6 – 8 Grade

Digging Deep into Science Literacy

Activity: Continuous Waves

Purpose

You have probably seen waves on the ocean, on a lake, or even in the bath. These waves are 'disturbances' that move through the water, but similar disturbances can move through other things, such as springs, strings, groups of people, the air, and even the earth itself. In this unit we will investigate some of the properties of different types of waves and how we can understand them. The key question for this exploration is:

> ***What are some different types of waves and what are some of their characteristics and properties?***

Initial Ideas

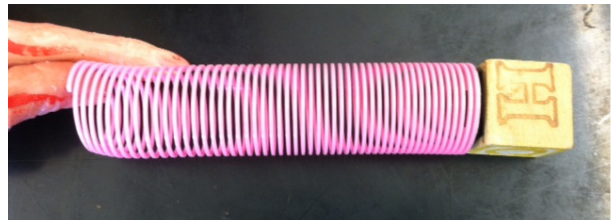
You will need:

- Spring with block attached

You have probably seen (or even been a part of) a stadium crowd doing 'The Wave' (sometimes also called the 'Mexican Wave'). Your instructor may even lead the class in a demonstration!

What conditions/factors are necessary for such a 'Wave' to be successful? (In thinking about this question it may help to consider what conditions/factors might be missing when a 'Wave' does not happen.)

Now place the spring and block on the table and pull on the open end of the spring so that its coils become ***slightly*** separated. (If the block moves, you have pulled too hard!)



Without letting go of the open end of the spring, what could you do to that end that would result in some sort of 'disturbance' moving along the spring to make the block at the other end move, even if only slightly? Experiment to find as many different ways of doing this as you can.

Describe the different ways you found to make a 'disturbance' move along the spring to make the block at the other end move. In each case, describe what you did, what the 'disturbance' looked like as it moved along the spring, and how the block moved at the other end. Also draw some pictures to illustrate your methods.

Do you think your 'disturbances' carried energy along the spring? If so, what evidence supports your thinking?

Participate in a class discussion. Make a note of any ideas that are different from those of your group.

Conditions for a Wave

In the Initial Ideas section, you created disturbances that traveled along a spring. The disturbances were examples of wave pulses and the spring was the ***medium*** through which these pulses traveled. (The medium for any wave is the material through which it moves. For example, for waves in the ocean the medium is simply the water.) In the discussion the class also probably identified another factor that is necessary for a wave to occur: a ***source*** (a way to get the wave started). Another necessity is a ***mechanism***, which is a way for the disturbance to be transmitted/communicated between different parts of the medium. For waves on springs (and strings), the different parts of the medium are physically connected together, and so it is effectively a series of contact push/pull interactions between them that is responsible for the transfer of energy.

In the following exploration, you will examine the behavior and properties of wave pulses that move along a spring.

Collecting and Interpreting Evidence

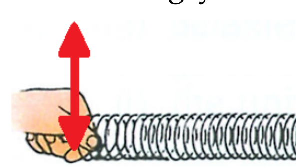
You will need:

- Long spring
- Computer with internet connection

Exploration #1: What are some different types of wave?

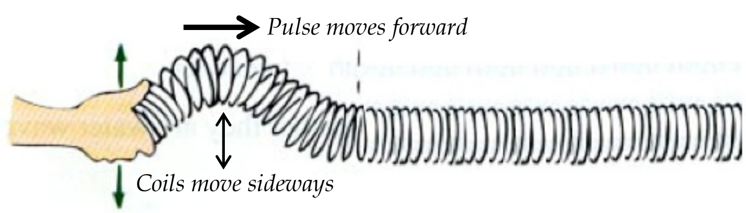
STEP 1: The class probably suggested several different ways to create wave pulses in a spring. Scientists generally classify waves into one of two different types, depending on how the parts of the medium move relative to the direction that the disturbance itself is moving. You will now use the large spring to examine these two types of wave.

Two members of your group should stretch the spring so it lies along your table with the coils distinctly separated. Now the person at one end should **quickly** move their hand sideways (at right angles to the length of the spring) and **back to its original position**. Do it only once for now and this should create a single disturbance (pulse) that moves along the spring. Repeat making these single pulses as necessary to answer the following question.



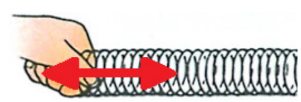
While the disturbance moves along the spring, carefully watch one of the coils near the middle. As the disturbance passes, does the coil move sideways in the same manner that the hand did, or does it move forward, in the same direction that the disturbance is traveling?

When the parts of the medium (the coils of the spring in this case) move side to side in a direction that is perpendicular (at right angles) to the direction that the wave that is moving through it, this is called a ***transverse wave***. By moving the end of the spring to the side and back you created a single transverse wave pulse that moved through the spring. (Note that moving the end of the spring upward and then back down would also create a transverse wave pulse, but the coils would be moving up and down instead of side to side.)



