ZOOMIN! Science

Tectonics: Where Will the Next Big Earthquake Hit?

Lesson Question

Which South American city is at greatest risk of damage and devastation from a significant earthquake?

Lesson Task

Students examine data on earthquake magnitude and frequency along the western coast of South America, in order to determine which population center is at greatest risk of a devastating earthquake. They then write a memo to government officials explaining the risk, with supporting evidence, so that they can educate, prepare, and protect their citizens.

Standards

Disciplinary Core Ideas

ESS2.B Plate Tectonics and Large-scale System Interactions

Science and Engineering Practices

Analyzing and Interpreting Data

- Analyze data using tools, technologies, and/or models in order to make valid and reliable scientific claims or determine an optimal solution.
- Compare and contrast various types of data sets to examine consistency of measurements and observations.

Engaging in Argument from Evidence

- Construct, use, and/or present an oral and written arguments or counterarguments based on data and evidence.
- Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.

Crosscutting Concepts

HS-ESS1-5 Empirical Evidence is needed to identify patterns.

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ASSESSMENT 18

OVERVIEW

Content Objectives

Students will understand:

→ **Earthquakes** are caused by movement of and interactions between tectonic plates;

→ **Scientists cannot predict earthquakes,** but can use data to forecast where and when they are more likely to occur;

→ **Earthquakes occur all the time,** but they pose greatest risk to humans when they are strong, occur near populated areas, and when physical infrastructure is weak;

→ **Assessing earthquake risk** involves multivariate analysis, using data on

- earthquake magnitude
- physical infrastructure
- population
- earthquake frequency and pattern

Data Skill Objectives

Math and Computational Thinking

- Using dotplots, student will be able to identify minimum value and maximum value, as well as peaks and spread of distribution of earthquake magnitudes.
- Students will be able to identify median values of earthquake magnitudes from a set of dotplots.

Analyzing and Interpreting Data

- Students will be able to read variables and compare and contrast different variables by earthquake presented in different formats (e.g., tables, color-coded maps, dotplots).

Engagement in Argument from Evidence

- Students will have an opportunity to notice and examine patterns.
- Students will be able to draw conclusions and justify their claims based on analyzing and interpreting earthquake data.

Instructional Sequence

Before you begin the lesson you should share a brief agenda with students:

→ **HOOK** We'll start together, by looking at a deadly 1960 earthquake and thinking about what we'd need to know in order to prevent disasters like this.

→ **BACKGROUND** We'll then go over some background information—what causes earthquakes, and how scientists assess the risks they pose to human life.

→ **DATA ORIENTATION** Finally, we'll spend some time getting familiar with the data sets that will help you figure out where in South America earthquake risks are greatest.

→ **INVESTIGATION** Then, on your own, you'll analyze three kinds of data to decide where earthquake risks are greatest—data on the stability of buildings, roads, and bridges; data on population density; and data on the frequency of high-magnitude earthquakes and where they are concentrated.

→ **WRITING** Finally, you'll write a memo to the mayor of the city you think is in greatest danger of a devastating earthquake, explaining how the data you have analyzed support your conclusions.

Lesson Background for Teachers

The western coast of South America has seen some of the strongest and most devastating earthquakes in recorded history. The 2010 earthquake off the Chilean coast was one of the world's costliest at $15-30 billion; the 1979 earthquake on the Colombian coast generated a tsunami that wiped out entire fishing villages; and the 1960 9.6-magnitude earthquake in Valdivia, Chile, remains the strongest earthquake on record.

The geological features along the western coast provide some clues about why this region is so prone to earthquake activity. The Andes Mountains, spanning 4,300 miles and seven countries, are home to the world's highest volcanoes and the tallest mountains outside of Asia. About 100 miles offshore, the ocean floor plunges thousands of feet to form the Atacama (or Peru-Chile) Trench.

These features, and the frequent earthquakes experienced in this region, are the result of a collision of massive scale between the Nazca and South America tectonic plates. These two plates are moving toward each other, forming a convergent boundary along the western South American coast. Where they meet, the heavier Nazca plate is forced underneath the South America plate, resulting in a subduction zone; as they continue to collide, this region will continue to experience frequent earthquakes. Though it's impossible to predict exactly when and where these earthquakes will occur, scientists do use historical earthquake activity to develop probabilities that an earthquake will occur in a given area over a given timespan.

