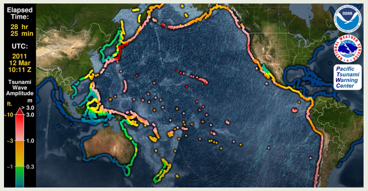
LESSON 3: What causes a tsunami to form and move?

PREVIOUS LESSON *We investigated patterns in the location and causes of tsunamis and figured out that most tsunamis are caused by strong, shallow earthquakes on colliding plate boundaries. We use this data to predict the location of where damaging tsunamis may occur in the future.*

THIS LESSON

INVESTIGATION

3 days



We analyze four different wave models to help us make sense of the causes of an earthquake-driven tsunami from different perspectives and identify the limitations of those models. We identify sources of data we would need to predict, warn, and protect people from future tsunamis.

NEXT LESSON *We will revisit the DQB and document responses to questions we are now able to answer. We will use data to construct an explanation to describe the related geologic forces that cause a tsunami to form and will also forecast impact for communities at risk. We will consider what can be done to protect communities from the effects of a tsunami.*

BUILDING TOWARD NGSS

MS-ESS3-2, MS-ETS1-1, MS-ETS1-2

WHAT STUDENTS WILL DO

3.A Analyze and interpret video data from different wave models to identify how changes (patterns) in the profile of the shore and ocean floor cause changes in the height of a wave (amplitude).

3.B Evaluate different wave models, identifying limitations and benefits in what each shows for explaining how tsunamis form (causes), move, and what happens when tsunamis reach the shore (effect).

WHAT STUDENTS WILL FIGURE OUT

- Waves move out in all directions from a disturbance in a ripple or circular manner.
- As waves move and interact with other waves or land, they transfer energy and switch directions. As this continues to happen, waves get smaller and smaller due to loss of energy that has been transferred to surroundings.
- When a wave approaches shore, it gets taller until it reaches the shore, where it collapses and flows onto the shore.
- The bigger the wave is when it reaches shore, the further onto the land the water will flow.

Lesson 3 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	3 min	**NAVIGATION** Brainstorm ideas for how an earthquake under the ocean can result in a tsunami.	A	
2	10 min	**FOIL PAN DEMONSTRATION** Watch how water behaves in a pan when the bottom of the pan is moved abruptly.	B	https://www.teachersopensciedfieldtest.org/tsunami, computer, projector
3	12 min	**MAP THE MODEL IN DEMO TO THE REAL WORLD** Use a mapping tool to analyze how parts of the demonstration could represent similar parts in the real world.	C	*Mapping the ___________ to the real world phenomenon: _________*, computer, projector
4	15 min	**ANALYZE NOAA TSUNAMI DATA** Watch a computer-generated model based on data collected about the Japan tsunami to see how the water in the Pacific Ocean behaves.	D	https://www.teachersopensciedfieldtest.org/tsunami, computer, projector
5	5 min	**NAVIGATION** Reflect on what has been figured out so far about how water behaves when disturbed from below.		
				End of day 1
6	5 min	**NAVIGATION** Reflect on what we know so far about how an earthquake causes a tsunami and what we still want to figure out.	E	*Mapping the ___________ to the real world phenomenon: _________*
7	8 min	**MINI WAVE TANK** Watch how water moves in a mini wave tank where the depth changes.	F-G	https://www.teachersopensciedfieldtest.org/tsunami, computer, projector
8	12 min	**MAPPING PARTS OF THE MODEL TO THE REAL WORLD PHENOMENON** Use the mapping tool to evaluate the appropriateness of the mini wave tank model for representing the real world.	H	*Mapping the ___________ to the real world phenomenon: _________*
9	20 min	**COMPUTER VISUALIZATION OF A TSUNAMI WAVE** Watch a computer-generated model that visualizes data showing how the water behaves after an earthquake occurs underneath the ocean.	I	https://www.youtube.com/watch?v=SlwZzbGh7Cw, computer, projector
				End of day 2
10	5 min	**NAVIGATION** Brainstorm with a partner how the four wave models can help us explain how a tsunami forms.	J	

Part	Duration	Summary	Slide	Materials
11	25 min	**REFLECT ON THE LIMITATIONS AND BENEFITS OF DIFFERENT MODELS** Use our observations and mapping tool to analyze the benefits and limitations of each model.	K	completed *Mapping the ___________ to the real world phenomenon: _________*, "Comparing different wave models" poster set up ahead of time to be completed with the class
12	10 min	**PUTTING THE PIECES TOGETHER** Use what we have seen in the four different models and what we have mapped to explain how an earthquake causes a tsunami.	L	
13	5 min	**NAVIGATION** Using the key pieces of data for tsunami hazards, brainstorm whether these would also apply to other hazards on the related phenomenon poster.	M	

End of day 3

Lesson 3 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Mapping the ___________ to the real world phenomenon: _________* • completed *Mapping the ___________ to the real world phenomenon: _________*		• https://www.teachersopensciedfieldtest.org/tsunami • computer • projector • https://www.youtube.com/watch?v=SlwZzbGh7Cw • “Comparing different wave models” poster set up ahead of time to be completed with the class

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Students will need two copies of *Mapping the ___________ to the real world phenomenon: _________*.

Be sure you have materials ready to add the following words to the Word Wall: amplitude and epicenter. Do not post this/these word(s) on the wall until after your class has developed a shared understanding of its/their meaning.

For day 2, one per class: “Comparing Different Wave Models” poster set up ahead of time to be completed with the class. For day 3, have chart paper available.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

In the previous lesson, students figured out that certain types of earthquakes result in tsunamis. Now, we want to figure out how this happens. We will use four different wave models to develop a conceptual model of what happens to a wave when it reaches shore. Using this conceptual model, we figure out that a tsunami will cause large damage to a community if the wave is really big, moving pretty fast, and developed in close proximity to that community. We end this lesson by identifying key data that one would need to determine how to detect future tsunamis, such as how strong the earthquake is, how far from shore the earthquake happens, and how fast the wave is moving. We consider generalizing these types of data (how big the event is that causes the hazard, how fast the hazard is happening, and how far from a community the hazard is occurring) to think whether they could help protect communities from other types of hazards. Students will use these key ideas in future lessons to think about how to forecast or predict when a community could be in danger from a natural hazard.

Where We Are NOT Going

Though we analyze what happens when waves interact with one another and notice that their energy seems to change when doing so, we only make sense of what happens when waves interact with and reflect off other matter, like the shore or the ocean floor. Beyond recognizing that waves reflect off objects, we will not be figuring out additional properties of waves, such as the superposition of wave interference, as these are above grade band.

LEARNING PLAN for LESSON 3

1 · NAVIGATION

3 min

MATERIALS: None

Display **slide A** and ask students to brainstorm with a partner possible reasons for why a tsunami can result from an earthquake. Say, *Last class, we figured out that a major cause of tsunamis are earthquakes that happen under the ocean. Turn and talk to an elbow partner about the questions on the slide.*

- How can an earthquake under the ocean cause a tsunami?

Ask a few partners to share their ideas from last class and support students in recalling what they learned about earthquakes in *OpenSciEd Unit 6.4: How and why does Earth's surface change? (Everest Unit)*.

Suggested prompt	Sample student response
In our last lesson, we revisited the world map we used during our Everest Unit and reminded ourselves where earthquakes occur around the world. What did we figure out about what causes earthquakes?	*We learned that earthquakes happen when plates interact at their boundaries.* *We figured out that when plates move towards each other and they collide, tension builds up until one plate moves over or past another plate.* *And in our last lesson when we looked at the plate boundaries map we saw earthquakes happen where plates are colliding and where they are spreading apart.*
Right, we saw that there are many different plates on Earth's surface and they are all moving. We saw that in some places, they run into each other and one plate goes under another plate, and in some places they are moving apart. What are some ways in which the land can be affected when there is an earthquake?	*When there are earthquakes, the ground shakes.* *Yeah... and sometimes tsunamis happen which can flood the land.* *And last class we saw that on one of the maps that landslides can happen when earthquakes occur.*
Do earthquakes under the ocean always result in a tsunami?	*No, we figured out earthquakes that are strong and shallow can cause a tsunami.* *For a tsunami to occur, the plates at the earthquake's location have to move towards each other and collide.*

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

Over the course of this lesson, students will be analyzing four different models of waves to figure out how they form and move. Each of the models is limited in what it can represent. On the last day of the lesson, as a class, students use what they have figured out from each model to reflect on the limitations and benefits from each model in helping them figure out how a tsunami forms and moves.

