Grades

9-12

Strategic

Science

Teaching

Title of Lesson:

Standing Waves

Essential Question:

How does energy move through space?

Conceptual Statement:

Waves carry energy from one place to another, and have characteristic properties by which they can be described.

Conceptual Learning Sequence:

This lesson is part of a conceptual unit on the characteristics of waves. It is appropriate after students know that energy has many forms. This lesson introduces the nature of waves and their characteristics, including that waves carry energy from one place to another.

Student Outcomes:

- Students explore the properties of waves.
- Students investigate waves through simulations and hands-on experiments that lead to under standing wave properties and the usefulness and limitations of models.
- Students use "Reciprocal Teaching" as they read sections of *John Glenn: A Memoir*, and apply it to their experiments and simulations.

Lesson Overview:

In this lesson, students engage in a simulation to introduce the concept of waves as a vibration that travels through space and time, and to pique their interest in wave properties. They investigate additional wave features in experiments using tuning forks. Students use "Reciprocal Teaching" as they read sections of *John Glenn: A Memoir*, and apply their understanding of waves to a new situation presented in the reading.

English Language Learning:

English Language Development standards are referenced in the lesson where appropriate. The hand icon appears throughout the lesson when learning strategies and lesson components are identified as pathways for academic success and reflect critical developmental differences for students who are English learners.

Literature in the Science Learning Cycle:

The literature selection, *John Glenn: A Memoir*, is used in the ELABORATE stage to help students extend their understanding by applying their knowledge of waves to a new situation.

Learning Strategy:

This lesson uses “Reciprocal Teaching,” where students explore science text and share with others. Students explain to each other how to read and comprehend science materials. This strategy uses four processes: questioning, summarizing, clarifying, and predicting. (See Appendix pages 178-179.)

Literature Selection:

Title: John Glenn: A Memoir
Author: Glenn, John, with Taylor, Nick
Publisher: Bantam Books, New York, 1999.
Annotation: This autobiography describes Glenn's experiences in testing new fighter jets, and gives a behind-the-scenes account of significant events in the U.S. space program.
Genre: Autobiography

California Science Content Standards:*

<u>Science Standard: Grades 9-12 Physics</u>

Waves

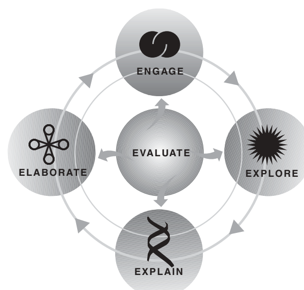
4. Waves have characteristic properties that do not depend on the type of wave. As a basis for understanding this concept:
   a. Students know waves carry energy from one place to another.
   b. Students know how to identify transverse and longitudinal waves in mechanical media, such as springs and ropes, and on the earth (seismic waves).
   c. Students know how to solve problems involving wavelength, frequency, and wave speed.

<u>Investigation & Experimentation</u>

1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other four strands, students should develop their own questions and perform investigations. Students will:
   d. Formulate explanations using logic and evidence.
   g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.

*Selected standards addressed within this lesson.

Lesson at a Glance



Science Learning Cycle	Objective Learning Strategy, Science Process	Suggested Time
ENGAGE	Students engage in a simulation that models how waves transfer energy from one place to another. Observing, Communicating, Comparing, Ordering	50 minutes
EXPLORE	By experimenting with tuning forks, students explore the mathematical relationship between frequency and wavelength. Observing, Communicating, Comparing, Ordering	50 minutes
EXPLAIN	Students explain their results by qualitatively comparing the wavelengths obtained with three different tuning forks. They use their data to calculate the speed of sound, and compare their results with other student groups. Communicating, Comparing, Relating,	50 minutes
ELABORATE	Students use "Reciprocal Teaching" as they apply their understanding of waves to the destructive standing waves that John Glenn experienced in testing jet fighter planes. Communicating, Comparing, Relating, Applying	50 minutes
EVALUATE	Students evaluate their understanding by designing simulations to model different wave properties and phenomena. Teacher evaluates student understanding of student outcomes in this activity as well throughout the lesson. Observing, Communicating, Comparing, Relating, Applying	100 minutes

Standing Waves

Teacher Background:

Waves are vibrations that move through space and time. While we are all familiar with waves, we tend to have the misconception that the material of the wave travels in the direction of the wave propagation. Upon deeper reflection, such as analyzing a wave traveling across a field of tall grass, we come to realize that a wave represents a disturbance or vibration moving across a medium, but that the parts of the medium do not leave their places. This is an example of a longitudinal wave in which the medium vibrates parallel to the direction of wave propagation. In a transverse wave (such as a slinky moving side-to-side), the medium vibrates perpendicular to the direction of wave propagation.

Unlike physical objects, more than one wave can exist in the same time and same space. When waves occupy the same space at the same time, they interact with each other resulting in interference patterns that depend on whether they are in phase with one another, and also depending on their frequencies and amplitudes.