Earthquakes occur all the time (approximately 50 every day), but they often go unnoticed because they are too small or too far away to be felt by humans. Even higher magnitude earthquakes can pose little to no risk if they take place in unpopulated areas where loss of life and destruction are unlikely. Therefore, earthquake risk can't be determined by magnitude alone, but by the likelihood of impact on humans. Scientists partner with governments and other organizations to help prepare communities and citizens to minimize damage and destruction from a potential earthquake, using data to determine areas and levels of risk based on infrastructure stability, population, historical frequency of strong earthquakes, and other factors.

Student Background Knowledge

Before starting this module, students should understand

- the movement and interaction of tectonic plates.

THE HOOK

[Estimated time: 10 minutes]

Chilean Earthquake of 1960

Purpose

Have students think about the information they will need to solve the lesson task—determining where a devastating earthquake might occur.

Earthquake Damage in Valdivia, Chile 1960

U.S. NOAA

Big Ideas

- **Strong earthquakes** can devastate populated areas.
- Scientists look at past earthquake activity—**location, frequency, and magnitude**—to assess the risks of a devastating earthquake happening in populated areas**.**

Facilitation Suggestions

- **Ask** students to read about the earthquake that hit Valdivia, Chile, and describe what they see in the picture.
- **Ask** students where in the picture they see evidence of how so many people may have died. (Hint: More dangerous than cracks in the street are collapsed buildings like the one in the far upper right.)
- **Pose the Think About It question for discussion**: *What would you want to know about past earthquakes in order to prevent disasters in the future?*
- **Collect** students' answers, which may include things like "Where they've happened most," "How strong they were," "How much damage they caused," "How often they happened."

TRANSITION TO BACKGROUND

You might say: "In order to figure out what city in South America is most at risk of a terrible earthquake, we need to know something about why earthquakes happen and how scientists assess their risks."

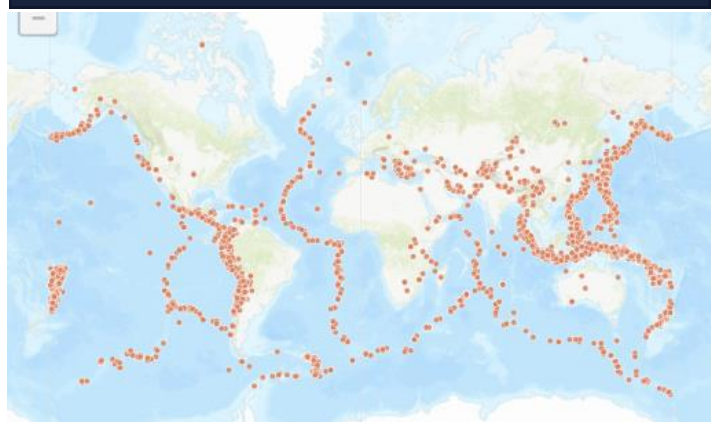
Background

[Estimate time: 20 minutes]

Project the background slides to the class, and have students actively read and discuss the content and questions, so they develop background knowledge needed in the investigation.

Background 1: Earthquakes and Tectonic Plates

Earthquakes 2016-2017



Data source: Earthquake Hazards Program, USGS.

Purpose

Help students understand the context of the earthquake activity they will be examining in the lesson—the *subduction zone*, where the Nasca plate is diving beneath the South American plate, releasing great energy.

Big Ideas

- Earthquakes are caused by the movement of Earth's **tectonic plates**.
- The strongest and deepest earthquakes occur in **subduction zones**—where one plate is diving beneath another, releasing energy.
- The boundary between the Nasca and South American plates is a **subduction zone**.

Facilitation Suggestions

- **In Panel 1,** tell students to look at the world map **showing earthquakes in 2016 and to describe any patterns they see.** Ask "What might account for the patterns you see?" (If they need a hint, click to enlarge the small image of Earth's tectonic plates, and flip back and forth between the two images.)
- **In Panel 2,** zoom in to the west coast of South America**, and have students describe the locations of the earthquakes they see at this level.** (They may say, "Some are right off the coast, but most are between the coast and the Andes mountains.") Have students read the panel text and look at the drawing showing a subduction zone.
- Ask **"How does the concept of a subduction zone help explain the pattern of earthquake activity you see?"** Encourage students to use the drawing (at right), which shows an oceanic plate diving beneath the continental plate, releasing energy all along an area from just off the coastline to where mountains and volcanoes have formed.
- **Be sure to have students** respond in writing **to the prompt "Why do so many earthquakes happen in western South America?" and to discuss subduction in their answer.** They will use these notes in their essay!

Background 2: Earthquake Magnitudes

Purpose

Help students understand that magnitude is an important measure of an earthquake's strength and destructiveness.

