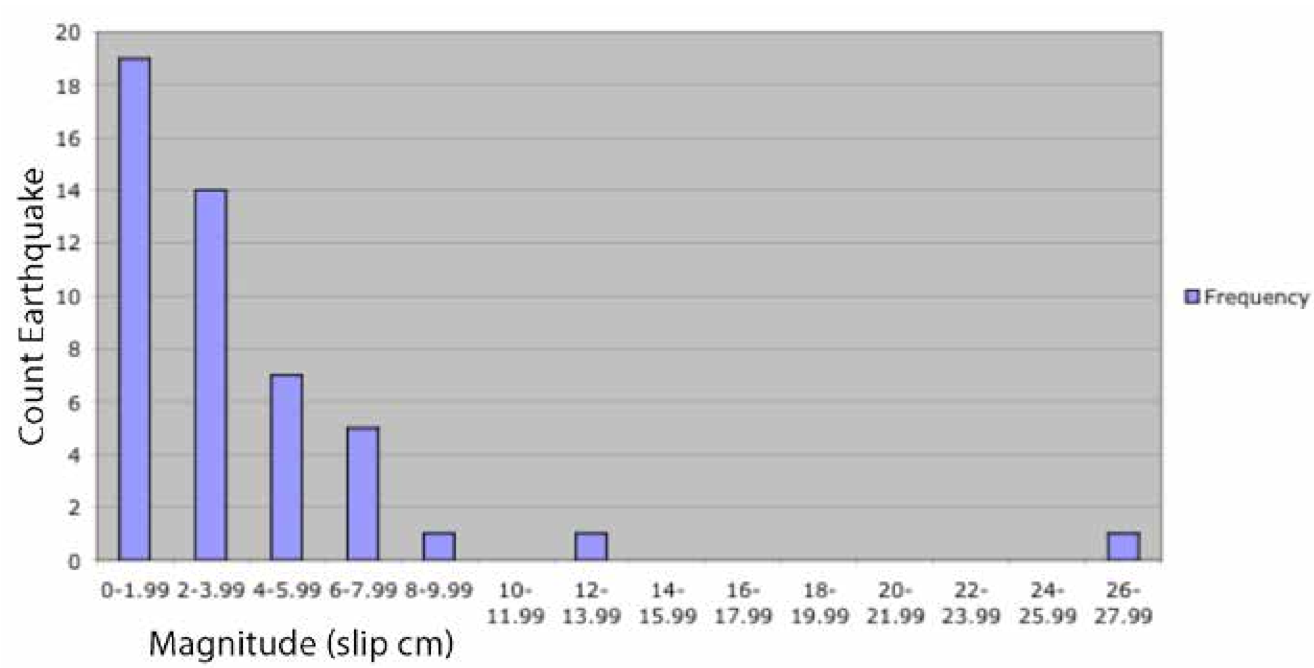
APPENDIX D—SAMPLE GRAPHS

These graphs use a compilation of 50 tests with the Earthquake Machine. See next page for the combined data, which plots earthquake frequency against earthquake magnitude in a single graph.