A standing wave is a particularly dramatic interference pattern. It has locations that do not change position (nodes), and locations that alternate rapidly between being displaced maximally to one side and then maximally to the opposite side. The name "standing wave" may sound calm, as if the wave stays in one position. This is true only at the nodes. The maximum positions rapidly alternate between being stretched to the maximum in opposite directions, resulting in the potential of standing waves to cause dramatic damage or produce dramatic results.

Scientists use models, mental and/or physical, to help them understand phenomena. Since a model is a representation, it has features that more or less accurately represent the phenomenon, and other features that do not.

Related California Content Standards

Mathematics: Grades 9-12

Algebra 1

15.0 Students apply algebraic techniques to solve rate problems, work problems, and percent mixture problems.

Trigonometry

2.0 Students know the definition of sine and cosine as y-and x-coordinates of points on the unit circle and are familiar with the graphs of the sine and cosine functions.

Grouping: Whole group, groups of 4, individual

For simulations and hands-on activities, mix the EL with the native speakers. For debriefing, include at least two EL with native speakers to form discussion groups.

Materials:

Per Class

1 Heavy duty 25 ft coiled phone cord
1 Short piece of strong string to tie one end of the phone cord
Chart showing the positions for Human Wave Model #2 (Teacher Page 1.0)
Chart showing the positions for Human Standing Wave Model (Teacher Page 2.0)

Per Group

3 Tuning forks (frequencies of 256-C, 320-E, 384-G)
1 Meter stick
1 500 ml or 1 liter Graduated cylinder
1 Clear plastic tube about 3 cm in diameter and 40 cm long

Per Student

1 Copy of *John Glenn: A Memoir*
Student Pages 1.0 and 2.0

Advance Preparation:

1. Cut the clear plastic pipe into lengths of 40 cm.
2. Find a good location to tie one end of the 25 foot coiled phone cord where you can stand about 2 meters away from where it is tied and where students can observe waves in the cord when you vibrate it side-to-side.
3. Create a chart illustrating the five positions in the Wave Model #2 simulation (Teacher Page 1.0).
4. Create a chart of the 9 locations in the Human Standing Wave Model simulation but do not fill in the Start or Alternate Positions (Teacher Page 2.0).
5. Have a strip of paper for each location of the Human Standing Wave Model (e.g., student at location 3 switches between +2 and -2 position).

Teacher Resources:

Tuning forks available from Carolina (www.carolina.com item WW-75-4218) or from Flinn Scientific, Inc (www.flinnsci.com item AP9032).

The Exploratorium website (www.exploratorium.edu) and Paul Doherty's wave lessons (http://www.exo.net/~pauld/summer_institute/summer_day10waves/day10_waves.html).

Teacher Tips:

- Do not stretch the phone cord. Get the heavy duty type, and have a backup phone cord available. Practice getting 1/2, 1, 2 or more waves by moving your hand side-to-side. Use flicks of the wrist and minimize arm motion.
- You can substitute a slinky for the phone cord but it works best on the floor or a tabletop.
- Obtain clear plastic tubing from an aquarium supply store.
- As an alternative to Step 7 in the ENGAGE stage, have students design their own Human Wave Model #2 (Teacher Page 1.0) rather than following teacher directions. Plan additional time if you select this alternative. Have students work in groups of four to brainstorm, share, and critique their models. If necessary, correct misconceptions and incorporate features into the student presentations so they are as accurate as Human Wave Model #2.
- You can model changing the frequency (EVALUATE stage, step 34) in two ways. In the first way, simply increase the speed of the beats. In this case, the wavelength remains the same (it is still spread over 9 students), and you have modeled the direct relationship between wave speed and frequency (speed of wave = frequency times wavelength). In the second way, keep the original beat but decrease the wavelength by eliminating the +1 and -1 positions. In this second case, you have modeled an increased frequency due to a decreased wavelength. With wave speed being constant, frequency and wavelength are inversely related to each other (frequency equals speed of wave divided by wavelength).

VOCABULARY

amplitude - the maximum displacement of the medium from its resting position

frequency - the number of waves that pass through a point per unit time

longitudinal wave - a wave that vibrates parallel to the direction of wave propagation (e.g., sound waves)

medium - the material though which the wave is moving

node - a location in the wave that does not move (no displacement of the medium from its resting position)

propagation - direction in which the wave moves through the medium

standing wave - a wave pattern that features stable nodes and locations that rapidly change position

transverse wave - a wave that vibrates perpendicular to the direction of wave propagation (e.g., water waves and light)

wavelength - the distance from any point on a wave to the next adjacent equivalent point (e.g., peak to peak)

wave speed - the speed with which the wave moves through a medium, either measured directly or calculated by multiplying wavelength times frequency

The Science Learning Cycle:

Standing Waves

ENGAGE:

1. Inform students that they will be exploring the nature of waves. Securely tie one end of a 25 ft length of heavy duty coiled telephone cord to a secure location. Fasten a piece of tape at one spot about halfway along the cord. Hold the cord horizontally about 2 meters away from the attachment location. Rapidly flick your wrist side-to-side just once.

2. Have the students describe what happens as a result of that single motion. (A disturbance moves along the length of the wire from you to the attachment point and back again. This happens several times with the amount of motion decreasing each time.)