Big Ideas

- Earthquake magnitudes are expressed on a logarithmic scale rather than a linear scale, so the difference in energy between magnitude 5 and 6 earthquakes is **vastly greater** than that between magnitude 4 and 5 earthquakes.
- The **magnitude of past earthquakes** is important data to use in assessing risk in a given area.

Magnitude Matters

Magnitude	Earthquake Effects
1-2	Not felt by people
3	May feel like the vibration of a passing truck
4	Dishes, windows, doors shake; Walls creak
5	Many awakened; Some windows broken; Objects overturned
6	Furniture moves; Plaster may fall; Poorly built masonry walls may collapse; Well-built buildings ok
7	Poorly built buildings seriously damaged, walls & roofs fall; Well-built buildings ok
8 and higher	Walls, chimneys columns collapse in poorly built structures; well-built buildings damaged

Facilitation Suggestions

- **Ask** students to read the table of magnitudes with a partner and discuss the question: *How strong would an earthquake have to be to pose a risk where you live?*
- **Collect** students' answers (most will likely say 8.0 or higher, but some may say 7, or even lower) and ask them to explain why. Most likely they will say it's because "buildings are well-built where we live."

Background 3: Two More Earthquake Risk Factors

Purpose

Help students understand two additional factors that are important in assessing earthquake risk: the quality of infrastructure, and population density.

Big Ideas

Earthquake danger is **greatest** in places where lots of people live, surrounded by old and weak physical infrastructure—old buildings, roads, and bridges made of stone or concrete—that can fall and crush them.

Facilitation Suggestions

- Have students work in pairs and look at each of the six photos as they decide: *Is the risk of death from a strong earthquake in this area high, or low? And why?*

Infrastructure and Population Matter

Images: Wikimedia and Wikipedia

- **Collect** students' answers and ask them to explain their conclusions. Students may disagree about details, but in general the risks are (clockwise from upper left):
    - low (low population, grass-roofed buildings not likely to crush people);
    - high (dense population, old masonry buildings);
    - low (dense population, steel-reinforced buildings);
    - low (rural, unpopulated area);
    - low (new suburban development);
    - high (densely populated slum neighborhood with concrete buildings).
- If students are curious about where each location is, encourage them to click on the "**Show Data Source**" link.

TRANSITION TO DATA ORIENTATION

Remind students of the lesson task—to determine which South American city is at greatest risk of a devastating earthquake—and explain that in the next step of the lesson, the Data Orientation, they will be learning techniques for working with and analyzing earthquake, infrastructure, and population data.

DATA ORIENTATION

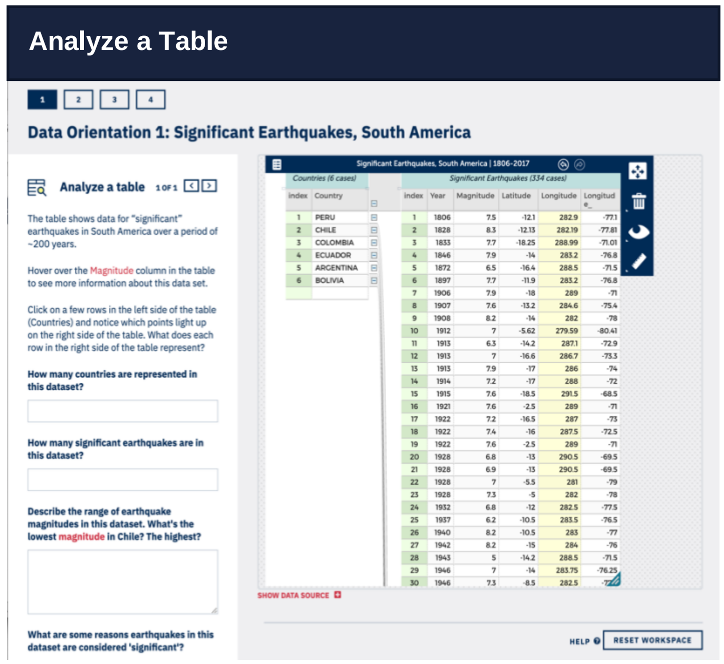
Estimated Time: 25 minutes

We recommend you continue to project the Data Orientation activities to the class, and guide students as they practice manipulating the data. As students complete each exercise, allow them to explore each data visualization, show them how to use CODAP to construct a graph, and discuss how using both the map and graph visualizations might help them identify areas of highest risk.