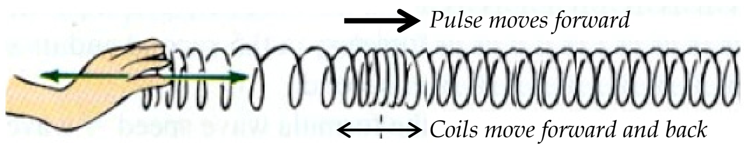
Top view of transverse wave pulse moving along a spring

STEP 2. Now have the person at one end of the spring **quickly** move their hand forward a few inches (toward the other end of the spring) and **back to its original position**. This should create a different looking single wave pulse that moves along the spring. Repeat making these pulses as necessary to answer this question.



While this pulse moves along the spring, carefully watch one of the coils near the middle. As the pulse passes, does the coil move forward and backward like the hand did, or does it move sideways like it did for a transverse wave?

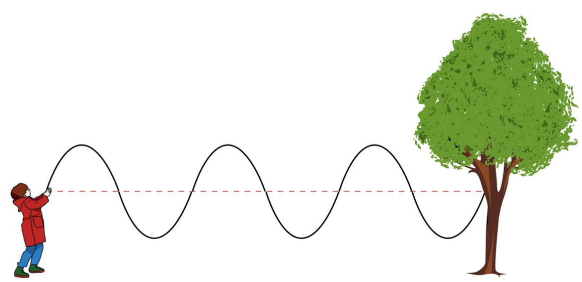
When the parts of the medium move back and forth in the same direction as the wave that is moving through it, this is called a ***longitudinal wave***. (Sometimes also called a compression wave.) By moving the end of the spring forward and back, you created a single longitudinal wave pulse that moved through the spring.



Top view of longitudinal wave pulse moving along a spring

You have now seen how both transverse and longitudinal wave pulses can move along a spring. Notice that, in both cases, if we focus on the wave pulse itself (the disturbance), we see it move forward through the medium, transferring energy as it goes. But if we focus on a small piece of the medium (a single coil of the spring), while it does move slightly as the wave passes (side to side or back and forth depending on whether it is a transverse or longitudinal wave pulse), after the wave has passed that piece of the medium is back where it started (or close to it). Thus, a wave is a way of transferring energy (and hence information) though a medium without any overall movement of the material itself.

Exploration #2: What are some characteristics of continuous waves?



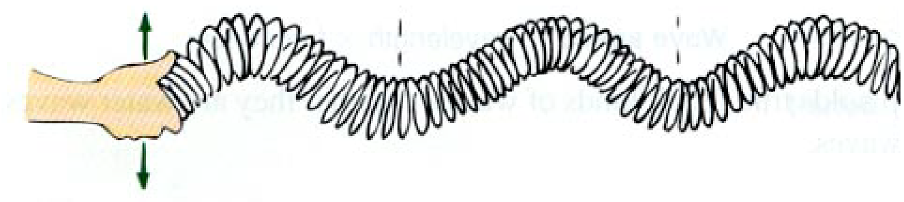
In the previous exploration, you examined the behavior of single wave pulses on a spring. If the source that created these pulses were to keep repeating exactly the same motion over and over again, it would create a series of identical pulses that move through the medium. We call such a series of identical pulses a ***continuous wave***, and in this exploration, you will examine these in more detail.

STEP 1. In the previous exploration, you created single wave pulses on a spring in two ways. You created a *transverse* wave pulse by moving the end of the spring to the side and then back again. If you were to keep repeating this motion, moving your hand 'side-to-side' in the same manner over and over again, you would create a series of pulses that would move along the spring.

Stretch the spring out along the table (or floor) as you did in the previous exploration and try this now.

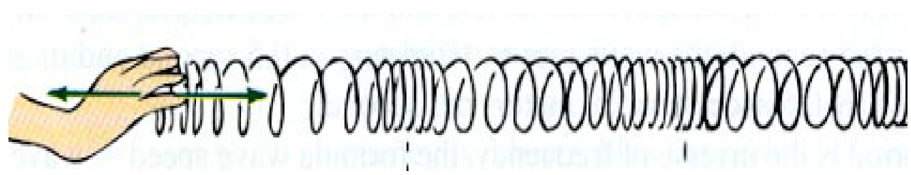
The pattern you see on the spring while you are doing this should look something like that shown below. It consists of a regular series of identical pulses that move along the spring as a ***continuous transverse wave***.