3. Have the students focus on the piece of tape. Flick the cord again. Ask them what direction the disturbance is moving (along the length of the wire). Ask them to compare how each individual part of the wire is moving relative to the direction that the disturbance is moving (the parts of the wire are moving back and forth, perpendicular to the direction that the disturbance is moving down the length of the wire). Repeat the disturbance so students can confirm these observations.

4. Stand as before, but now move your hand side to side rapidly enough so that a full wavelength of motion is readily observed. Make sure students can observe the full wavelength. Compare again the motion of the wave (along the length of the wire) to the motion of the sections of the wire (back and forth, perpendicular to the direction of wave propagation).

5. Have students conduct the simulation that shows Human Wave Model #1 (Teacher Page 1.0).

6. Ask students to read the description of transverse waves (Student Page 1.0). Ask them how Human Wave Model #1 accurately represents transverse waves. In what ways, does Human Wave Model #1 inaccurately represent transverse waves? Chart the main discussion points.

7. Have students conduct the simulation that shows Human Wave Model #2 (Teacher Page 1.0). Alternatively, you can have them engage in this simulation in an open-inquiry mode (see Teacher Tips).

8. Ask students to discuss whether Human Wave Model #2 more accurately represents transverse waves than Human Wave Model #1. Refer to the discussion about the accuracy and inaccuracy of Human Wave Model #1.

EXPLORE:

9. Introduce the concepts of wavelength, frequency, and amplitude with the following demonstration. Securely tie one end of the 25 foot heavy duty coiled telephone cord as in Step 1 above. Show how a side-to-side motion can generate a wave whose wavelength is equal to the length of the coil. Decrease the frequency and demonstrate that the wavelength is now equal to twice the length of the coil (only see half a wave on the coil). Demonstrate that faster side-to-side vibrations (higher frequencies) result in shorter wavelengths (more than one full wave in the same length of coiled wire). Have students note the amplitude of the waves.

10. Explain to the students that they are going to experiment with sound, which is another wave phenomenon. Assign students to groups of four and ask them to identify who will assume the following roles: 3 investigators, 1 recorder/reporter. Note: have students rotate roles periodically during the experiment.

11. Have one investigator from each group obtain the materials for their group. Distribute Student Page 2.0.

12. Instruct the students to follow the procedures, and to record their observations with all 3 tuning forks. Remind them to only use a soft object to strike the tuning fork (e.g., piece of rubber, heel of shoe, not the graduated cylinder or the lab bench!). Ask the recorder to write observations and measured distance of maximum sound. Remind groups to predict the distance for the second and third tuning forks. Have all students record measurements and predictions in a student-made data table.

13. When the investigation is completed, have the students return the materials to the collection center.

The Science Learning Cycle: **Standing Waves**

EXPLAIN:

14. Have the recorder/reporter from each group whiteboard their group's results. Have the group describe their observations and the relationship between frequency and the distances they measured (inversely related).

15. Ask the recorder/reporter to share their results, and have the class discuss agreements and discrepancies among the results.

16. Introduce the equation that wave speed = wavelength times frequency. The frequency is in Hertz which is a "per second" unit.

17. Have students use their group data to calculate the wavelength in meters for each tuning fork (Student Page 3.0, Part 1). Remind them that the distances they measured of maximum sound were locations equal to one-quarter of the respective wavelengths. Ask several students to share their answers to the two questions in Part 1.

18. Ask students to complete Part 2 of Student Page 3.0, calculating the speed of sound for each tuning fork. Have them whiteboard their calculations and ask groups to share their data with each other. Discuss the range of values obtained.

19. Have the students compare their results with the accepted value for the speed of sound (approximately 345 meters per second in dry air at 20 degrees Celsius). Discuss the range of values and possible sources of experimental variation.

ELABORATE:

20. Have students read the beginning of Chapter 11 of *John Glenn: A Memoir* (pages 203-212) as homework, and/or describe John Glenn's role as a test pilot for fighter jet planes.

21. Tell students that they will be using "Reciprocal Teaching" as a way to help them understand what they are reading. Write the words QUESTIONING, SUMMARIZING, CLARIFYING, and PREDICTING on the board or on chart paper. Discuss the meaning of those words (as described in Appendix, pages 178-179) with students, and explain that they will be practicing those processes using readings from *John Glenn: A Memoir*.

22. Preface the following reading by telling students that it involves John Glenn testing the F7U Cutlass fighter jet designed and made by the Chance Vought Company. Have students read four paragraphs beginning with the words "The low-altitude armaments . . . " (page 213) and continuing through ". . . operation of the fuel control-flameout" (page 214).

23. In the next few steps, model "Reciprocal Teaching" as if you are the reader/discussion leader. Model "Questioning" by asking the students, "What caused the engines to quit at high altitude?" (air is thin at that altitude and firing the canons caused a standing wave that interfered with the airflow and operation of the fuel control).

24. Model "Summarizing" for the four paragraphs by restating in your own words what happened in the four paragraphs.

25. Model "Clarifying" by focusing on the last paragraph as being a difficult paragraph. Note that John Glenn compared the standing wave to the sound wave resonating in an organ pipe. Tell them that these are both phenomena that occur when waves interact with each other.