Data Orientation 1: Significant Earthquakes in South America

Purpose

Familiarize students with the NOAA Significant Earthquakes data set and the CODAP data table.



Big Ideas

Between 1806 and 2017, 334 significant earthquakes were recorded in six countries along the western coast of South America. An earthquake is considered significant if it meets one of the following criteria:

- Magnitude 7.5 or greater.
- Moderate damage recorded ($1 million or more)
- 10 or more deaths
- Generated a tsunami
- Some well-built wooden structures destroyed; most masonry and frame-built structures destroyed
- Large ground cracks, landslides from river banks and steep slopes, and/or shifts in sand and mud.

Facilitation Suggestions

- **Give students time to explore the data set by examining and interacting with the data table.** Encourage them to scroll through the table and click on a few rows on the left and right sides of the table to see the relationship. Use the questions to make sure students understand the table's structure and what data are available for each western South American country.
- **Point out that clicking Show Data Source will reveal more information about the data set.** Note that these data were compiled from many sources and the magnitudes listed were measured or calculated on varying, but roughly comparable, scales including moment magnitude, surface-wave magnitude, body-wave magnitude, and local magnitude. This could be an opportunity to discuss energy release during an earthquake, historical and current methods for measuring an earthquake's size, and the best uses for and limitations of each method.

- **Solicit students' ideas about why these data might be useful in answering the lesson question.** As students consider the criteria for "significant earthquakes," solicit their ideas about why these data can help them answer the lesson question. Ask *"Why might it be useful to look at significant earthquakes to identify South American cities at risk of damage and devastation from a strong earthquake? Why not look at all earthquakes, or only the very strongest?"*

Data Orientation 2: Mapping Earthquakes

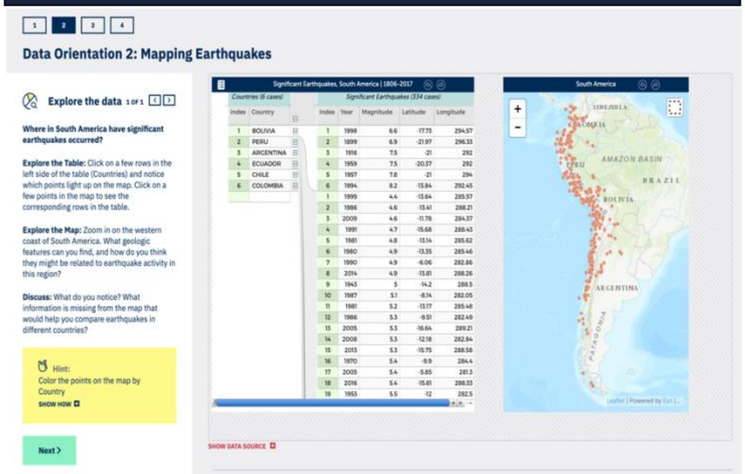
Purpose

Introduce the CODAP map, where students can examine the geographic distribution of significant earthquakes.

Big Ideas

The earthquakes in this data set occurred along the subduction zone between the Nazca and South American plates. The map provides a different way of visualizing the data, and allows you to look for geospatial patterns that would be very difficult or impossible to identify using the table alone. The map and table are linked, and the table can be used to modify the map display.