Suggested prompt	Sample student response
Which types of these earthquakes are likely to cause tsunamis? Which types of these earthquakes are less likely to cause a tsunami? What did we figure out from the maps we analyzed last class?	*We figured out that earthquakes that are strong and shallow are the types that can cause a tsunami.* *Yeah...and we figured out that the plates have to collide.* *Earthquakes that happen under the ocean that are weaker or deeper under the surface don't lead to tsunamis.* *And we figured out that if the earthquake happens and if the plates move apart or past each other, there is less of a chance of a tsunami too.*

Say, *Now that we have more information about what types of earthquakes can cause a tsunami, let's see if we can figure out how this happens. In our Everest Unit we were more focused on what happened to the land when plates moved and an earthquake was sometimes a result of that. Now let's think about how the water in the ocean is affected when an earthquake occurs. We will be analyzing four different models of waves to see what we can figure out about how tsunami waves form and move.*

Let's begin by thinking about our experiences with water. Think about a time in which you played with a large amount of water, like in a bathtub, sink, pool, or lake. If the water is calm and not moving, and then something happens to move the water, like a rock being thrown into the water, soap falling into the bathtub, or a dish is put into a kitchen sink of water, what are some things you remember observing about the water? What does the water do? How does the water move?

Accept all students' reflections from what they remember seeing happen, but listen for these ideas to be shared:

- How the water begins moving back and forth within the container when something disturbs it, or it slides sideways across a surface.
- If something drops in a tub of water, there are little waves that move away from the spot where the item was dropped.
- If something moves through the water, the water moves with it and seems to bunch up around the item. When the item stops, the water keeps moving back and forth.
- If I jump in a puddle, it splatters all over, away from the spot in which I jumped.

Say, *All of these ideas are about something disturbing, or making the water move, from above or from the side, but the tsunami waves we are investigating happened because of an earthquake that occurred on the ocean floor below the water. Thinking back to the examples we shared, now imagine what would happen if instead of the water being disturbed (or moved) by something entering the water from above or the side, you could move a spot on the bottom of a container (i.e., tub or sink) or body of water (i.e., lake, ocean, puddle) to mimic the motion caused by an earthquake. What do you predict you would see happen to the water? How would the water move?*

2 · FOIL PAN DEMONSTRATION

10 min

MATERIALS: science notebook, https://www.teachersopensciedfieldtest.org/tsunami, computer, projector

Display **slide B.** Say, *Let's begin by making some observations of how water behaves when the surface that is below it is disturbed. This will be the first of four different models we will analyze so we can figure out how waves form and move. In the first video there is a large foil pan that is filled with water. The pan is set on top of two bricks, so that the bottom is exposed and can be accessed from below. We will watch the video twice to make observations of what is happening to the pan and then to the water. Before we watch, let's set up a page in our science notebook to record our noticings and wonderings. Leave the top title line blank for now. Let's come back and decide as a class what we want to title this page after we have made some observations.*

Project https://www.teachersopensciedfieldtest.org/tsunami for the class. Watch the video at least two times. After watching the video the first time, have students record their noticings and wonderings while watching it a second time. They may ask to watch it more than twice.

✱ ATTENDING TO EQUITY

Support for Universal Design for Learning: As students share and hear one another's observations from this video demonstration or respond to your questions, they may ask to watch the video again. Be prepared to show the video to ensure all students have a

ALTERNATE ACTIVITY

If you have the time and the supplies (an extra large disposable foil roasting pan, two bricks or books, and water), you could choose to demonstrate this live in your classroom. Place a large disposable foil roasting pan on top of two items, such as bricks, or thick books, so that you can access the pan from underneath and it won't be moved around. Fill the pan ¼ full with water. After the water has become calm and isn't moving anymore from being poured into the pan, you are ready to simulate the earthquake. Use a solid thin object, such as a metal butter knife or handle of a large metal spoon, to push up slowly on the bottom of the pan in one spot. Hold this for a few seconds until the water stops moving. Then release this quickly to simulate the earthquake and watch what happens to the water. It can be helpful to have a student capture a slow motion video of this as you demonstrate it so students can watch what happens to the water multiple times.

Share out observations to begin making sense of how and why the water behaves as it does when disturbed by the movement of the surface under the water.

Suggested prompt	Sample student response
What were some of the things you noticed in the demonstration? What happened when the bottom of the pan was moved?	*When the pan moved up, the water seemed to move out of the way from the space where the pan moved up. Then when the pan moved back down in place, the water moved back towards the center.*
What did you notice the water do as it moved away from the part of the pan that was moved?	*It moved in circles away from that spot until it reached the edge of the pan. Then it seemed to bounce off the side of the pan, or reflect off in a different direction.*
How do you think the wave's energy compared before and after it hit the wall of the container? How do you know?	*There was less energy after it hit the wall of the container. I am not sure, but it did seem like the waves become smaller over time, so maybe some of the energy was transferred to the pan.* *I think some is transferred to the wall.*
How might the movement of the water differ if the bottom of the pan was moved in a different way, such as shaken in a side to side motion?	*The water would still move, but maybe in more of a side to side movement too, instead of up and down.*

Tell students, *These observations of the waves getting smaller over time and the possibility that it could be that the waves are transferring energy to the wall of the pan, is an important property of waves. When waves reflect off of an object, some of their energy is transferred onto that object. As you analyze the next three models, watch for how waves may be transferring energy to other objects it collides with and watch what happens to the waves and to the objects it collides with. These ideas might help us as we are trying to figure out more about tsunami waves and how they move.*

ADDITIONAL GUIDANCE

The purpose of using *Mapping the ___________ to the real world phenomenon: _________* with students is to support them in making connections between the real world phenomenon being investigated and any simulations (models, investigations or demonstrations) used in the classroom. Many times when a simulation of a real world phenomenon is used with students, they may struggle to connect the representation or model that is used in the classroom with the real world phenomenon. This mapping tool is an analogical tool that provides the space for students to consider the different parts or components of the simulations and link them to their analog in the real world phenomenon.

common understanding of the phenomenon. For some students, the task of watching and recording observations can be challenging, so offering students the opportunity to view the video again supports *engagement* by providing a new purpose for rewatching it as they will be focused on observing specific elements.

In this lesson, there will be three other video clips to watch and make sense of, so this strategy will be useful for these video clips as well.

Say, *Remember, we are trying to figure out how an earthquake can cause a tsunami. Is there anything we saw that might help us in our quest to figure this out?*

Some responses you might hear from students:

- Not really, because tsunamis are really big and this pan is so small.
- Kind of. It helps us see how water moves away, and is reflected from a disturbance in the surface under it.
- It helps a little bit to see what happens when the surface under the water moves.
- There isn't a beach or shore, so it is hard to see what happens when waves get near the shore.

Tell the students they are going to use a mapping tool as a class to identify the relationships between the components in the demonstration and what they represent in the real world.

3 · MAP THE MODEL IN DEMO TO THE REAL WORLD

12 min

MATERIALS: science notebook, *Mapping the ___________ to the real world phenomenon: _________*, computer, projector

Map model of the demonstration to the real world event (earthquake-driven tsunami) from a top view. Hand out *Mapping the ___________ to the real world phenomenon: _________* to each student. Display **slide C.** Facilitate a discussion to decide how to map the different parts of the demonstration to the real world. Tell students not to tape this in their notebooks at this time. Remind students they used a similar mapping tool in *Everest Unit* to consider how the convection demo helped us better understand what was happening in the mantle of the earth. Talk through the different columns and what we will be recording in each box. As you facilitate this discussion, it will be helpful to be able to record what the class agrees upon. Use the projection of **slide C** onto a whiteboard and record into the different cells what the class agrees upon.