26. Model "Predicting" by asking students what they think will happen next.

27. Assign students to groups of 3 and ask them to choose a discussion leader for each group. Ask the students to read the next three paragraphs in the book, and use "Reciprocal Teaching" to discuss the paragraphs. Have the group discussion leaders in each group first ask a question to their group about the reading, and then summarize and clarify. Have them conclude their role as discussion leader by asking the group to predict based on the reading.

28. Tell the students that the military abandoned the Cutlass because of other problems. John Glenn then tested the F8U Crusader. On one flight he had problems controlling the plane after he tested its cannons. The next reading describes what happened after he landed. Have students read 5 paragraphs beginning "After I landed . . ." (page 218) through"… like a bullwhip and just flicked it off (page 219). Have a different student in each group serve as the discussion leader and follow "Reciprocal Teaching" to debrief these paragraphs.

29. Ask students to read the next 2 paragraphs (pages 219-220). Using "Reciprocal Teaching," have a different student in each group play the role of discussion leader.

30. Have the students share their experience using "Reciprocal Teaching," and how it helped make the text more understandable.

EVALUATE:

31. Have students in groups of 4 take a piece of chart paper and divide into four sections. Label the sections: Telephone Cord; Human Wave Models; Tuning Forks; John Glenn reading. Have them list in each section the characteristics of waves they learned.

32. Have students from several groups share their learnings and discuss as a whole class (wavelength, frequency, amplitude, wave equation, medium moving perpendicular to direction of wave propagation, waves interacting with each other to make loud sounds or cause structural damage).

33. Review the terms wavelength, amplitude, and frequency by revisiting Human Wave Model #2. Divide the following three tasks among the groups (several groups will have the same task). Each group will use Human Wave Model #2 as the basis for their demonstration. Each group will propagate a wave based on their given task:
    - Task #1 is to demonstrate what wavelength is (the length of the wave shown by all 9 students at any point in time), and model a wave with twice the wavelength.
    - Task #2 is to demonstrate what amplitude is (distance from sitting to standing with arms raised, or from sitting to squatting with hands on floor), and model a wave with twice the amplitude.
    - Task #3 is to demonstrate what frequency is (how many complete waves pass through any point per second) and model a wave with twice the frequency (see Teacher Tips).

34. Remind students about the standing waves that caused damage to John Glenn's plane. Follow the directions on Teacher Page 2.0 to have students model, observe, and analyze a standing wave.

35. Have students work in groups of 4 to discuss how a standing wave could cause serious damage to the wing of John Glenn's plane. Ask each group to make a drawing that illustrates how the standing wave caused the damage (parts of the wing had to swing from one extreme position to another while other parts of the wing did not move at all). Ask students to label node, amplitude, and wavelength on their drawing.

35. Have the groups share and critique their drawings and explanations.

37. Jiggle the coiled telephone wire so that it displays one full wavelength. Have students observe the wire and individually write what is happening (it is a standing wave).

Teacher Reflection:

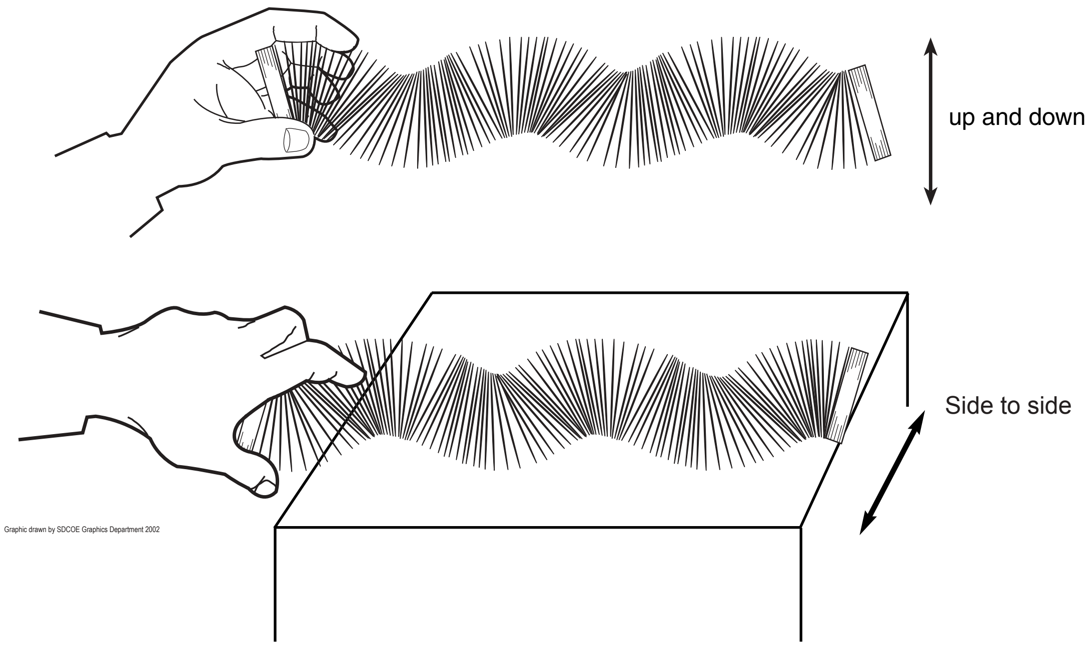
1. How does the student work provide evidence that they learned the properties of waves, and that they recognize the limitations and usefulness of models?
2. What instructional strategies used in this lesson promote student understanding? How do you know?
3. How does the literature selection support student understanding of the science concepts and processes?
4. How would you modify instruction to ensure understanding of student outcomes by all students?