Explore the Data



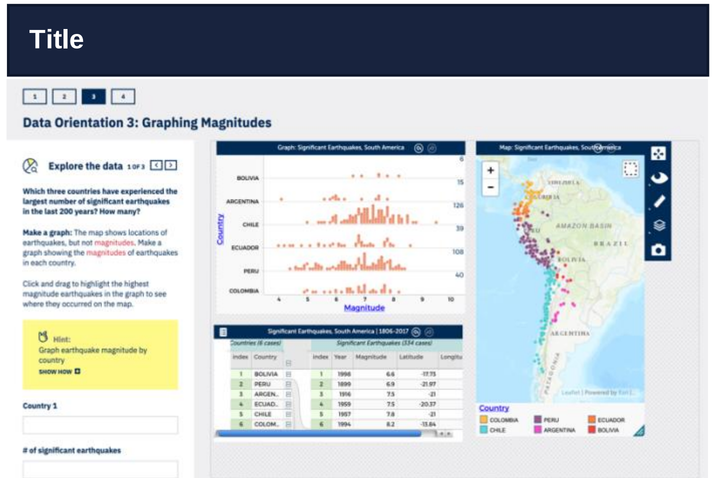
Facilitation Suggestions

- **Point out the connections between the map and the table.** Encourage students to click on both visualizations (points in the map, rows in the table) to see the corresponding data highlight in both displays.
- **Prompt students to use the table to modify the map display.** Encourage students to drag different column headers (e.g, "Magnitude") onto the center of the map. Demo: Drag "Country" onto the center of the map.
- **Discuss the patterns that students notice in the map.** As they explore the earthquake data in the map, prompt students to look for and share any patterns they find interesting or that could be related to risk in these countries. Ask *"Who would like to share a map that they created? What ideas do your maps give you about which countries might be more at risk?"*
- **Discuss the limitations of the map and the table for making comparisons among countries.** In addition to the patterns and ideas students share, gather their ideas about other ways they could visualize or analyze the data to make comparisons among countries. *Ask "What questions do your maps raise about the earthquake activity in each country? How do you think we could look at or use the data to answer them?"*

Data Orientation 3: Graphing Magnitudes

Purpose

Introduce the CODAP graph, where students can visualize and compare distributions and measures of center for earthquakes in each South American country.



Big Ideas

The graph can be used to visualize and compare distributions of earthquake magnitudes in each country. Graphs are created by dragging column headers to the x- and y-axes. The graph's analysis tools can be used to characterize and make quantitative observations about the data for each country. The table, map, and graph are linked, and the table can be used to modify the graph display.

Facilitation Suggestions

- Remind **students that "Hints" provide short demonstrations of important data moves.** In Panel 1, students are prompted to create a graph of Country versus Magnitude. The "Hint" demonstrates the process of dragging "Magnitude" onto the x axis and "Country onto the y axis. "Hints" are available in other parts of the lesson in case students forget or are unsure about how to use the data tools.
- Note the connections **between the table, map, and graph.** Encourage students to click on all three visualizations (rows in the table, points on the map, and points on the graph) to see the corresponding data highlight in all three displays.
- Point out **that the graph shows the total number of earthquakes in each country.** In Panel 1, if students are having trouble identifying the total number of earthquakes in each country, show that the totals are located on the right side of the graph.
- Discuss **different ways of comparing magnitude.** In Panel 2, consider as a class why using the median might be a good choice (versus mean, maximum/minimum values, or mode). Ask "How might we compare magnitude between these countries?" This also could be an opportunity to look at box-and-whisker plots (added using the Ruler Menu), which shows that Chile has two outliers.

Data Orientation 4: Assessing Earthquake Risk

Purpose

Remind students of the factors they will examine in the investigation and consider in their overall risk assessment.

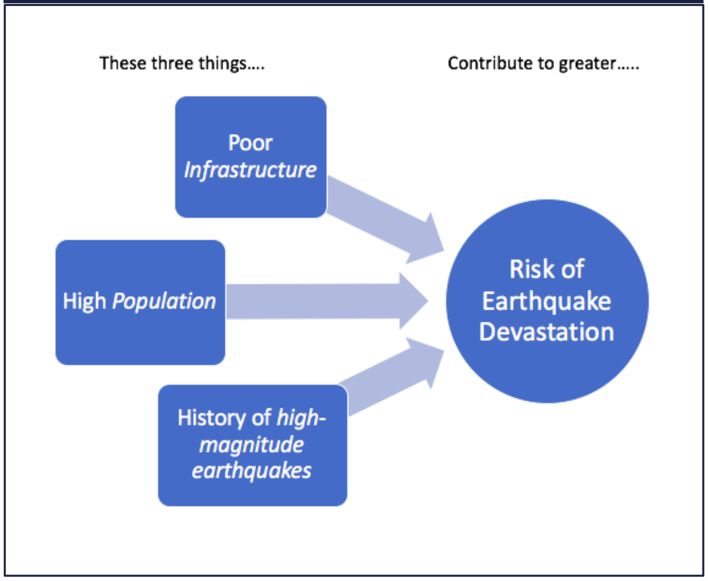
Big Ideas

Infrastructure, population levels, and historical frequency of strong earthquakes contribute to the overall risk of devastation from future earthquakes.