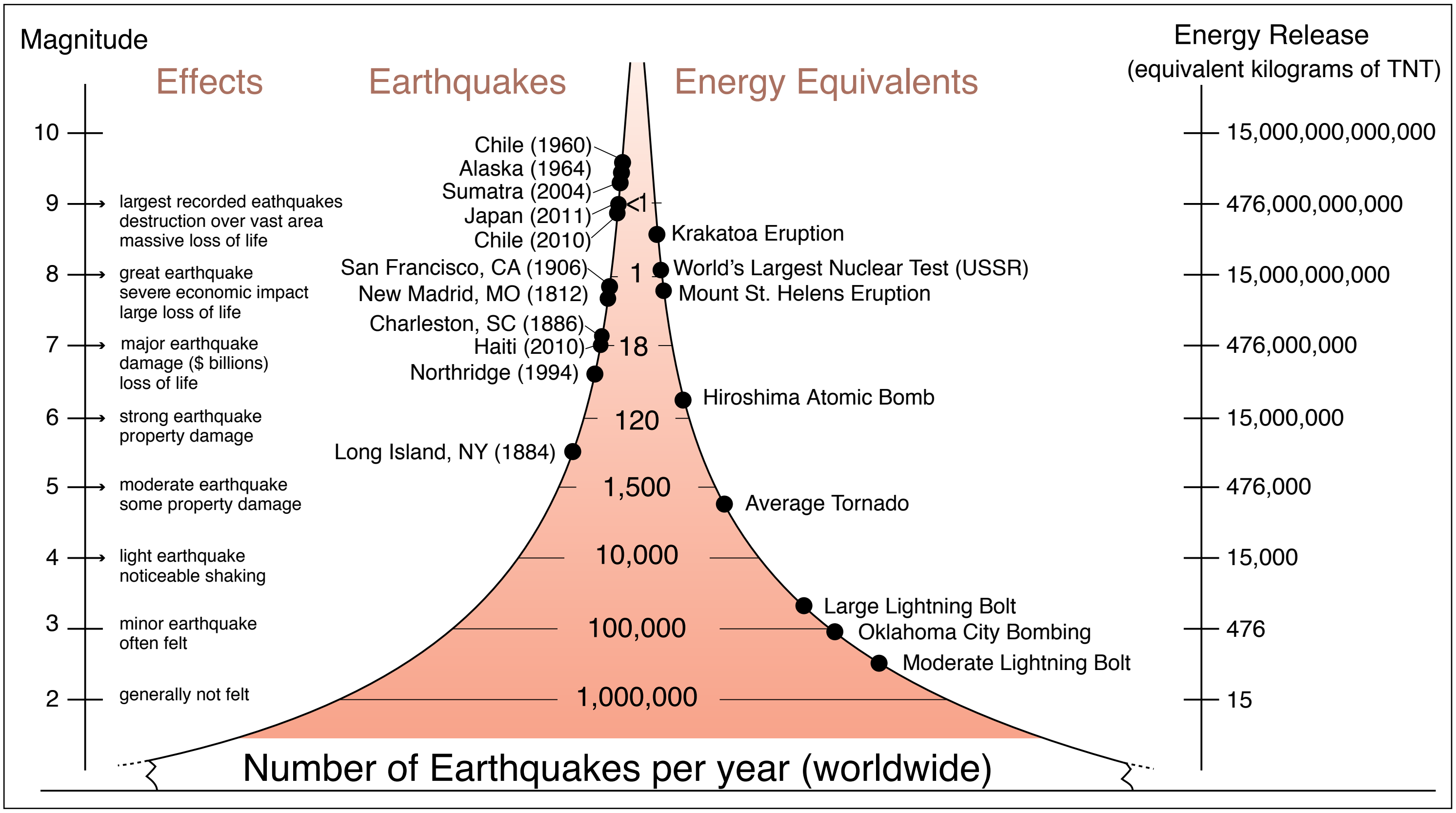
Example for Group A data: Earthquake Frequency



Example for Group B data: Earthquake Magnitude



APPENDIX E– HOW OFTEN DO EARTHQUAKES APPEAR



Graphic showing Earthquake frequency and magnitude. *This graphic is extracted from the 1-page IRIS fact sheet, "[How often Do Earthquakes Occur? .](#) This graphic illustrates information on the frequency of earthquakes of various magnitudes, along with details on the effects of earthquakes and the equivalent energy release. On average, magnitude 2 and smaller earthquakes occur several hundred times a day world wide. Major earthquakes, greater than magnitude 7, happen more than once per month. "Great earthquakes", magnitude 8 and higher, occur about once a year.*

APPENDIX F—FREQUENCY OF M5+ EARTHQUAKES FOR THE WEST COAST OF THE US

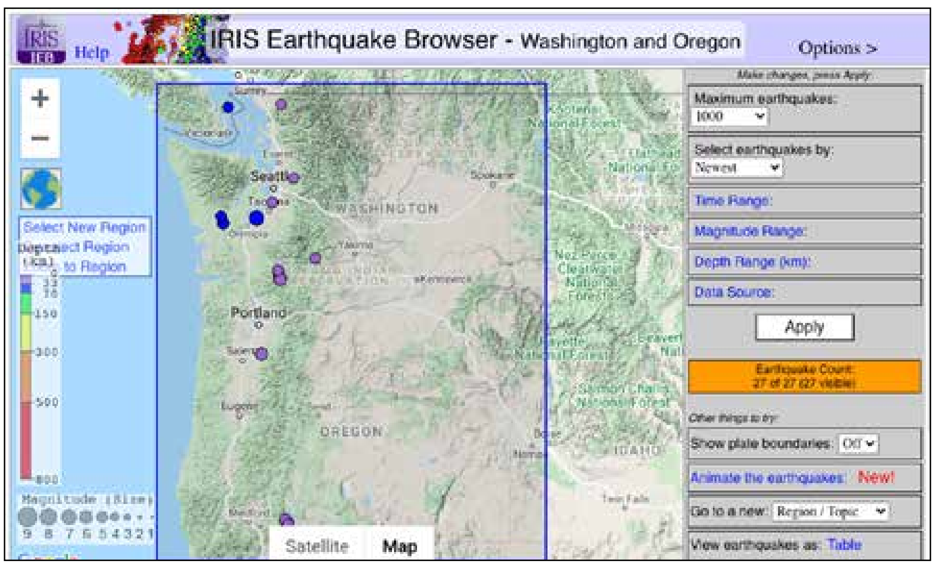
Earthquakes occur on faults that can vary in size from small cracks or fissures to faults hundreds of miles long. Long faults are typically plate boundaries, such as the San Andreas Fault Zone in California (~1300 km or 800 mi long) or the 1,000 km long Cascadia Subduction Zone (CSZ) in northern California and the Pacific Northwest.