Transverse Waves

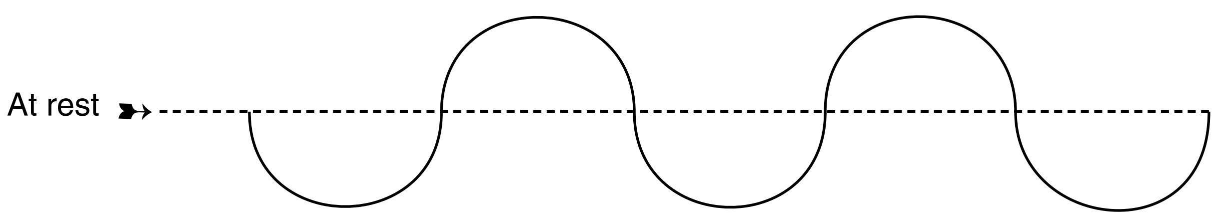
Waves transfer energy from one place to another without transferring matter between the two points. When you vibrate a rope or wire, you can see a wave travel down the length of the wire. The parts of wire itself are moving perpendicular to the direction that the wave moves. The same kind of thing happens with a water wave traveling across the ocean. The water in any one place is moving vertically up and down while the wave itself moves horizontally across the ocean.

The material through which the wave is moving is called the medium. In the case of the stretched wire, the wire is the medium. In the case of the water wave, the ocean is the medium.

These are examples of transverse waves. With a transverse wave, the pieces of the medium move up and down (or side to side) while the wave itself moves perpendicular to that direction. The pieces of the medium do not travel with the wave. In this way, the wave transfers energy from one point to another without transferring matter.



A wave is spread out over space and time. It is not located in any one definite place. When we graph the shape of a wave, it looks like:

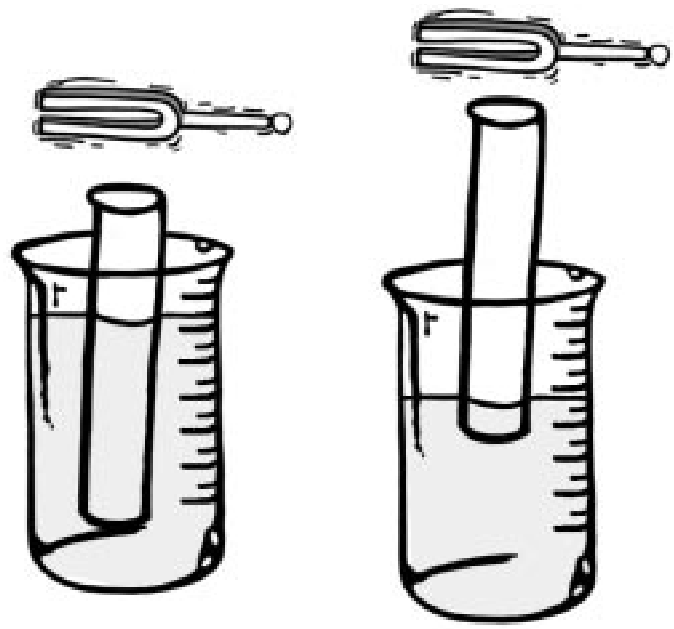


Note that each piece of the wave can have many different possible positions. The center line represents its rest position. Any point in the wave can vary from being at rest to moving up to a maximum distance above or below its rest position.

Tuning Forks

You are going to experiment with tuning forks to investigate the relationship between wavelength and frequency. In your group of 4, assign one person as the recorder/reporter. The other three are investigators. Have one of the investigators get the materials for the experiment.

Fill the graduated cylinder near the top with water. Assign one investigator to strike and hold the tuning fork. Assign another investigator to hold and move the plastic tube slowly upwards. Assign the third investigator to measure the length of the column of air when there is the maximum sound. Look at the figure below to see how you need to synchronize the movement of the tube and the tuning fork.



C (256 Hertz)
Strike the C (265 Hertz) tuning fork against a soft object (for example, a piece of rubber or rubber heel of a shoe; NOT the graduated cylinder or any hard object such as the lab bench). Hold the tuning fork about 1 cm above the tube. Slowly and continuously raise the tuning fork and the tube (synchronized with each other) until you find the first place of loud sound. Hold the tuning fork and tube at this place of maximum sound. Have the third investigator then measure the distance from the top of the water to the bottom of the tuning fork. Record your measurement. Repeat at least two or more times until you are comfortable with accuracy of the measurement.