Facilitation Suggestions

- Discuss **other factors that may contribute to risk.** As a class, consider the limitations of this model and the other types of data or information that could help determine the relative risk in these locations (e.g., emergency preparedness, devastation from previous strong earthquakes, current areas of tension along the plate boundary)

Think About It`



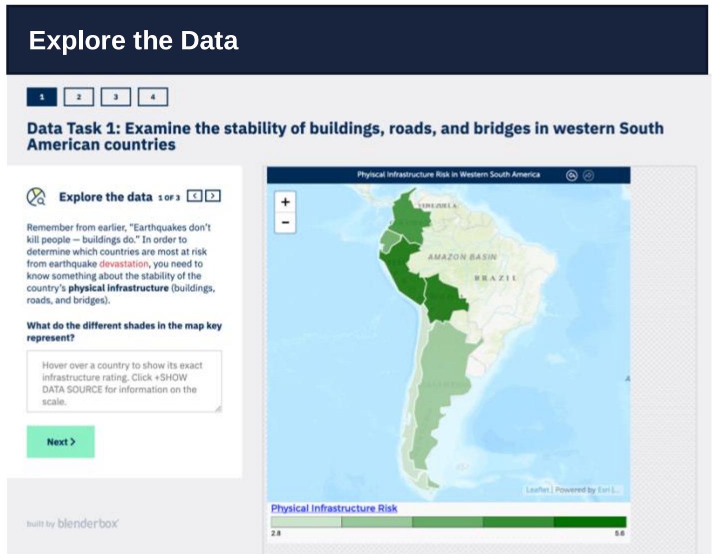
TRANSITION TO INVESTIGATION

Now that students are familiar with the visualization and analysis tools, they will continue to work with data on their own to answer the question, *"Which South American city is at greatest risk of damage and devastation from a significant earthquake?*

INVESTIGATION: Which City Is Most At Risk Of A Devastating Earthquake?

Estimated Time: 40 minutes

Data Task 1: Examine the Stability of Buildings, Roads, and Bridges in Western South American Countries



Purpose

Students identify the western South American countries that have the highest risk of failing infrastructure.

Big Ideas

- Because earthquake risk is greater in countries and cities where physical infrastructure is weak, identifying countries with poor infrastructure is an important part of assessing where risks are greatest.

Facilitation Suggestions

- Check with students **and make sure they click SHOW DATA SOURCE to read about the World Health Organization's Infrastructure Risk Index**.
- Remind **students that they can revisit the Data Orientation section** if they need a refresher on how to use the data tools.
- If students make mistakes with their maps and graphs and need to start over, or they just want to try something new, point out **the undo button at the top of the graph and the RESET GRAPH button at the bottom right corner of the browser window.**

Undo:

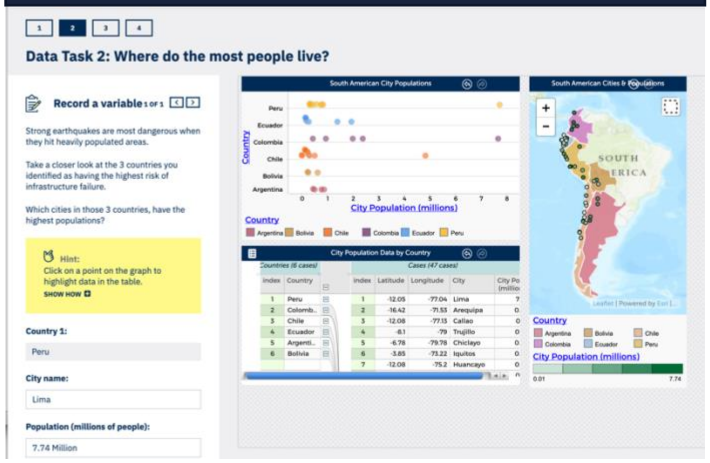
Start Over:

Data Task 2: Locate High-Population Cities

Purpose

Students identify the most populous city in each of the three countries they have identified as having relatively poor infrastructure.

Record a Variable



Big Ideas

Because earthquake risk is greater in highly populated areas, identifying the largest cities in countries that have weak infrastructure is useful in assessing where risks are greatest.

Facilitation Suggestions

Initially, students may not be aware that all three data windows display the same data set—the population of cities in western South America. Encourage them to click on different rows and points to see the correspondences.

If students are uncertain about what to do, suggest this sequence: (a) on the graph—locate one of their weak-infrastructure countries, and click on the city with the highest population; (b) in the table—note the name of the city, and what population it has (in millions). Students also may wish to look at the map to see where the city is relative to others.