ADDITIONAL GUIDANCE

If you cannot project the slide onto a whiteboard, but you have a document camera, you can print off an extra copy of the handout and fill it in as students share. If neither of these options are available, this table could be replicated onto poster paper. It will be important to record what the class agrees on in a public way. In addition, students will need to have a record of this on *Mapping the ___________ to the real world phenomenon: _________* so they can refer to it on Day 3 when the class compares the four different wave models. The lesson is written having you project this to record what the class agrees upon because transferring this to poster paper may be challenging with how many columns are needed. Yet, you may wish to have a hard copy record of what each class agreed upon and therefore may wish to make a poster for this, or use a copy under a doc camera to record each class's ideas.

As a class, record what demonstration is being mapped to what phenomenon. For example:
Mapping the __foil pan demo_ to the real world event: ___earthquake-generated tsunami_

Complete the first row as a class. Begin by filling in "the ocean" in the first box under "is like this feature in the real world." **Tell students that they will need this mapping tool later, so they should be sure to fill it in, either as the class comes to agreement on what to include and/or in their own words, to capture how the model compares to the tsunami.** Then ask, *What in the foil pan demo represents the ocean?* Students should say the water in the pan. Next, ask why the water in the pan is like the ocean and why it isn't like the ocean. Fill in the last two boxes. Do one more row together as a class. Fill in "the ocean floor" in the next row under "is like this feature in the real world." Ask, *What in the demonstration represents the ocean floor?* Students should say the bottom of the pan. Fill in the last two boxes together as a class.

Now, ask the students to turn and talk with an elbow partner about what other elements they should add to the mapping tool. Say, *What other elements or things that you saw happen in the pan could represent what is going on in the real world? Take a couple of minutes with a partner and fill in the next couple of rows.*

ASSESSMENT OPPORTUNITY	**Building towards: 3.A** Analyze and interpret video data from different wave models to identify how changes (patterns) in the profile of the shore and ocean floor cause changes in the height of a wave (amplitude). **What to look for**: Students will be analyzing four different wave models over the course of the unit. After using each model, the class will pause and share what has been figured out about waves and tsunamis. After analyzing **this first model**, listen for students to identify the following key ideas about how waves form and move: • The up and down motion of the pan (or land) causes the water above it to move, causing large waves to form. • These waves move out from the location where the bottom of the pan is disturbed (moved). • The water forms a wave above the spot where the bottom of the pan is moved. These waves move out in all directions until they reach the edge of the pan. • At the edge of the pan, the waves collide with the pan and then reflect back away from the wall. • The waves getting smaller over time. Waves may be transferring energy to the wall of the pan. **What to do**: Students analyze this model through watching a video. Some students may struggle with recording observations while watching. Make these videos available to students to watch on their own outside of class multiple times, so that they have enough time to make sense of what they are observing, and find patterns of cause and effect to explain how a tsunami forms and moves. Another option, if the technology is available in your classroom, is to watch the video as a class once together, and then have students play it again in small groups to make their observations. In addition to these ideas, if time is available and you have the materials, this can be done as a live demonstration where students would gather around and make their observations. In this case, the demonstration could be done multiple times.

Ask for volunteers to share and add to the class table.

Note: Though there are only so many rows included on the handout, encourage students to add in more rows on their own if there are other elements they want to map to between the demo and the tsunami wave. In addition, as the class shares and you record what they agree on, do not feel limited by the number of rows on the handout if there are more elements than rows that students identify.

An example of how the table might look filled in can be found below:

This part in our model...	is like this feature in the real world...	because	..and not like it because..
the water in the pan	the ocean	a large amount of water uninterrupted water	it is way too small not to scale it is way less water than in the ocean
the bottom of the foil pan	the ocean floor	it is solid like the land	too thin and too flexible the ocean isn't contained in foil and it is MUCH smaller

the bottom of the pan moving	when an earthquake happens under the ocean as a result of the plates moving the plates under the ocean	the bottom of the pan moves up and then down	in an earthquake, the land is broken apart, not one piece and bendy the pan moves up and down, but is still whole, where as the land breaks or collides at the plate boundaries where the earthquake happens
the movement of the water after the bottom of the pan is moved	how the ocean water moves after an earthquake occurs waves radiating out (and waves bouncing off the edge and each other)	when the water is disturbed, it moves away from this in a wave-like ripple pattern	the waves stop much quicker and do not get as large the pan is smooth on the bottom and the ocean is different depths and bumpier

Ask students, *Okay, thinking about the tsunami video we saw and the demo we just analyzed, do you feel this helps you figure out anything about how an earthquake can generate a tsunami? Did mapping the different parts of the foil pan demonstration help us explain any aspects of the tsunami?*
Students should suggest:

- We have some ideas about how the water and waves behave after an earthquake happens.
- We still don't know how this becomes a tsunami, but we now know the wave starts where the earthquake happens.

Say, *Would you say this is an appropriate and useful model to use as we try to figure out aspects of the tsunami?* Students should suggest something like:

- This model is only somewhat helpful because it is missing parts of the tsunami in the ocean, like the shore and it is way too small compared to the ocean.

Ask students, *Okay, if you could redesign this investigation, what other elements would you want to include to help us in our figuring out?*

Students should suggest:

- We would want to see what happens to the wave when it moves around the ocean (to deeper or shallower areas).
- The water in the pan is all the same depth, but in the ocean it is deeper in some parts and more shallow in other parts and there are islands and other things in the ocean that weren't included in the demo.
- The beach or shore is missing.

4 · ANALYZE NOAA TSUNAMI DATA

15 min

MATERIALS: science notebook, https://www.teachersopensciedfieldtest.org/tsunami, computer, projector

Introduce a new computational visualization. Display **slide D.** Tell students, *I have another model to share with you. This is a computer visualization model created by scientists at the NOAA (National Oceanic and Atmospheric Administration) using data collected of the tsunami we investigated in lesson 1. We will watch this video a few times. We will use the same Notice and Wonder chart to record our observations. To help us keep track of which video our noticings are from, let's draw a horizontal line under what we have recorded so far. As you watch this next video clip, record your new noticings and wonderings underneath this line in the t-chart. Also, let's label the top section of this t-chart in the left margin "Foil Pan Wave Demo." Then under the horizontal line, title this section "NOAA Tsunami Data."* See the slide for an example.

Project https://www.teachersopensciedfieldtest.org/tsunami . The first time through the video, encourage students to watch it and make initial observations on their chart.✱

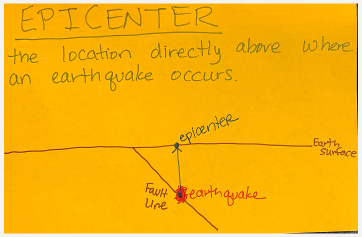
✱ ATTENDING TO EQUITY

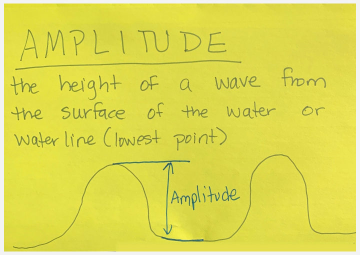
Support for Universal Design for Learning: The visualization students will be watching is somewhat complicated. It will be important to take time to help them make sense of what the different keys are in the video and what the different colors *represent*. After watching this video once through, watch the

After watching the video clip **the first time**, pause and as a class make sense of the data that is being represented in the video clip. Use the suggestion prompts below for ideas on questions to guide this sensemaking. As you work as a class to make sense of all that is represented here, it can be helpful to have volunteers come up and point out what they are explaining or referring to in the computer model.

Suggested prompt	Sample student response
What part of the world is represented in the video?	*We can see different countries and all of the Pacific Ocean.*
The colored key on the side says, "Tsunami Wave Amplitude." Does anyone know what amplitude means?	*How tall a wave is.* *The height of a wave from the surface of the water, or waterline (lowest point).*
There is also a counter on the top left that says, "Elapsed Time." What do you think this means?	*This shows how much time passes on the video.*
Did anyone notice how much time passed in the visualization?	*Over a day.* *Like 35 hours or so.*
Over the 35 hours, what can we summarize happened during this time?	*It took the wave that long to move across the ocean!* *The wave started near Japan, and it looked like it kept moving across the ocean until it collided with something else, like an island or something. Then it would reflect off of that island and keep moving.*
So what is happening right at the beginning of the video?	*The earthquake that happened near Japan caused the tsunami.*
And then what happens?	*We see the way the water, or waves, move from that spot where the earthquake happens. And they move out across the ocean.*

Watch the visualization a second time. Say, *Let's watch this one more time. Pay close attention to what is happening to the water or waves from right when the earthquake happens to 35 hours or so later. This time when you watch the visualization, watch how the water waves move from the epicenter as they spread across the Pacific Ocean. Epicenter is the name scientists use to refer to the spot on the surface of the crust directly above where the plates move, causing an earthquake to occur. Let's be sure to add this word, epicenter to our word wall.*





Add "amplitude" and "epicenter" to the Word Wall.

visualization an additional time and pause it periodically to allow students to make sense of the visualization. It can be helpful to have students come up and point out different things they noticed and what they represent. For example, someone might notice the colorful bar on the left side of the video that has numbers and is titled Tsunami Amplitude. Ask this student to come up and point to this colorful bar so that everyone in the class understands what is being referred to.