Enter your results in a data table.

G (384 Hertz)
Repeat the experiment with the G (384 Hertz) tuning fork. Predict what distance you will measure for the place of maximum sound and record that predication in your data table.

Enter your measured results in the data table.

E (329 Hertz)
Repeat the experiment with the E (320 Hertz) tuning fork. Predict what distance you will measure for the place of maximum sound and record that prediction in your data table.

Enter your measured results in the data table.

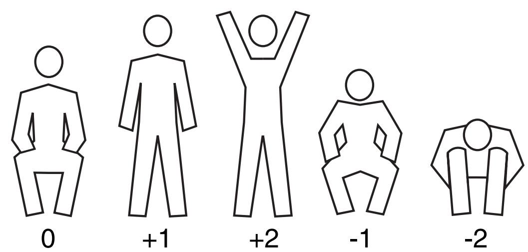
Do the Wave

Human Wave Model #1: Place 9 chairs in the front of the room facing the rest of the class. Have a student sit in each chair and ask them to "do the wave" going from their left to their right. When the wave reaches the end person, have the person on the other end begin again.

Distribute the reading about transverse waves (Student page 1.0). In groups of four, have the students discuss how Human Wave Model #1 does and does not accurately represent the nature of a transverse wave. (Accurately - it is a disturbance in the medium that moves through the medium; the particles of the medium move perpendicular to the motion of the wave; the particles of the medium do not travel with the wave; waves involve a transfer of energy between two points without being a transfer of matter. Inaccurately - at any moment, a wave is spread out continuously in space and time; any location in the wave has more than two possible positions; there are "below the line" positions in addition to "above the line" positions in the wave.)

Human Wave Model #2: Invite a different group of 9 students to sit in front of the room facing the rest of the class. Tell them they are going to demonstrate Human Wave Model #2, that you think may be a more accurate representation of a transverse wave. On a large piece of chart paper, indicate the movements that they will make as below:

0 = seated
+1 = standing, arms at side
+2 = standing, hands over head
-1 = squatting arms at side
-2 = squatting, hands on floor



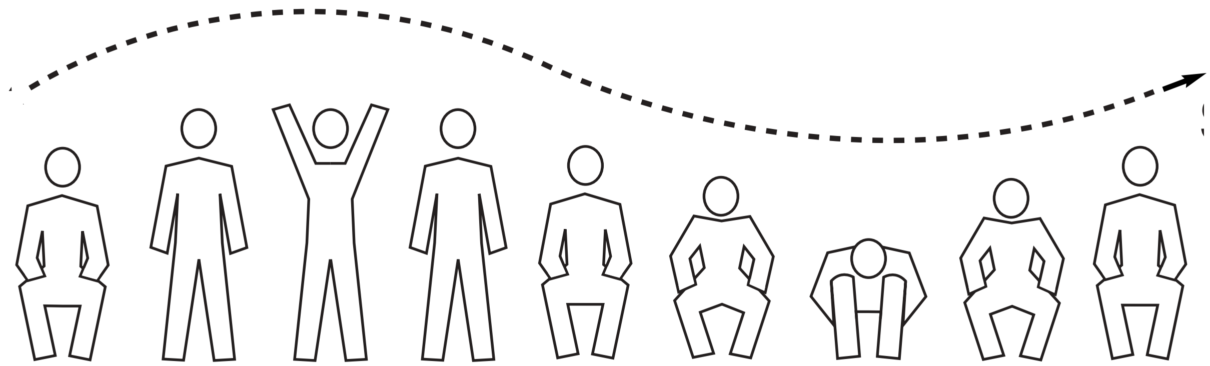
Have the students take their START positions and notice from the chart (reading horizontally) the sequence of their positions. For each beat, they will move one position to the right.

HUMAN WAVE MODEL #2								
Location	START	NEXT	NEXT	NEXT	NEXT	NEXT	NEXT	NEXT
1	0	+1	+2	+1	0	-1	-2	-1
2	+1	+2	+1	0	-1	-2	-1	0
3	+2	+1	0	-1	-2	-1	0	+1
4	+1	0	-1	-2	-1	0	+1	+2
5	0	-1	-2	-1	0	+1	+2	+1
6	-1	-2	-1	0	+1	+2	+1	0
7	-2	-1	0	+1	+2	+1	0	-1
8	-1	0	+1	+2	+1	0	-1	-2
9	0	+1	+2	+1	0	-1	-2	-1