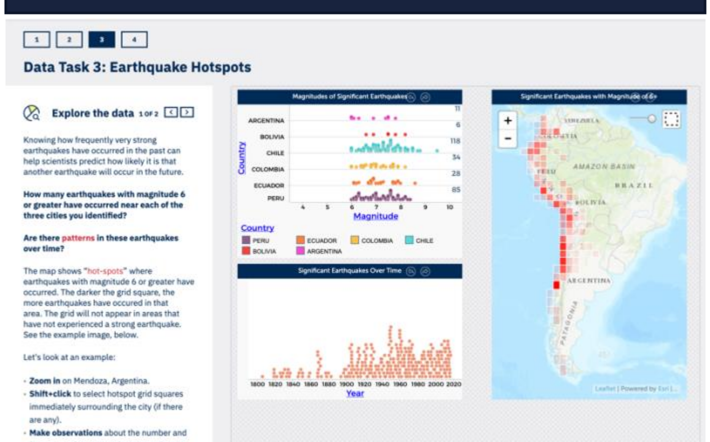
Remind students that they can move and resize any data display to see more or less of it. To move a display, click and drag the top bar; to resize a display, grab and drag the left, right, or lower edge..

Data Task 3: Earthquake Hotspots

Purpose

Students examine the frequency of strong earthquakes near the cities identified in Data Task 2.

Explore the Data



Big Ideas

Areas that have experienced frequent large earthquakes in the past may have a higher probability of experiencing one again in the future. Scientists use the average rate or frequency (occurrences over a set period of time) of these earthquakes to determine the probability of another earthquake.

Facilitation Suggestions

- **Remind students that they're now working with a subset of the full significant earthquake data set.** The analysis of earthquake frequency focuses only on strong (6.0–6.9), major (7.0–7.9), and great (over 8.0) earthquakes. If necessary, return to "Background: Magnitude Matters" for a refresher on why earthquakes of these magnitudes may pose the most risk of devastation in populated areas.
- **Help students consider how much area they should include in their analysis of frequency.** While an earthquake's magnitude remains the same, no matter how far away you are from the epicenter, the intensity, or how strong it feels, can vary based on your location. Ask *"How do you think the risk changes as an earthquake occurs farther from the city center? Should you examine the same size area for each of your three cities? Why or why not?"*
- **Point out that not all areas of the map have hotspot grid squares.** Students may be confused when they see areas without grid squares near their city, and may be unsure of what to select. Remind them that these areas have not experienced strong earthquakes since 1806 and to select only those squares that they consider to be immediately surrounding their city. For example, the image to the image to the right shows areas that might be selected for La Rioja, Argentina.
- **Make sure students are able to find the total number of earthquakes in their selected areas.** If students are having trouble, point out that there are two ways students can find the total number of strong earthquakes: (1) hovering over each selected grid square to reveal the number of "cases" or earthquakes in that square, then adding the numbers for each square to find the total; or (2) counting the number of highlighted points in the graph when all of the squares in their chosen area are selected.

Data Task 4: Summarizing the Results

Purpose

Students identify the city they think is most at risk, based on the physical infrastructure, population, and frequency data they collected.

Big Ideas

- An area's earthquake risk is determined by both the likelihood that a strong earthquake will occur there in the future and by the damage such an earthquake is likely to cause to humans.
- It also is informed by the historical frequency of strong earthquakes.

Facilitation Suggestions

Encourage students to make an argument for their choice relative to their other candidate cities. As students identify the city they think is most at risk, prompt them to justify their choice using data and by making comparisons to the other cities they analyzed.

TRANSITION TO WRITING

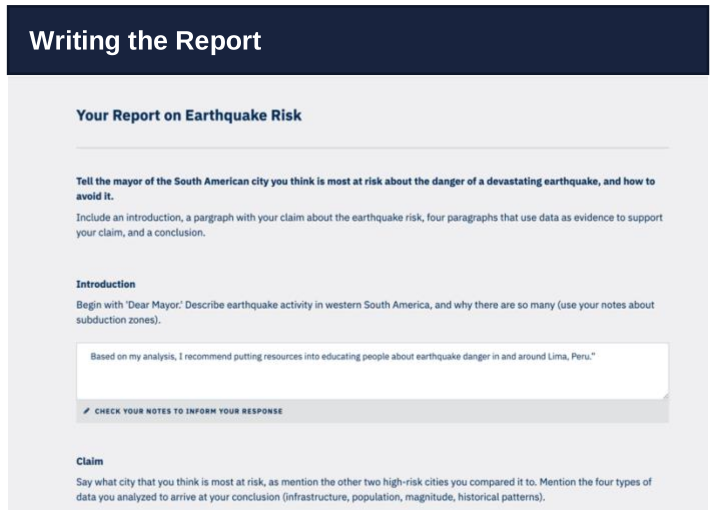
Explain that students will now be reviewing their notes and completing a structured writing exercise to present their answer to the lesson question.

WRITING TASK: WHERE WILL THE NEXT DEVASTATING EARTHQUAKE HIT?