The fault's length, depth extent, slip, and rigidity combine to determine the maximum magnitude of an earthquake. Because of these factors, the largest magnitude earthquakes (M9+) occur only at subduction zones. Since 1970, there have been 27 moderate or strong earthquakes in WA and OR: 25 moderate M5+ and 2 strong M6+ earthquakes (Figure 1). Of these earthquakes in the Pacific Northwest, none have been along the subduction zone! What does that tell us about when the next great earthquake will occur?

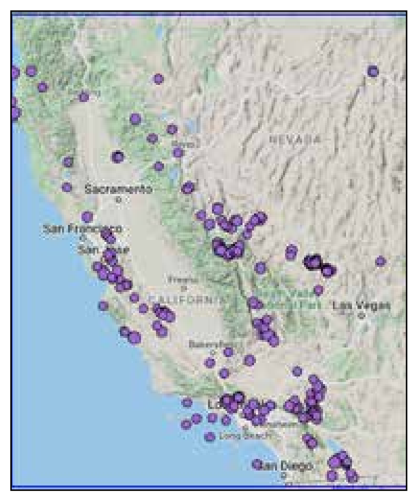
Recurrence intervals, or the time between great earthquakes, can help provide some answers, but we still cannot predict when the next great earthquake will occur.

On the CSZ, geologists estimate that 40 major earthquakes have occurred since 9845 B.C. (Figure 2). Scientists examined soil samples at more than 50 undersea sites along the CSZ to determine the magnitude and timing of each quake. The last known megathrust earthquake was on January 26, 1700, just over 300 years ago with an estimated moment magnitude between 8.7–9.2. Geological evidence indicates that such great earthquakes have occurred at least seven times in the last 3,500 years, with a recurrence interval of 400 to 600 years.

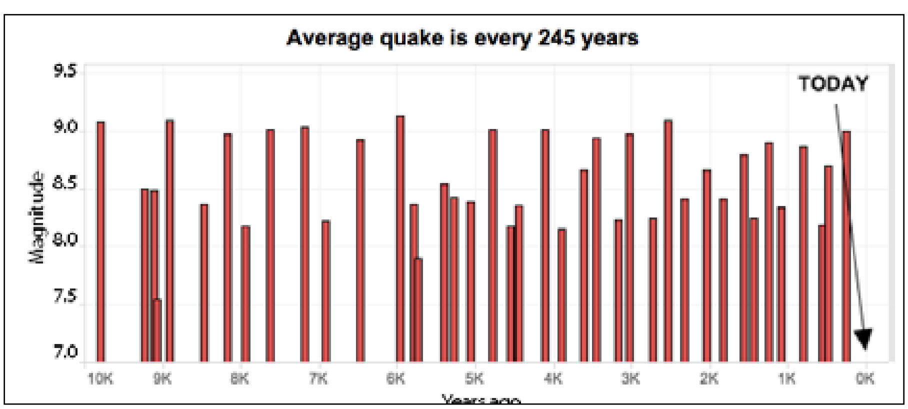
In California, an estimated 192 M5+ earthquakes have occurred since 1970: 165 M5+, 22 M6+, and 5 M7+ earthquakes (Figure 1B). Did you notice that on average, 10 M5 earthquakes occur for every 1 M6 earthquake? The same is true globally. Even an M5 earthquake can be damaging, and since these occur frequently, the ShakeAlert® earthquake early warning system is critically important for all west coast states to provide warning for when moderate to major earthquakes occur.



Left: The IRIS Earthquake Browser (IEB) showing earthquakes in [Washington and Oregon greater than M5 since 1970] selected from the Options panel.



Above: [IEB with California and Nevada] selected for all earthquakes greater than M5 since 1970.



Left: Graph of 10,000 years of Cascadia earthquakes greater than M7. For more detail on each event, click [HERE].

APPENDIX F – NGSS SCIENCE STANDARDS AND CROSS CUTTING CONCEPTS

https://www.nextgenscience e/ms-ess3-2-earth-and-human-activity

Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

Science and Engineering Practices

Analyzing and Interpreting Data

Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings.

Disciplinary Core Ideas

ESS3.B: Natural Hazards

Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events. (MS-ESS3-2)

Crosscutting Concepts

Patterns

Graphs, charts, and images can be used to identify patterns in data.(MS-ESS3-2)

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time.

Incorporated Research Institutions for Seismology

IRIS

FACILITATE. COLLABORATE. EDUCATE.

Founded in 1984 with support from the National Science Foundation, IRIS is a consortium of over 100 US universities. In partnership with its Member Institutions and the scientific community, IRIS manages and operates comprehensive, high-quality geophysical facilities that enable exciting discoveries in seismology and the Earth sciences. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and the verification of a Comprehensive Test Ban Treaty.

NSF