ADDITIONAL GUIDANCE	In this section you are adding two words to the Word Wall. The first word, amplitude, is a term students should have learned in Grade 4, 4-PS4-1: Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks). This term will be helpful for referring to the height of waves that are formed by earthquakes. The second word, epicenter, is a word that students encounter when making sense of the computer model to describe the location where the earthquake occurs that causes waves to travel away from that point in all directions. Since they may refer to the word again, it might be helpful to post on the Word Wall.

After watching the second time, use the prompts below to support students in making additional connections between what is seen in this visualization and what happens when a tsunami occurs.

ASSESSMENT OPPORTUNITY

3.A.1 Analyze and interpret video data from different wave models to identify how changes (patterns) in the profile of the shore and ocean floor cause changes in the height of a wave (amplitude).

What to look for: Students will be analyzing four different wave models over the course of the unit. After using each model, the class will pause and share what has been figured out about waves and tsunamis. After analyzing this second model, listen for them to identify the following key ideas about how waves form and move:

- These waves move out from the location where the plates move and collide with one another (epicenter) in all directions.
- The amplitude (or height) of the waves that are further out in the ocean don't seem to be as big as the ones that reach the shore.
- As the waves move toward the shore where the land is shallower, the amplitude changes (based on the color scale in the model).
- Waves reflect off of (or bounce off of) other things they collide with in the ocean like shorelines and islands.

What to do: Students use videos of two physical models and two computer visualizations to observe and analyze various wave behaviors. This second visualization is rather complicated with the amount of different measurements being represented. Some students may struggle with recording observations while watching. Make these videos available to students to watch on their own outside of class multiple times, so that they have enough time to make sense of what they are observing, and find patterns of cause and effect to explain how a tsunami forms and moves. Another option if the technology is available in your classroom is to watch the video as a class once together and then have students play it again in small groups to make their observations.

Suggested prompt	Sample student response
Some of you thought you had seen that the wave generated by the earthquake near Japan moved across the whole Pacific. After watching a second time, did the waves make it across the whole ocean?	*Yes!* *I saw it reach the west coast of the United States and even down near the Andes in South America!*

Suggested prompt	Sample student response
We know from earlier lessons that this wave reached Japan very quickly. Did anyone notice how long it took for waves to reach the west coast of the US?	*It looked like between 9 and 10 hours later!*
Do you think these waves would be considered fast or slow moving waves? Why?	*Fast, because they reached the west coast of the United States only hours later and this is pretty far away!* *These must be fast-moving waves. They reached the shore of Japan very quickly and moved across the whole ocean in a little over a day!*
We noticed there are different colors that showed up along the shores all around the Pacific. What do these different colors represent again?	*The different colors show the amplitude or how tall the waves are when they reach the shore.*
What are some things you noticed about the amplitudes of the waves that reach the different shores?	*Well… the darker red, or taller waves, are closer to where the earthquake occurred, but there are still pretty big waves even across the ocean on the shore of the west coast or South America.* *It looked like the waves that reached the west coast were light red and orangish, so it seems like they were still pretty big.* *Near Japan, the color is very dark red which is an amplitude of over 10 feet.*
Okay, so we know the tsunami waves that reached the shore in Japan caused a lot of damage. After looking at this model, why do you think the tsunami waves that reached Japan were so damaging?	*If the waves are really high, they could cause lots of damage when they hit the shore because all that water moves up onto the shore.* *If the waves are moving really fast, they must have lots of energy that could then cause damage when they hit the shore.*
From the foil pan demo, we are pretty sure that waves transfer energy to things they interact with, like the edge of the pan in the demo or the shore near the ocean. What relationship might there be between the amplitude of a wave, and the amount of energy it can transfer?	*The taller waves transfer more energy when they reach the shore because there is more water crashing on the shore.*
What relationship might there be between how fast it is moving and the amount of energy it can transfer?	*I think maybe the faster the waves move, the more energy they would transfer to the shore.*
Okay, what if the wave is tall and fast? What relationship might there be between the amplitude of a wave, how fast it is moving, and the amount of energy it can transfer?	*The tsunami wave seemed to move fast towards Japan and was tall. So maybe, waves that are both fast and tall will transfer a lot of energy to the shore because there is a lot of water moving fast onto the land....*

5 · NAVIGATION

5 min

MATERIALS: None

Take stock so far. Say, *Okay, let's think about the two models we have analyzed today. What can these two different models, the foil pan demo and the computer model of the Japan tsunami, together help us figure out about how an earthquake can cause in a tsunami?*

Suggested prompt	Sample student response
In the foil pan demo, what did we figure out happens when the wave interacts with the edge of the foil pan? What did we see happening?	*When the waves collide with the edge of the pan, they transfer energy and then switch directions.* *We also noticed that over time as this happens again and again, the waves get smaller and smaller after they have transferred energy to other things they collide with.*
Okay, but we agreed the foil pan is missing some parts of the model for a tsunami, so we looked at the NOAA tsunami visualization. In the visualization, what did we see happen with the waves after the earthquake happened near Japan that could help us figure out more about how a tsunami happens after an earthquake?	*The earthquake happened and immediately waves started moving out from the epicenter.* *The waves moved all the way across the Pacific very fast... like a little over a day only.* *It was like the waves were reflected from the epicenter until they collided with other things in the ocean, then they reflected off of those things.*
In trying to figure out how a tsunami results from an earthquake, we felt the foil pan demo had a few aspects that helped us figure this out, but was missing a lot. What about this visualization? Is this an appropriate and helpful model to analyze in order to figure out more about the tsunami?	*This model is more helpful than the foil pan demo because it has more in the model, like wave amplitude. The whole ocean is included and the movement of the waves.* *It is more appropriate because it is closer to scale to what happened when the tsunami reached Japan. It shows how close Japan was to where the earthquake happened, and then how the waves reflected away from there until they hit other shores or islands.*
How do these two models help us to figure out how an earthquake can cause a tsunami?	*Well we figured out that not all earthquakes cause a tsunami, but earthquakes that are strong and closer to the surface, cause the water above to move a lot very quickly.*
But, wouldn't this happen all the time when water is disturbed by an earthquake...that waves would move away from the epicenter and then keep reflecting back and forth as they interacted with other things like the shore? What is different when there is a tsunami?	*Maybe the earthquake needs to be closer to the shore to be dangerous. Even though we saw that the water all the way across the Pacific was affected by the Japan tsunami, only Japan had damage from a tsunami. The other areas that had smaller waves were further away from the earthquake.*

Suggested prompt	Sample student response
Why would proximity, or closeness to the place where the earthquake happens matter?	*Because we saw that over time the waves get smaller and smaller as they interact with things, maybe things in the water (like other shores or things in the ocean like islands). So, if the wave that happens from the earthquake happens closer to shore, then it will still be big and moving faster when it reaches the shore?* *Yeah...also if the tsunami happens closer to shore and is moving fast, then people would have less time to get to safety.*

Say, *It sounds like we still have more we want to figure out, like if faster waves transfer more energy, do taller waves transfer more energy, or if a wave is tall and fast, will it transfer more energy? And we want to know what happens to waves and their energy when they reach shore. Next time, we will look at a couple more wave models to see if we can collect some more evidence to help us figure this out.*

End of day 1

6 · NAVIGATION

5 min

MATERIALS: science notebook, *Mapping the ___________ to the real world phenomenon: __________*

Take stock of the previous wave models. Display **slide E.** Say, *Yesterday we looked at two different models of waves caused by a disturbance under the surface to analyze how water moves. Let's summarize what we have figured out so far about what happens when an earthquake results in a tsunami. And, what do we still need to figure out?* Ask students to turn and talk briefly with a partner.