Estimated Time: 30 minutes

Purpose

Students synthesize what they have learned by answering the lesson question in the form of a memo to the mayor of the city they have determined is most at risk of a devastating earthquake.



Big Ideas

- Students can learn skills of effective scientific communication by making an evidence-based claim and supporting it with data.
- Beyond simply citing data, students can be asked to explain what the data mean—an important skill, and a step they often leave out.
- Communicating in the form of a fictitious memo to a city official can help reinforce the need for clear science writing, bullet points as text, sentence case with.

Facilitation Suggestions

- Tell students **they will write a memo to the mayor of the city they think is most at risk of a devastating earthquake, giving their analysis and recommendations for what to do**.
- **Preview the "Writing" page and the outline that students will follow.**

  1. *Intro Paragraph*—Begins with "Dear Mayor," and explains why so many earthquakes happen in western South America. (Students will need to use their notes about subduction zones from the "Background" section.)
  2. *Claim Paragraph*—Identifies the city most at risk, as well as the other two high-risk cities examined. Identifies the four types of data that were analyzed (infrastructure, population, magnitude, historical patterns).
  3. *Evidence and Reasoning Paragraphs*—Four short paragraphs presenting data that support the claim: one each on infrastructure, population, magnitude, and historical earthquake patterns. Each evidence paragraph should explain how the evidence supports the claim, and should include
     - a summary sentence;
     - a sentence citing data and making a comparison to the other high-risk cities;
     - an explanation of what the data point means ("This means that…" statement).

4. *Conclusion Paragraph*—Restates the claim about the mayor's city being most at risk. Recommends one or two things that the mayor and the city can do to reduce the risk of death and injury, based on the analysis (e.g., educate people, improve buildings, roads, and bridges, spread medical clinics around the city). Explains what the result of these adjustments might be.

Sample Essay

Dear Mayor,

As you probably know, a lot of earthquakes happen along the western side of South America. This is because the area is a subduction zone. That means that one of the Earth's tectonic plates is sliding underneath another plate. This releases energy in the form of earthquakes.

Based on my data analyses, I have determined that your city, Lima, is the area most at risk of a devastating earthquake. I compared Lima to two other high-risk areas: Cochabamba, Bolivia, and Bogota, Columbia. I looked at four kinds of data—physical infrastructure, population, earthquake magnitudes, and earthquakes over time.

First, the physical infrastructure is not very good in Peru. With a rating of 4.9, the buildings are better than in Bolivia, but worse than those in Columbia. The weak buildings mean that more people will be hurt in a collapse.

Second, Lima, at 7.74 million people, has a bigger population than the other two cities. This means that more people are in danger overall than in the other two cities.

Third, more earthquakes over magnitude 6 have happened near Lima than have happened near the other cities. Earthquakes of magnitude 6 or higher can cause buildings that are not well built to fall, injuring or killing people.

Finally, the strong earthquakes near Lima follow a historical pattern—they seem to happen every ten years or so. I don't see any patterns in the other cities. This means we have more reason to expect a strong earthquake will happen within ten years or so in Lima than in other areas.

In conclusion, your city is more at risk of a devastating earthquake than other areas in South America. Because of this I recommend that you inform people of the danger, and work to strengthen the physical infrastructure—the buildings, roads and bridges—in your area. By doing this you can avoid a large loss of life if, and when, the next big earthquake strikes your area.

I wish you the best of luck.

Sincerely,

Assessment

Look for the following when evaluating students' writing tasks.

INTRO PARAGRAPH

- ❑ Begins with "Dear Mayor"
- ❑ Explains that many earthquakes happen in western South America because it is a subduction zone
- ❑ Defines a subduction zone in terms of tectonic plate movement and energy release

CLAIM PARAGRAPH

- ❑ Identifies the city determined to be most at risk
- ❑ Identifies the other two high-risk cities examined
- ❑ Identifies the four types of data that were analyzed—infrastructure, population, magnitude, historical patterns

EVIDENCE AND REASONING PARAGRAPHS

- ❑ There should be 4 paragraphs — on infrastructure, population, magnitude, and historical patterns
- ❑ Each paragraph should present the numerical evidence *and* explain how it supports the claim. For example by including:
  - A summary sentence
  - A sentence citing data and making a comparison to the other high-risk cities
  - An explanation of what the data point means (e.g., "This means that…")

CONCLUSION PARAGRAPH

- ❑ Restates the claim about the mayor's city being most at risk
- ❑ Recommends one or two things that the mayor and the city can do to reduce the risk of death and injury
- ❑ Explains what the result of these efforts might be