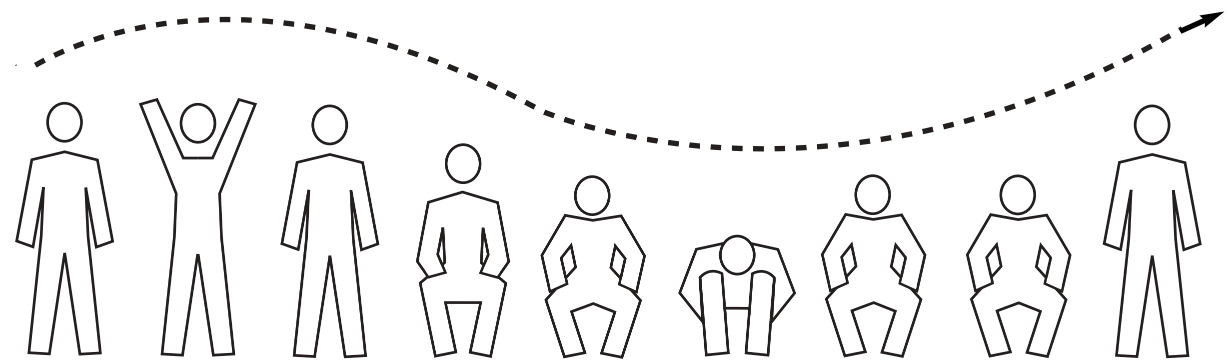
Use a steady beat to have the students model at least one full round of 9 beats. Also stop the beat at least three times during the demonstration and have students note the position of each location in the wave (in other words, what the wave looks like at a particular instant in time). Repeat with at least one other group of 9 students.

Transverse Wave

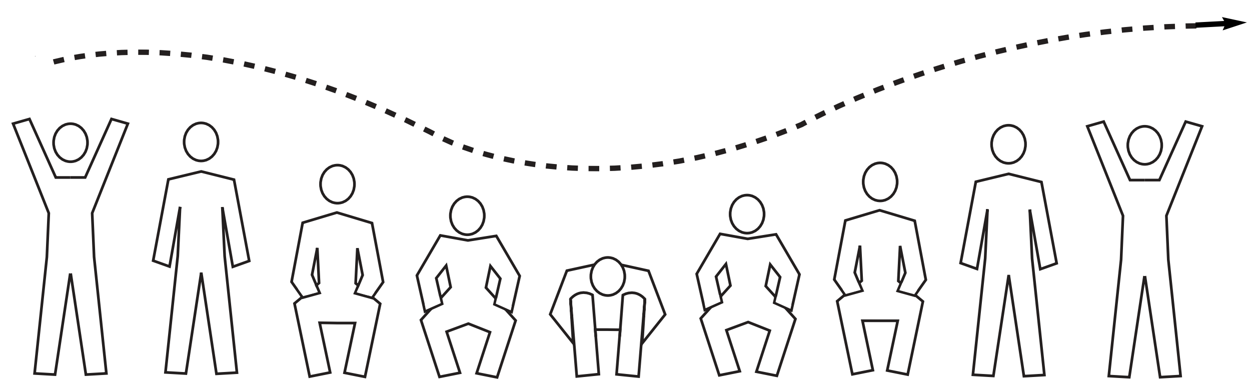
START



BEAT 1



BEAT 2

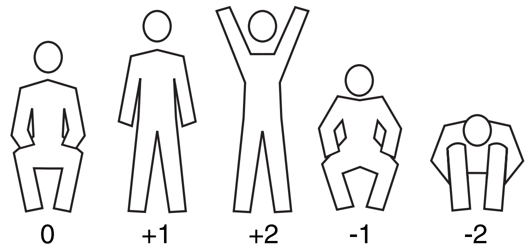


Note the wave propogates right to left and that medium motion is up and down.

Human Standing Wave Model

Place 9 chairs in the front of the room facing the rest of the class. Invite 9 students to sit on the chairs facing the class.

0 = seated
+1 = standing, arms at side
+2 = standing, hands over head
-1 = squatting arms at side
-2 = squatting, hands on floor



Place a chart on the board of the Human Standing Wave Model indicating the 9 student locations but not the start or alternate positions. Assign at least one student in the class to observe each of the 9 students. Give each of the 9 seated students a piece of paper indicating the two positions that they should take in modeling a standing wave.

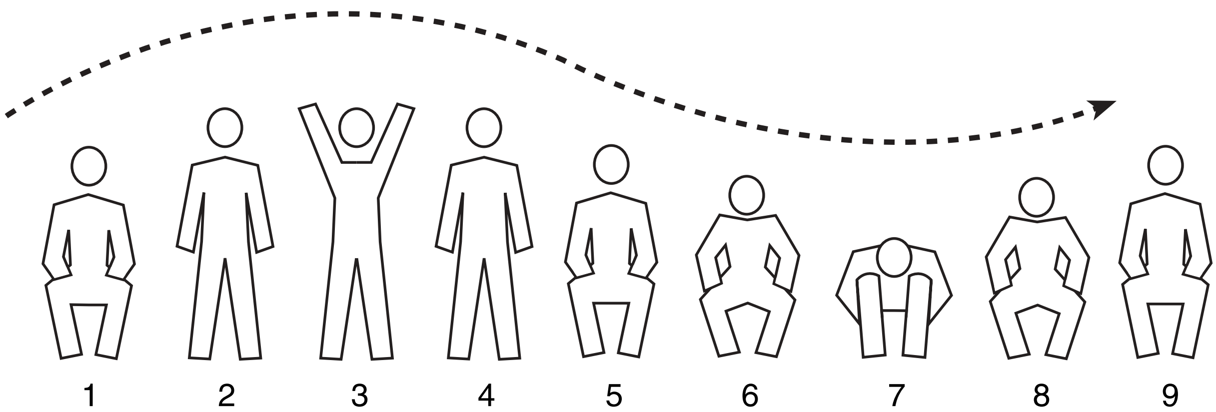
Use a steady beat (drum, bell or other device) to indicate when the students switch from one position to the other. After several rounds, have the observing students fill in the chart noting the two positions for the student they observed. A correctly completed chart looks like the one below.