Have a few students share their ideas. They should mention that they have figured out that water reflects out away from where the land has been disturbed (or epicenter, if an earthquake) until it reaches the edge (of the pan or the shore). But, we still don't know why some places get tsunamis and some places get smaller waves. So, we want to see what happens when waves reach the shore that were caused when earthquakes happen *and* how waves of different amplitudes and speeds behave when they reach the shore.

7 · MINI WAVE TANK

8 min

MATERIALS: science notebook, https://www.teachersopensciedfieldtest.org/tsunami, computer, projector

Prepare students to make some observations of a wave from a different viewpoint. Say, *I have another video that shows how water moves after a disturbance. In this video, there is a mini wave tank which is a long plastic bin that has one end that is deeper than the other end. This model will allow us to investigate how the wave forms and how it moves through different depths from a side perspective, or rather we can watch the waves from a side view. This will demonstrate how waves behave and what happens as different sized waves hit the shore. We will watch it one time together, then we will pause and see if we can make sense of it. Before we make observations of this model, let's remind ourselves what else we wanted to figure out about waves to help us determine how an earthquake can cause a tsunami. This will help us determine if what we see in the mini wave tank will be helpful in figuring out how an earthquake causes a tsunami. Can anyone remind us?*

Ask for a few students to share what they recall from last class. They should suggest something like:

- Last class we were still wondering what happens to the waves when they reach the shore.
- We were also wondering what happens to the energy of the wave when it reaches shore.

Display **slide F.** Ask students to open their notebooks to the same page where they recorded their noticings and wonderings from the first two wave models. Ask, *What title would make sense for the two models we watched yesterday and for the observations you have recorded?*

Have a few volunteers share some ideas. Facilitate this brief discussion to help them suggest a title that captures the idea that they were making observations about waves, how they move when looking at them from above, or how waves move when disturbed from below. Some examples:

- How Waves Move When the Surface Under the Water Moves
- Movement of Waves Out From the Epicenter

Say, *On the page opposite your chart from yesterday, make a new Notice and Wonder chart. Leave the title margin blank again and we can come back and add a title after we make our observations. See the example on the slide. Again, we will watch this video a couple of times. The first time through, you are welcome to just watch. The second time through, add to your Notice and Wonder chart.*

Display **slide G.** Say, *As we watch the video of this model, let's try to track the wave as it gets to shore and see what happens. There are two parts to this model. In the first part of the video, the wave represents a regular ocean wave and what happens when it reaches shore. The second part of the clip models what happens when there is a tsunami caused by an earthquake. As you watch, pay attention to the wave and see if you can find any evidence for what happens at the shore when faster waves and different-sized waves reach it.*

Project https://www.teachersopensciedfieldtest.org/tsunami . Watch the video through once. Then, watch it again and encourage students to record their observations.

After watching this clip, ask a few students to share some of their observations.

Suggested prompts	Sample student responses	Follow-up questions
How is this wave model different from what we saw last class?	*We only see how a wave moves in one direction.*	*Can you tell me more about what you mean when you say it moves in one direction?*
	We can see what happens when water moves from deeper to shallower water.	*Where is the shallow part? What about the deep part?*
	This is a long narrow body of water.	
What were we thinking happened to the energy of the wave when it reaches land, or interacts with something?	*We thought it transferred its energy to the shore, or what it collided with.*	*Did you see anything in the video of this model that is evidence for or evidence against this idea?*
How did the wave behave after the water was disturbed, or moved, at the end of the bin?	*After it was disturbed, or moved by the board, it seemed to roll towards the wood at the other end of the long bin.*	
What does the wooden wedge represent?	*The shore or the beach.*	
When it reached the wooden wedge, what happened?	*The water rolls up onto the board, slows down, and then goes back the other way.*	

Suggested prompts	Sample student responses	Follow-up questions
Did each wave do the same thing when it reached the wooden wedge?	*Kind of...in each part of the video, the water moved up onto the wooden piece, but in the first part it didn't move onto the wood as far.* *Yeah...and it seemed to stop moving quicker than the wave in the second part of the video.*	
What do you think is happening when the waves get closer to the wooden wedge that is making them change in size?	*Maybe since the water would be less deep here, the water above the land gets pushed upward.*	*What do you think causes the water to get taller when it gets nearer to the wooden wedge?*
Why do you think the waves slowed down when it hit the shore?	*We were thinking the wave transfers energy to other things it collides with, so maybe it transfers energy to the shore when it crashes onto the land.*	
What were we able to observe about how waves move that was different from the previous two demonstrations?	*The waves here seemed to change how big they were as they got closer to the wedge; where in the foil pan demonstration, the waves all seemed the same.* *When the waves get closer to the wedge, they seem to get taller, or bigger.* *The waves seemed to roll in this demonstration where as in the foil pan they seemed to move out as ripples.*	*Why do you think the waves change their height when they get closer to the wooden wedge?*
Why might we want to see what happens to the waves when the depth is different?	*Because we want to figure out what is different about a tsunami and a regular wave. And maybe it has to do with depth changes in the ocean as the wave moves to the shore.*	
How might these observations help us to explain how an earthquake can lead to a tsunami?	*Well, if the wave gets bigger as it gets closer to the wedge, then that could be what is happening to the wave when it gets to the shore.*	*But, wouldn't this happen with all waves? Why would there be tsunami-type waves sometimes and not others?*

Tell the students they are going to work together as a class to use the same mapping tool from last class to identify different parts used in the mini wave tank demonstration that represent parts in the real world.

8 · MAPPING PARTS OF THE MODEL TO THE REAL WORLD PHENOMENON

12 min

MATERIALS: science notebook, *Mapping the ___________ to the real world phenomenon: _________*

Mapping parts of the mini wave tank model to the real world event (earthquake-driven tsunami) from a side view. Hand out a new copy of *Mapping the ___________ to the real world phenomenon: _________* to each student. Display **slide H.** Facilitate a discussion to decide how to map the different parts of the demonstration to the real world. Tell students not to tape it in their notebook at this time. Remind students what the different columns represent and what we will be recording in each box. As you facilitate this discussion about how parts of the mini wave tank model are similar to what happens during a tsunami, it will be helpful to record what the class agrees upon. Project **slide H** onto a whiteboard and record what the class agrees upon in the different cells.

ADDITIONAL GUIDANCE

If you cannot project the slide onto a whiteboard, but you have a document camera, you can print off an extra copy of the handout and fill it in as students share. If neither of these options are available, this table could be replicated onto poster paper. It will be important to record what the class agrees on in a public way. In addition, students will need to have a record of this on *Mapping the ___________ to the real world phenomenon: _________* so they can refer to it on Day 3 when the class compares the four different wave models. The lesson is written having you project this to record what the class agrees upon because transferring this to poster paper may be challenging with how many columns are needed. Yet, you may wish to have a hard copy record of what each class agrees upon and therefore may wish to make a poster for this, or use a copy under a doc camera to record each class's ideas.

Together as a class, record how components of the mini wave tank model map to the phenomenon. For example:

Mapping the <u>mini wave tank</u> to the real world event: <u>earthquake-generated tsunami</u>

Complete the first row as a class. Begin by filling in "the ocean" in the first box under "is like this feature in the real world." **Tell students that they will need this mapping tool later, so they should fill it in either with the class as we come to agreement, and/or in their own words to capture how the model can be used to explain the tsunami.** Then ask, *What in the mini wave tank model represents the ocean?* Students should say the water in the long bin. Next, ask why the water in the long bin is like the ocean and why it isn't like the ocean. Fill in the last two boxes. Do one more row together as a class. Fill in "the ocean floor" in the next row under "is like this feature in the real world." Ask, *What in the demonstration represents the ocean floor?* Students should say the bottom of the long bin. Fill in the last two boxes together as a class.

Now ask students to turn and talk with an elbow partner about what other elements to include in the mapping tool. Say, *What other elements or parts of the mini wave tank model could represent what is going on in the real world? Take a couple of minutes with a partner and fill in the next couple of rows.*

Ask for volunteers to share and add to the class table. Once this table is complete, you may want to take a photo of the board before moving on as you will need to erase this information and may wish to refer to it for students who are absent or in the future.

