When asked to imagine a wave, many students imagine a physical wave, such as a breaking ocean wave or a ripple in a pond. Physical-sciences courses, however, usually examine more abstract waves, such as sound and electromagnetic waves. Water waves may be more relatable to students than typical periodic motion models like springs, strings, or pendula. This activity uses water waves as an engaging hook, provides a kinesthetic experience for students, and incorporates modeling, measurement, and mathematics into understanding wave properties. The activity also aligns with a range of practices and concepts in the Next Generation Science Standards (NGSS), the Common Core State Standards, and the Ocean Literacy Principles (Figure 1).
CATCHING WAVES: MAKING WAVE PRINTS TO INTRODUCE WAVE PROPERTIES

Background

Water waves are similar to other types of waves. Waves are generally caused by a disturbance or vibration, and they transfer energy without causing a net movement of matter. In the ocean, waves are usually generated by wind. When waves move across the ocean, water does not travel great distances, but energy does. Water waves that travel at a constant rate and do not change significantly over time can be described using standard wave terminology (Figure 2). A wave profile diagram (Figure 3) is a side view of a water wave used to show wave features, including crests, troughs, wave height, and wavelength.

This introductory wave activity is adapted for middle school, with permission, from Exploring Our Fluid Earth, a free, online aquatic science curriculum (www.exploringourfluidearth.org) based on The Fluid Earth (Klemm et al. 1990) and The Living Ocean (Klemm et al., 1995). Before this investigation, students observe waves in an ocean, lake, river, or even a swimming pool or puddle. Although in-person observations are preferred, students can instead watch videos of waves. Students describe features such as wave shape, wavelength, wave height, wave direction, and how waves break. In class, students share their wave observations, discussing the features they noted. This discussion can serve as formative assessment, revealing students’ prior knowledge through their use of wave vocabulary. For example, students may understand that waves have crests and troughs but may refer to these wave features using alternate descriptions, such as “top” and “bottom.” During the class discussion, ba-
sic wave terms can be introduced or reviewed, referring both to students’ wave observations and a diagram of a transverse wave (Figure 3). If a student refers to the “top” and “bottom” of a wave, you may ask if other students observed similar wave shapes. Then you can create a diagram of a transverse wave (such as in Figure 3) and label the crest and the trough.

In the activity, students create a standing wave in a wave tank and “catch” the wave by making a print of it. Many practices of science described in the NGSS are incorporated in this activity, which also highlights some particular processes used in scientific inquiry, including replication and description (Duncan Seraphin et al. Forthcoming). Replication is validating knowledge through repetition. Scientists replicate their own work using multiple trials in an experiment and also replicate the work of other scientists in order to confirm their methods and findings. In science, description means creating an accurate and adequate representation of ideas, things, or events using words or mathematical equations. Multiple processes occur throughout scientific investigations in the laboratory, the field, and the classroom.

Subsequent wave-tank activities in the Exploring Our Fluid Earth curriculum explore wave interference, wave shoaling and breaking, and orbital water motion in waves. These activities can be used as follow-up or extensions to learn more about waves and wave properties.

**The activity**

**Materials**

Materials are listed in the Activity Worksheet. Clear wave tanks are best so that waves can be seen from multiple angles, and this unique piece of equipment quickly captures student interest. The procedures are written for an acrylic tank 1.4 m long, 30 cm high, and 12 cm wide (Figure 4), which we had made by an aquarium builder. Other types of tanks also work, with adjustments to the procedure (see Figure 5). A paddle just narrower and higher than the tank is placed in a groove at the bottom of the tank (Figure 4).

We have had success conducting this activity various ways: with multiple tanks in one classroom, as a station in a rotation, and as a demonstration. When using multiple tanks, or as a station in a rotation, students should work in groups of three or four. If used as a station in a rotation, groups who have already collected data using the tank can analyze their data while groups that have not yet worked with the tank make predictions or practice wave calculations.

There are a few safety precautions. Tanks are very heavy when filled and should not be moved when full.
Towels should be on hand to clean up possible splashes and keep the floor dry to prevent slip-and-fall accidents. Students must wear chemical splash goggles.

**Generating wave profiles**

A standing wave is one that only moves up and down, not forward, in the tank. Generating standing waves takes practice. Some people are better “wave makers” than others, so students should take turns trying to generate standing waves. Initially, students have an open-ended opportunity to determine how to generate standing waves. This involves replication—students have to be consistent in timing and technique to create standing waves. Description is also necessary when students explain to each other the shape and motion of the wave and discuss how to create a standing wave. While one student practices, others watch and tell the wave maker when a standing wave is generated. Students are often surprised at how hard it is to create standing waves and usually nominate a skilled wave maker for the next part of the procedure.