HUMAN STANDING WAVE MODEL		
Student Location	Start Position	Alternate Position
1	0	0
2	+1	-1
3	+2	-2
4	+1	-1
5	0	0
6	-1	+1
7	-2	+2
8	-1	+1
9	0	0

Invite another group of 9 students to sit in front of the class. Without giving them the piece of paper for their location, have them model a standing wave. Have the class critique their demonstration.

Standing Wave

Start



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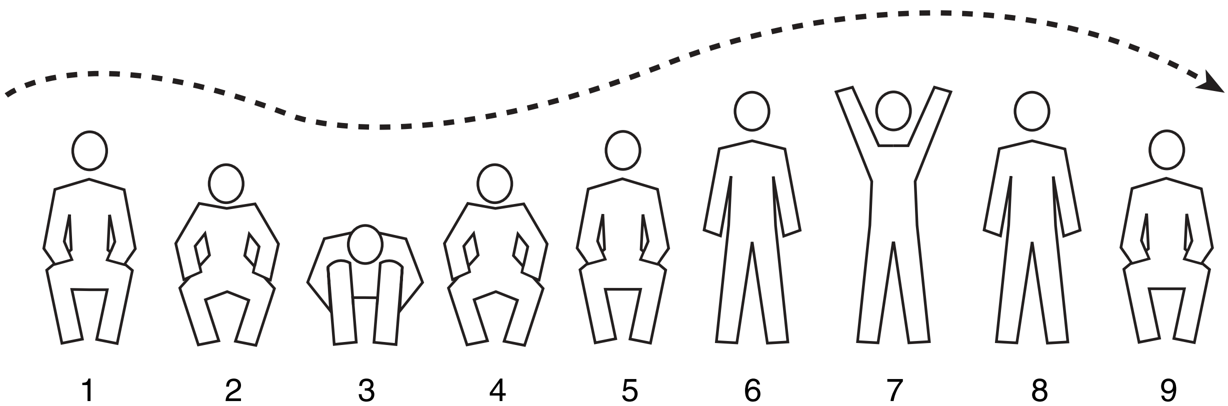

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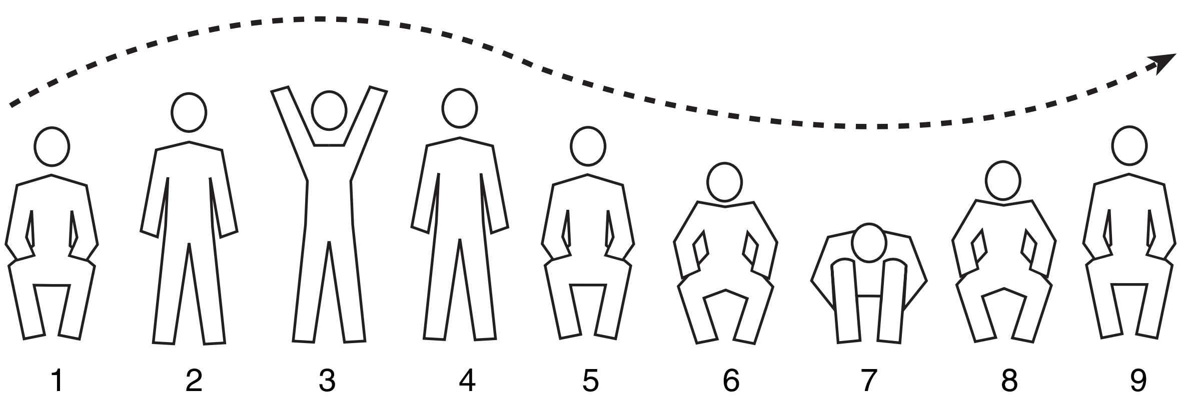
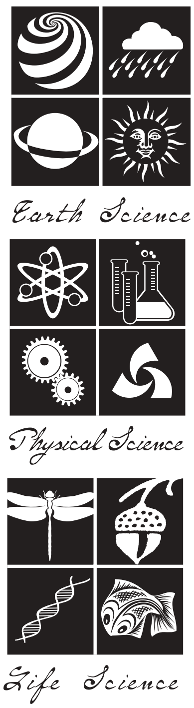


1, 5 and 9 are seated the whole time.
Maximum fluctuations at positions 3 and 7.



Strategic Science Teaching, Grades K-12:

A Sampler of Science Lessons Connecting Literature with the California Standards

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3) teaching and learning strategies to promote content literacy,
4) use of the 5 E's Learning Cycle and science investigations,
5) strategies for English Learners, and
6) complete lesson plans.

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