Note: Though there are only so many rows included on the handout, encourage students to add in more rows on their own if there are other elements they want to map to between the demo and the tsunami wave. In addition, as the class shares and you record what they agree on, do not feel limited by the number of rows on the handout if there are more elements than rows that students identify.
An example of a completed mapping tool is below.

This part in our model...	is like this feature in the real world...	because...	...and not like it because...
the water in the long bin	the ocean	water	there is way less water than in the ocean and it is not salt water
the long plastic bin	the ocean floor	it is solid like the land and is under the water	it is only a small slice/section of the ocean
the green or black paddle at the end of the long bin	the earthquake--the cause of the water being moved	it makes the water move	it is not causing the water to move by moving the bottom of the bin instead it is moving the water from the side
the movement of the water after the board is moved	how the ocean water moves after an earthquake occurs	when water is disturbed, it moves away from this spot, called the epicenter, in a wave-like pattern	the water in the ocean moves in all directions, not just one way
the wedge at the other end of the long bin	the beach	the land gets higher and the water depth gets shallower	the beach is made of sand--not wood, and this is much smaller
the changing bin depth	the way the land gets shallower closer to shore	one end of the bin is deeper than the area near the wooden wedge	This is not to scale. The ocean is much deeper out where the earthquake happened than the shore. The difference in depth in our bin is much smaller than the difference in the depth in the ocean to the shore.

ASSESSMENT OPPORTUNITY

3.A.2 Analyze and interpret video data from different wave models to identify how changes (patterns) in the profile of the shore and ocean floor cause changes in the height of a wave (amplitude).

What to look for: Students will be analyzing four different wave models over the course of the unit. After using each model, the class will pause and share what has been figured out about waves and tsunamis. After analyzing this third model, listen for them to identify the following key ideas about how waves form and move:

- The amplitude of the waves that are further out in the ocean don't seem to be as big as the ones that reach the shore.
- As the waves move towards the shore where the land is shallower, the amplitude changes.
- When the wave reaches the shore, it seems to fall over on itself and spread out onto the land.
- The bigger the wave that reaches the shore, the more it will move onto land.

What to do: Students use videos of two physical models and two computer visualizations to observe and analyze various wave behaviors. Some students may struggle with recording observations while watching. Make these videos available to students to watch on their own outside of class multiple times, so that they have enough time to make sense of what they are observing, and find patterns of cause and effect to explain how a tsunami forms and moves. Another option if the technology is available in your classroom is to watch the video as a class once together, and then have students play it again in small groups to make their observations.

Suggested prompts	Sample student responses	Follow-up questions
How might these observations help us to explain how an earthquake can lead to a tsunami?	*Well, if the wave gets bigger as it gets closer to the wedge, then that could be what is happening to the wave when it gets to the shore.*	*But, wouldn't this happen with all waves? Why would there be tsunami-type waves sometimes and not others?*
Did mapping the different parts of the mini wave tank help us explain any aspects of the tsunami? Would you say this is an appropriate and useful model to use as we try to figure out aspects of the tsunami?	*It helped us see a little bit of what happens to waves when they move through different depths of water.* *It also looks like the energy of the wave is transferred as it interacts with other things, like the wood wedge.* *But it is way too small compared to the ocean.* *Yeah, and it only shows a very small snapshot of what is happening...and the disturbance to the water happens from the side not underneath.*	

Say, *Okay, so now we have some more observations to use to help us try to figure out how an earthquake can lead to a tsunami. But, we still aren't sure why sometimes there are tsunami-type waves and other times there are not. What else are we still wondering about that will help us explain how an earthquake causes a tsunami?*

Some possible students responses:

- There are waves in the ocean all the time. How are these waves made so big? What is the connection between the earthquake and the tsunami?
- Why is it that only the earthquakes that happened when plates collide are the ones that lead to tsunamis?

9 · COMPUTER VISUALIZATION OF A TSUNAMI WAVE

20 min

MATERIALS: science notebook, https://www.youtube.com/watch?v=SlwZzbGh7Cw, computer, projector

Display **slide I.** Tell students, *I have another computer-generated model that scientists designed using data from tsunamis that were caused by earthquakes. Let's use this to visualize how a tsunami wave forms after an earthquake, and observe what happens to it as it moves towards the shore. The perspective in this video clip is from the side view, like the wave tank. We will watch this visualization a few times, pausing to make sense of what we are seeing. We will use the same Notice and Wonder chart to record what we see after viewing it the second time.*

Ask students to draw a horizontal line under their previous noticings to record some new ideas for this final model. Have students label the right margin of the t-chart, "Tsunami Wave Visualization." See the slide for an example.

First time through the video, watch and make observations.

ADDITIONAL GUIDANCE	This model may be challenging for students to make sense of. The whole video is a computer-generated simulation of what happens when an earthquake happens under the ocean. The model shows what happens, starting at the fault line, and follows the wave close-up all the way to the shore. Students will need support in making sense of what they are looking at. If students request to watch the visualization more than the allotted times, you may wish to have the students verbalize why they want the class to watch it again, or articulate what they will be looking for to provide a purpose for viewing it. If available, you may wish to provide access to the visualization for students to watch in small groups, or on their own outside of class.

After watching the visualization **the first time**, pause as a class to make sense of what they have observed. Use the suggested prompts below to help guide this.

ASSESSMENT OPPORTUNITY

3.A.2 Analyze and interpret video data from different wave models to identify how changes (patterns) in the profile of the shore and ocean floor cause changes in the height of a wave (amplitude).

What to look for: Students will be analyzing four different wave models over the course of the unit. After using each model, the class will pause and share what has been figured out about waves and tsunamis. After analyzing this last model, listen for them to identify the following key ideas about how waves form and move:

- Earthquakes that cause tsunamis are strong and shallow or nearer to the surface of the plates.
- When these types of earthquakes happen and cause part of the land to move up and another part to move down (vertically), a tsunami can happen.
- It looks like the way the land moves when the plates collide cause the land to move up and down which causes the water above it to move, causing large waves to form.
- These waves move out from the location where the plates move past one another (epicenter) in all directions.
- The amplitude of the waves that are further out in the ocean don't seem to be as big as the ones that reach the shore.
- As the waves move towards the shore where the land is shallower, the amplitude changes.
- When the wave reaches the shore, it seems to fall over on itself and spread out onto the land.
- The bigger the wave that reaches the shore, the more it will move onto land.

What to do: Students use videos of two physical models and two computer visualizations to observe and analyze various wave behaviors. Some students may struggle with recording observations while watching. Make these videos available to students to watch on their own outside of class multiple times, so that they have enough time to make sense of what they are observing, and find patterns of cause and effect to explain how a tsunami forms and moves. Another option if the technology is available in your classroom is to watch the video as a class once together and then have students play it again in small groups to make their observations.

Suggested prompt	Sample student response
Before we watch this again, let's make sure we all know what is being represented in this visualization. What are we seeing happening?	*We see the land break and one part move upward causing the water to move upward and form a wave.* *Yeah. We saw the wave forms almost immediately as the land moved upwards.*

Suggested prompt	Sample student response
What does this upward movement of the land represent?	*The earthquake that happens when the plates collide.*
How does this movement of the land cause the water to move?	*When the land broke apart from the earthquake, it moved upwards. This movement upward made the water move upward too.* *Yeah...it was like as the land moved upward, it pushed the water upward too.*
Okay, so then what is happening between the land and the water to cause the water to begin moving?	*As the land moves upward, it transfers some of its energy to the water, causing the water to move.* *Yeah... maybe this is like when we figured out energy can be transferred through different types of cups in OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit).*
Right, we know that energy can be transferred from earlier models and from OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit). So, if the land is transferring energy to the water causing waves, what happens next?	*In the visualization, the wave moves away from where the land broke towards the shore.* *Maybe like how we found out energy can be transferred through thinner walled cups easier than the thicker walled cup. But here the energy is being transferred from the land that moves to the water.* *Yeah... or like in the foil pan demo, moving the bottoms of the pan made the water above it move too.*
How did we know the water wave was moving towards the shore?	*At the end, there were little images that looked like buildings, so I think that was supposed to represent the shore.*
What other things did you notice?	*We saw what happened from the side at the location where the land broke. Later, it shifted to show the wave from above.* *In the far distance, you can see something that looks like the shore.* *Then we shift and look at the wave from the side again, all the way until it reaches what is supposed to be the shore.*

Say, *We are going to watch it again. We think energy is transferred from the land that breaks to the water, causing waves that move towards shore. This time when you watch, pay close attention to the ocean floor and what happens to it from when it breaks until the wave reaches/ hits the shore. Also, watch to see if we can see when energy would have been transferred to the water from the ocean floor and how the wave moves towards and at the shore.*

Play the visualization a second time.