Next, students create waves at set frequencies and paddle-stop distances. To create the frequencies, a metronome is played over either speakers or headphones. Digital metronomes can be found online or downloaded as apps onto mobile devices. For each wave, the paddle hits the front paddle stop once per beat (Figure 6). The water level should be kept below the decorative ridge near the top of the window box. Wave heights will be lower in the window box than in longer tanks, because waves are generated at higher frequencies.
of paper, which can be created before the activity by taping together smaller pieces of paper. Regular-sized pieces of construction paper taped end-to-end to a length of about two-thirds of the tank work well. Students create standing-wave profiles with combinations of two paddle-stop settings and two frequencies, predicting what will happen to the wave when they change the settings.

Teamwork is fundamental to making prints. One person creates waves, another watches the side of the tank for a standing wave, and a third person dips the paper. The “dipper” has to be told when to dip, because it is hard to see the standing wave when looking straight down into the tank. The paper is dipped quickly and carefully into the standing wave, avoiding the sides of the tank. A good print is a watermarked profile with a regular wave pattern (Figure 7). Students can be discouraged by prints that are crooked or lumpy, but this is an opportunity to develop and test strategies to create better standing waves and prints. Again, replication is key here, both in the wave generation and the printmaking. With a few practice prints, and some encouragement, students can make good profiles for making measurements.

**Data collection and analysis**

The paper will begin to dry and absorb water, changing the wave shape, so students should trace their profile immediately after making a print (Figure 7). Each profile should also be labeled with the paddle-stop setting and frequency. Students then identify the crests and troughs of the wave and measure the wavelength and wave height (Figure 3). Each group makes four prints, one of each combination of paddle stop and frequency. As a modification, different groups can be assigned to one combination each. Replication and calculating group or class averages reduce the error due to timing, measurement, or irregular prints. Representative results for two trials of each combination of frequency and paddle-stop setting are shown in Figure 8. Results will vary based on wave-tank dimensions.

In the activity questions (see Activity Worksheet), description is important. Students describe how they created standing waves, as well as trends in wavelength and wave height related to frequency and paddle-stop settings. Students are asked to describe the relationship between frequency and wavelength both in words and mathematically. Finally, students calculate wave speed and period and describe the relationship between the two. Centimeters should be converted to meters if appropriate for the scale of the tank.

**Assessment and evidence of learning**

Assessment occurs throughout the activity. Students engage in informal self-assessment and metacognitive reflection as they determine how to make a standing wave and “catch” the wave in a print. For both teachers and students, clear wave tanks make formative assessment easier, as the waves are visible from multiple angles. Informal assessment can also happen through inquiry questioning by the teacher. Wave prints, data tables, and written answers to questions provide evidence of learning and can be used for formal, summative assessment.

**Discussion**

Making and analyzing wave prints is an inquiry-based, hands-on way to introduce waves and wave properties. Expected results will show that

- as frequency increases, wavelength decreases;
- at the same paddle-stop setting, wave height increases as frequency increases; and
- as paddle-stop setting distance increases with constant frequency, wave height increases.

Students create three wave models: one in the tank, one in their prints, and one using equations. When using models to teach science, it is important to point...
CATCHING WAVES: MAKING WAVE PRINTS TO INTRODUCE WAVE PROPERTIES

out how the model is like and unlike the target concept (Harrison and Coll 2007). Water waves have similarities and differences compared to other wave types. For example, water waves and sound waves are both mechanical waves, but sound waves are longitudinal waves, whereas water waves are transverse. Another difference exists between the energies of classical mechanical waves, such as water waves, and electromagnetic waves—the energy of a classical wave is proportional to its amplitude, but the energy of an electromagnetic wave is proportional to its frequency. It is also worth noting that the wave model in the tank is a standing wave, but ocean waves propagate, or move, across the surface of the ocean. Although these differences are not explicitly addressed in this activity, it is possible that these connections could be made in subsequent activities. This activity was designed as an introduction or review of waves, and it provides a context for using water waves as a model for other waves.

This activity has been adapted for a range of middle school students. Modeling portions of the activity, such as setting up the wave tank and dipping the paper, can reduce student reading anxiety and increase comprehension of the procedure. Another way to adapt the activity is to focus on qualitative relationships rather than quantitative measurements. Doing examples as a class or in small groups can help students with algebraic calculations. More advanced students can manipulate multiple combinations of paddle-stop settings and frequencies and use graphs to analyze data. Working in groups and taking turns in different roles gives all students the opportunity to participate and work together to generate data. The physical, visual, mathematical, and even musical (keeping time with the metronome) processes of this activity provide various ways for students to tap into different strengths. Finally, we believe that relating the activity to the ocean can increase engagement in all learners.

Throughout the activity, students engage in different aspects of scientific inquiry. The process of creating waves is open ended. We encourage teachers to allow students to determine how to make standing waves and create the best wave prints. Analyzing wave prints is more guided inquiry, in which students use mathematical formulas to support their understanding of wave properties. In addition to the standards listed in Figure 1, this activity aligns with NGSS practices, disciplinary core ideas, and crosscutting concepts (Figure 9).

The wave standards in the NGSS emphasize the use of waves in transmitting information and in technology systems, especially in digital communication technologies. Water waves are also used in technological and information transmitting applications. In many places, wave buoys and turbines are used to generate electricity. Other types of buoys are deployed across the world ocean to collect and transmit information for weather, tsunami, and surf forecasting. At a more low-tech level, sailors and surfers read ocean waves to determine surf and weather conditions before using waves for transportation and recreation. Finally, wave content can be covered using water waves in classes such as marine or Earth science, providing exposure to physical-science concepts outside of physics-based courses. Multiple
entry points to the same content can deepen student understanding over time (NRC 2012).

**Conclusion**

Even without a surfboard, any student can catch a wave. In this inquiry activity, students experience waves kinesthetically and visually, generate standing waves, and “catch” those waves by making wave prints. Students explore and quantify the effects of wave frequency and pulse size on wavelength and wave height by measuring their wave prints. Generating standing waves and making wave prints is a unique introduction to wave properties that goes beyond traditional springs, pendulums, or strings. Through this activity, students learn content and engage in many NGSS practices of science and engineering. We encourage you to teach about wavelength, wave period, frequency, wave height, and wave speed by exploring water waves.

**References**

### Alignment of activity with NGSS practices, disciplinary core ideas, and crosscutting concepts

<table>
<thead>
<tr>
<th>Practices</th>
<th>Disciplinary Core Ideas</th>
<th>Crosscutting Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking Questions and Defining Problems</td>
<td>Wave Properties</td>
<td>Patterns</td>
</tr>
<tr>
<td>Students evaluate their data and qualitative relationships as compared to known wave equation.</td>
<td>Students determine the relationship between wavelength, frequency, and wavespeed.</td>
<td>Students use wave prints and recorded and calculated data to identify patterns.</td>
</tr>
<tr>
<td>Developing and Using Models</td>
<td>Defining and Delimiting Engineering Problems</td>
<td>Cause and Effect</td>
</tr>
<tr>
<td>Students use transverse wave models to describe waves and create wave prints.</td>
<td>Students are tasked with creating a standing wave under specific frequency and paddlestop conditions.</td>
<td>Empirical evidence is used to make claims about the effect of changing paddlestop settings and frequency on other wave properties.</td>
</tr>
<tr>
<td>Using Mathematics and Computational Thinking</td>
<td>Developing Possible Solutions</td>
<td>Systems and System Models</td>
</tr>
<tr>
<td>Students use mathematical expressions to describe the relationships between wave properties.</td>
<td>Students take turns making waves, and developing strategies to create standing waves.</td>
<td>A wave model is used to simulate waves and the interactions between paddlestop settings, frequency, and wave properties.</td>
</tr>
<tr>
<td>Obtaining, Evaluating, and Communicating Information</td>
<td>Optimizing the Design Solution</td>
<td></td>
</tr>
<tr>
<td>Students collect, analyze, and share data through written and verbal communication.</td>
<td>Students observe the effects of their various wave-making strategies and optimize their standing waves.</td>
<td></td>
</tr>
</tbody>
</table>

---

Lauren Kaupp (kaupp@hawaii.edu) is a science specialist at the Curriculum Research & Development Group (CRDG) in the College of Education at the University of Hawai‘i at Manoa in Honolulu, Hawaii. Joanna Philippoff is the program manager for Teaching Science as Inquiry: Aquatic Science, also with CRDG. Kanesa Seraphin is an associate professor at CRDG and the director of the Center for Marine Science Education with the University of Hawai‘i Sea Grant Program. Matthew Lurie is a graduate assistant with CRDG and a doctoral student in the Department of Botany at the University of Hawai‘i at Manoa.