Suggested prompt	Sample student response

Suggested prompt	Sample student response
What happened at the ocean floor?	*First, it broke or split apart.* *Then, the land moved up and down vertically.* *It gets less and less deep as the video plays until we see the shore at the end of the video.*
After the land broke, the visualization showed us the wave moving, but did you notice anything about the ocean floor while the wave was moving?	*Up until the video zoomed into another part of the wave, it didn't seem like the land changed much more after the first break.* *The amount of space or depth of the water seemed to be the same for over the first half of the video.*
Did others notice that too? What about the rest of the visualization? What did you notice about the ocean floor in the second half of the visualization?	*Yeah! As soon as the ocean floor broke, the water moved in a wave very smoothly all the way to shore.* *It looked like the wave started as soon as the land moved up which shows the water moves because the land moved. That seems like it would support our idea that energy is transferred from the land to the water above it.*
What did you notice about the wave as it moved? Did it stay the same the whole time? Or did it change in any way?	*The wave did change over time..it got bigger* *Yeah… at first it seemed like it was about the same size until the part of the visualization where the ocean was less deep… then it seemed like it got bigger.*
Okay, so when you noticed the wave begin to change and the amplitude increased, what else did you see happen with the wave? the wave amplitude increasing?	*At first, it seems like it is pretty deep and the wave looks the same size.* *Closer to the end, we saw the land getting higher and the water becoming less deep. I think this means we are getting closer to the shore.* *This is when the wave looked like it was getting taller.*
So, do you think the amplitude of the wave is the same the whole time in the video? How did this correspond to wave depth?	*No! It seemed like towards the middle to end, when the land was higher up (or shallower) and the water was less deep, the wave got bigger or taller.* *It's amplitude increased as it reached the shore.*
What ideas do you have for why the amplitude would increase as the wave moves closer to shore? How do you think this led to the wave increasing in size?	*Hmm…maybe the water gets pushed up somehow nearer to shore.* *It almost seemed like the wave needed more room, so it grew taller.*

Suggested prompt	Sample student response
Okay...let's think back to the beginning of the video. We had said it is deeper out in the ocean where the land broke apart from the earthquake. And, when an area is deeper, it would have more water than an area that is shallower. So, if the earthquake happens out in the ocean and land is quickly pushed upward when an earthquake happens, it forms a big wave. As this big wave of deep water is moving towards the shore that gets more shallow, what happens to it?	*Well, it seems like if there is a lot of water (from deeper) in the ocean that is part of the wave moving towards shore, then as the land gets shallower, the water would get pushed upward.* *Yeah...because there is not as much space for the water but there is still the same amount of water.* *Yeah... or maybe the wave is made of a certain amount of water and when the land gets shallower that same amount of water is still there so it gets pushed up where there is room for it.*
And... if there is still the same amount of water in the wave but less room between the ocean floor and the top of the wave then how does this affect what we see happening at the shore?	*Well... when the wave reaches shore there is no more space for the wave so all that water crashes to the shore and moves all up and out onto the land.*
So, if this is happening, how might this help us figure out why sometimes there are tsunamis when earthquakes happen?	*Well maybe if the ocean gets shallow quicker, and not gradually, maybe this pushes the wave up and up until it gets to shore. It gets so big that when it reaches land, it crashes over onto the land.*
Let's take a moment and think about the foil pan demo and the mini wave tank. What similarities and differences did you notice between the demo, the mini wave tank and this simulation?	*The water in the foil pan moved only after the bottom of the pan was moved. So, the energy from the movement of the foil pan transferred to the water above it and caused it to move.* *And in the mini wave tank...the water started moving as soon as the green (or black) little board moved in the water. So, the energy from the movement of the green board made the water begin to move. It had transferred energy to the water.*

Say, *Okay, wow! We have analyzed four different wave models. Next class, let's take stock of how we can use each model to help us explain how an earthquake could cause a tsunami.*

End of day 2

10 · NAVIGATION

5 min

MATERIALS: None

Motivate as a class how the four wave models can help us figure out what causes tsunamis. Display **slide J.**

Reflect, *Over the last two classes, we looked at four wave models. None of them were perfect models, but combining what we observed from each model could potentially help us figure out how tsunamis form and how they affect the land. Let's take some time to think about the benefits and limitations of each model for helping us to better understand tsunamis. Or in other words, let's think about what elements from each model helped us (was beneficial) figure out some things about how an earthquake causes a tsunami? And what elements may have been missing from each model, or was limiting in helping us figure this out?*

11 · REFLECT ON THE LIMITATIONS AND BENEFITS OF DIFFERENT MODELS

25 min

MATERIALS: science notebook, completed *Mapping the ___________ to the real world phenomenon: _________*, "Comparing different wave models" poster set up ahead of time to be completed with the class

Ask students to come into the Scientists Circle. Ask students to bring their science notebook and *Mapping the ___________ to the real world phenomenon: _________*s with them to the Scientist Circle. Display **slide K.** You will want to have a sheet of poster paper ready with the following table prepared ahead of time to be filled in:

Comparing different wave models

Models	Benefits	Limitations
Foil Pan Demo		
NOAA Tsunami Visualization		
Mini Wave Tank		
Tsunami Wave Visualization		

As a class, discuss each model. Have students turn to the Notice and Wonder chart in their notebook and encourage them to use the mapping tools they filled out as well. Tell them that as a class you will revisit each wave model and think about what we figured out from each and any limitations from the model--in other words, what was incomplete from the model for helping us explain what happens when a tsunami forms and moves.✱

Say, *Turn to your elbow partner and take a couple of minutes to talk about each of the four models. Share with each other what you think was helpful (or beneficial) about observing that model to help us explain a tsunami and what was incomplete (or limiting) about what each model could tell us about how tsunamis form. Be ready to share your ideas.*

ASSESSMENT OPPORTUNITY

3.B Evaluate different wave models, identifying limitations and benefits in what each shows for explaining how tsunamis form (causes), move, and what happens when tsunamis reach the shore (effect).

What to look for: Students ability to identify the benefits and limitations of each of the four wave models that can be used to explain how an earthquake can cause a tsunami. Students will work with a partner initially to look back through what they have recorded about waves, earthquakes, and tsunamis from the four wave models that were analyzed on days 1 and 2 of this lesson. With their partner, they will identify benefits and limitations. See the example table in the body of this lesson for samples to listen for in terms of benefits and limitations.

What to do: Students may struggle to identify the limitations of each model. This word may be unfamiliar to them in this context. Encourage them to use the mapping tool from *Mapping the ___________ to the real world phenomenon: _________* and what they observed to help students realize that the word 'limitations' refers to models' inability to give us a complete picture of what's happening during a tsunami. Provide example(s) to help students realize that none of these models by themselves will help explain how tsunamis form, but if they were to put pieces of what they observed from each simulation together, they will have a more complete picture of what happens that causes a tsunami.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

This lesson uses four different ways to model the generation and movement of water waves, including tsunami waves. Each one allows students to learn something new about the phenomenon, while it also has limitations that do not fully represent the phenomenon. Comparing multiple ways to model the waves achieves two purposes for students:

- They develop a critical lens for evaluating the limitations of models and can see those limitations across different ways of modeling the same phenomenon.
- It also prepares students to think like an engineer by using multiple models to study a phenomenon in order to fully understand how it works and how to design solutions necessary to address an identified problem.

After students have had a few minutes to think about this with their elbow partner, discuss the benefits and limitations of each model and record what is shared on the class poster. An example of a completed table is below.