ACTIVITY WORKSHEET: Catching a wave

In this activity, you will create standing waves in a wave tank and examine the effect of frequency and length of wave pulse on wavelength (L), wave height (H), wave speed (S), and wave period (T). Standing waves appear to move up and down in place and do not move forward in the tank.

Materials (per tank)
- Paddle
- Water
- 3 rulers
- Masking tape
- Metronome
- Construction paper
- Pencil or pen

Procedure
1. Set up the wave tank as shown in the diagram above.
   - Fill the wave tank halfway with water.
   - Tape one ruler to the end of the wave tank as a backstop to stop the paddle from going past vertical.
   - Tape a second ruler along the top edge of the wave tank (the yellow ruler in the diagram).
   - Tape a third ruler 5 cm in front of the backstop as the paddle stop.

2. Set the paddle in the paddle groove and practice generating standing waves.
   - Predict what will happen when you use the paddle to create wave pulses. Draw or describe your predictions.
   - Take turns creating waves. Observe as others create waves and let the wave maker know when a standing wave is created.
   - Determine the best method for creating a standing wave.
   - Record your method for creating a standing wave.

3. Make profiles of a standing wave at a frequency of 120 beats (waves) per minute and a paddle-stop setting of 5 cm.
   - Set the metronome to 120 beats per minute.
   - Make a standing wave using your method from step 2. The paddle should hit the front paddle stop once per beat.
   - How do you know when you have created a standing wave?

4. Print a watermark profile of the standing waves.
   - Tape construction paper together to make a long sheet two-thirds the length of the wave tank.
   - Hold the paper near the top corners just above the water level (see diagram above).
   - Quickly but carefully dip the paper in and out of the water.
   - Trace the profile of the waves with a pencil.

5. Label the crests and troughs on your wave profile.
   - Devise a method for measuring wavelength on your wave profile (see diagram below).
   - Devise a method for measuring wave height on your wave profile (see diagram below).
   - How did you identify the crests and troughs on your wave profile?

6. Use your method from step 5 to measure the wavelength and wave height of your wave profile (see diagram below). Record these measurements on your wave profile and in the data table provided.
ACTIVITY WORKSHEET: Catching a wave (continued)

7. Predict and give reasoning for what will happen when you change the frequency or paddle-stop settings as follows:
   a. Frequency = 100 waves per minute; paddle stop = 5 cm
   b. Frequency = 120 waves per minute; paddle stop = 10 cm
   c. Frequency = 100 waves per minute; paddle stop = 10 cm

8. Test your prediction from step 5. Repeat steps 3–5 for the following conditions:
   a. Frequency = 100 waves per minute; paddle stop = 5 cm
   b. Frequency = 120 waves per minute; paddle stop = 10 cm
   c. Frequency = 100 waves per minute; paddle stop = 10 cm

   - Did your results match your predictions? Explain.
   - What patterns or relationships do you see in your data?

Data table  Effects of frequency and length of wave pulse on wavelength (L), wave height (H), wave speed (S), and wave period (T).

<table>
<thead>
<tr>
<th>Length of wave-pulse paddle-stop setting</th>
<th>Number of wave pulses per minute (frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (F) = 120 waves per minute = 2 waves per second</td>
<td>Frequency (F) = 100 waves per minute = 1.7 waves per second</td>
</tr>
<tr>
<td>5 cm</td>
<td>Wavelength (L) = Wave height (H) = Wave period (T) = Wave speed (S) =</td>
</tr>
<tr>
<td>10 cm</td>
<td>Wavelength (L) = Wave height (H) = Wave period (T) = Wave speed (S) =</td>
</tr>
</tbody>
</table>

Questions
1. Describe how you created standing waves in the wave tank. In your description, include information about the paddle and your timing.
2. If the paddle stop is constant, what happens to the wavelength as the frequency decreases?
3. Describe the relationship between frequency and wavelength that you observed. How could you express this relationship mathematically?
4. How did frequency and paddle-stop setting affect the wave height? Explain your answer.
5. One equation for wave speed is speed = frequency x wavelength (S = FL).
6. Using the information in the data table, calculate wave speed (cm/s) for each of the four standing waves you measured. Record your results in the data table.
7. Describe how frequency and wave speed are related.
8. The period of a wave is the inverse of its frequency (T = 1/F). Use this relationship to calculate wave period in seconds per wave.
9. What is the relationship between wave period and wave speed?
10. How are the waves you created in the tank similar to and different from waves in the ocean?