Model	Benefits of this model	Limitations
Foil Pan Demo	We can see how waves begin to move and ripple out from the part of the pan that is moved, like how waves ripple out away from the epicenter of an earthquake. We can see the behavior of the waves reflecting off the pan walls. We can see what happens to the energy of the wave when it collides with the side of the foil pan - the wave transfers energy and reflects back.	The water was at the same depth, so it was difficult to model how these waves affect the land when it changes. We could only see what happened when the water collided with a vertical wall of the pan, not a shallower shoreline. The waves are very small compared to the tsunami.
NOAA Tsunami Visualization	We can see that water in the ocean moves like the water in the pan and that a tsunami that begins far away from the US, can still affect the shores of the west coast. We can also see how strong the waves are along all the shorelines of the Pacific. This model is made from actual data of the tsunami.	We can use this to see how the wave moves across the ocean and how intense the waves are that hit shore all along the Pacific, but we don't see any effects on the land beyond the shore. We can't clearly see how the depth of the water might be different and how this might affect the waves, like at different shorelines.
Mini Wave Tank	This helps us focus on the up and down motion of the wave and what happens when the wave gets to shore.	This is so small compared to the ocean. Also, it is like a thin slice of the ocean, so we can only see what the water does in one direction.
Tsunami Wave Visualization	We can use this to get an idea of what happens when a large wave reaches shore without anyone getting hurt and without any houses being damaged. We can see the land breaking, like in the earthquake, and how the water moves from this point on towards the shore. Data of waves were used to make this video.	It is computer-generated and not real. The different views make it difficult to see everything that is happening. We have to put together the different pieces to try to make sense of what is happening with the wave.

Once the table is complete, pause with the class and ask the students to look back over what we have recorded. Ask them to look for any similarities listed in the table between the parts of each model. For example, there most likely will be something included for each model about the movement of the waves. Also, ask students to look for any similarities between limitations between models. For example, the foil pan demo and the mini wave tank are at a much smaller scale than the ocean, which may affect what we are seeing the waves do.

12 · PUTTING THE PIECES TOGETHER

10 min

MATERIALS: None

Facilitate a discussion to determine what pieces of data from what we have figured out over the last few days would be helpful to us as we try to figure out how to better warn people, or protect people when a tsunami occurs. **Display slide L.** Say, *We have analyzed four different models of waves over the last couple of days to figure out how an earthquake causes a tsunami. We have also mapped different pieces of these models to a tsunami. Take a couple of minutes with a partner and look back through your notebook and your handouts to find some things you feel we have figured out that will help us to answer this question, How can an earthquake result in a tsunami? Before you get started, let's think about what we might be looking for in our notebook.*

Suggested prompt	Sample student response
Do you think we will need general information about all waves?	*Probably. Because even though not all waves are tsunamis, we need to know how waves behave to help us figure out what is similar and different about a tsunami.*
Will it be helpful and important to look at what we saw in all four of the models? Or just some of the models?	*All four...none of them are the same, so if we can use all four, we might be able to get a clearer or more complete idea of how a tsunami forms from an earthquake.* *Yeah, I agree with all four. They all have pieces of a model of a tsunami, so if we look back at all of them we might be able to figure out more.* *Each model showed something different about waves and how they behave when they interact with other things.*
Okay, as you work with your partner, look for ideas from the four models that will help us explain this tsunami.	

Ask students to turn and talk to a partner about the question on the slide and give them about 8 minutes to work together

- What have you figured out that would help explain how an earthquake can result in a tsunami?

ADDITIONAL GUIDANCE

If students are struggling with what they should be looking for in their resources about the four different wave models, it can be helpful to talk through one example together. For example, you could say, *We figured out that tsunamis can be caused by earthquakes. So, look through what you have recorded about the relationship between the earthquake and the tsunami, and decide with your partner what parts of this relationship we need to explain this phenomenon.*

Say, *Let's share out what we've figured out.* As students share these ideas, record them on a poster until you have the progression similar to the list in the Key Ideas box. Use the prompts that follow to help prompt or probe student ideas.

KEY IDEAS

Purpose of this discussion: Use what has been observed over the past couple of lessons to explain how an earthquake could cause a tsunami to form. **Record this on a poster as the class shares these ideas**.

Listen for these ideas:

- Earthquakes that cause tsunamis are strong and shallow or nearer to the surface.
- When these types of earthquakes happen and the land moves up (vertically), a tsunami can happen.
- The movement of the land up and down causes the water above it to move and large waves are formed.
- These waves move out from the epicenter in all directions.
- The waves that are further out in the ocean don't seem to be as big as the ones that reach the shore.
- As the waves move towards the shore where the land is shallower, they get bigger or taller.
- When the wave reaches the shore, it crashes onto the shore and then spreads up onto the land.
- The bigger the wave that reaches the shore, the more it will move onto the land.

Suggested prompt	Sample student response
What did we figure out about when a tsunami could occur?	*Tsunamis can occur when there are strong earthquakes that happen at a shallow depth.* *And we figured out that when the earthquake happens and a tsunami forms, the plates move towards each other and collide.*
When these earthquakes occur under the ocean, how does it affect the ocean?	*We saw in the computer video of the tsunami that when an earthquake occurs in the ocean and the land breaks apart, it makes the water above it move. Energy is transferred from the land moving up to the water above it.*
Why would some types of movement from earthquakes result in the large tsunami waves and other times tsunamis wouldn't happen?	*Tsunami waves are very large and move pretty fast to the shore. So, maybe the earthquakes that are stronger lead to tsunamis because they would be pushing the water with more energy if they are stronger.* *This would make the waves bigger!* *And I think the waves would be faster moving too.*
We think based on what we have investigated in the last few lessons, that waves have to be really tall and travel really fast to cause damage. What did we learn about from our models to help us understand how these waves form?	*In the mini wave tank and the computer generated tsunami wave, it looked like when the wave got closer to the shore, the water wasn't as deep as it was far out in the ocean, pushing the water up and making it taller.* *I agree. In the computer visualization, the wave seemed to grow taller as it was closer to shore.* *The amount of water that is part of the wave from far out in the ocean is still there, but because the land isn't as deep, it gets pushed up and taller.*

Say, *So if we wanted to try to collect data to warn an area at risk for a tsunami, what key pieces of data would we want to know about the earthquake and tsunamis? Let's think about what we have figured out to help us.*

Using the poster, point to different statements, and talk through how these could be generalized to be useful in identifying what data would need to be collected about tsunamis to determine if an area would be at risk of damage from a tsunami. Such as, *We noted there are specific types of earthquakes that are strong that lead to tsunamis, so it looks like we would want to know how strong the earthquake is.*

Then, write in a different color, "how strong the earthquake is."

Point to a different statement such as, *We also would want to know how big the waves are and how fast they are moving.*

Then, write in a different color, "how big and fast the wave is."

Say, *We also would want to know communities or areas or people that are living and working close enough to the earthquake that caused the tsunami and could be affected.*

Then write in a different color , "how close to a community the tsunami occurs."

An example is below:

How can an earthquake cause a tsunami?

- Earthquakes that cause tsunamis are strong and shallow, or nearer to the surface of the plates. how strong the earthquake is
- When these types of earthquakes happen and the land moves up and the other part moves down (vertically), a tsunami can happen.
- The movement of the land up and down causes the water above it to move and large waves are formed.
- These waves move out from this spot in all directions. what direction the tsunami is moving
- The waves that are further out in the ocean don't seem to be as big as the ones that reach the shore. how big and fast the wave is
- As the waves move towards the shore where the land is shallower, they get bigger or taller.
- When the wave reaches the shore, it seems to fall over on itself and then spread out onto land.
- The bigger the wave that reaches the shore, the more it will move onto land. how close to a community this occurs

13 · NAVIGATION

5 min

MATERIALS: None

Display **slide M.** Ask the students to turn and talk with a partner for a minute or two about the question on the slide: *If you could get these same key pieces of data about a different hazard, do you think it could be used to analyze other hazards and figure out ways to protect communities?*

Say, *So, if we look at some of our related phenomena, do you think knowing how big the hazard is, how fast it is moving, and how close it is to where communities are would all be important pieces of data we want when looking at ways to protect communities?*

Let a couple of students share. Then tell them that next class we will work more with this idea.