Continuous transverse wave on a spring

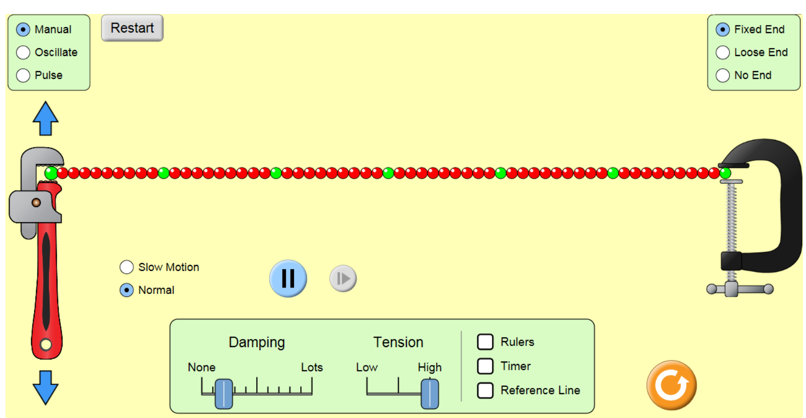


Similarly, in the previous exploration, you created a *longitudinal* wave pulse by moving the end of the spring forward and then back again. Stretch the spring along the table and keep repeating this motion to create a ***continuous longitudinal wave***.

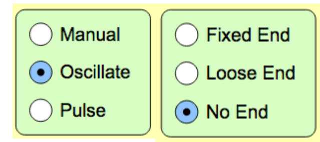
Continuous longitudinal wave on a spring



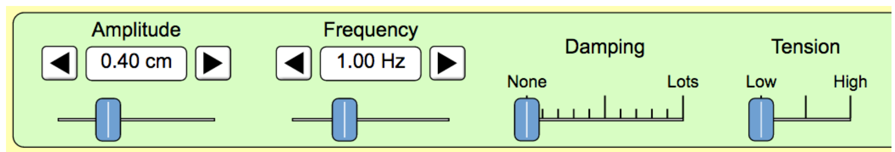
STEP 2. You will now use the *PhET Waves on a String* simulator to examine some properties of continuous waves. Open the simulator. It shows a straight string on which waves can be generated by a source that moves the left end of the string up and down. (This would be like you moving the end of your spring up and down.) Note that the string is represented as a series of dots – this is done to make it easier to follow the motion of one particular part of the string if necessary. (Imagine a transparent string with a regular series of dots painted on it.)



Select **Oscillate** as the source of the wave in the simulator. This will introduce a mechanism that moves the end of the string equal distances up and down repeatedly in a consistent manner. Also, set the string to have **No End**.

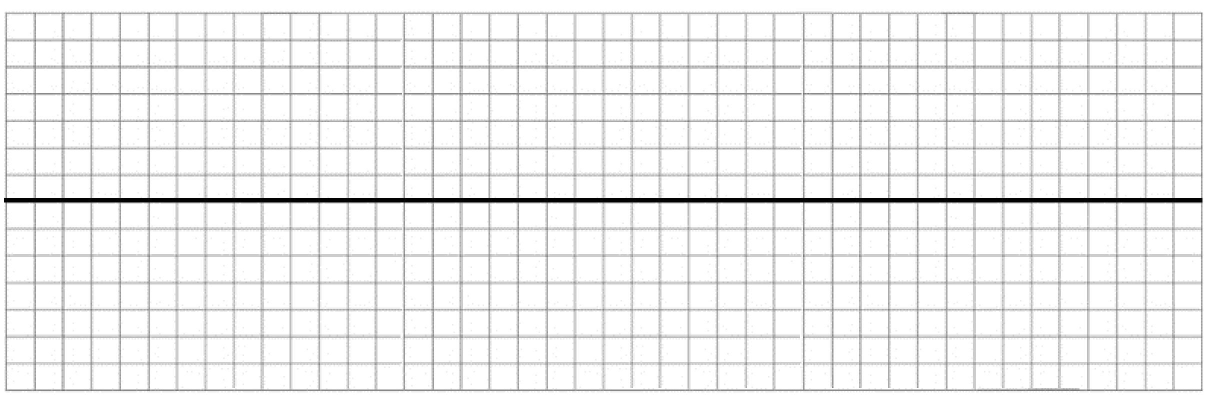


Next, set the controls at the bottom of the window as shown below. (**Amplitude** = 0.40 cm, **Frequency** = 1.00 Hz, **Damping** = None, **Tension** = Low.)



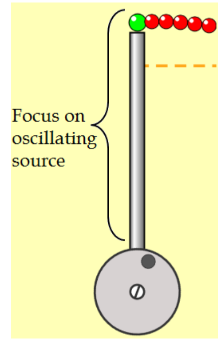
After a few seconds there should be a continuous transverse wave moving along the string. (Note that the source moves both above and below its equilibrium position, as does each part of the string.)

Pause the simulation and sketch the string to show a 'snapshot' of the continuous wave you have created. (Just draw a continuous line rather than the series of dots shown by the simulator.) The line below represents the equilibrium position of the string.



We will call the highest points of such a wave (above the equilibrium position) ***peaks*** and the lowest points (below the equilibrium position) ***valleys***. Mark all the peaks on your sketch with a **P** and all the valleys with a **V**.

STEP 3: Now try varying the amplitude and frequency controls and see what effect they have on the motion of the oscillating source. ***Focus your attention on the motion of the oscillating source.***



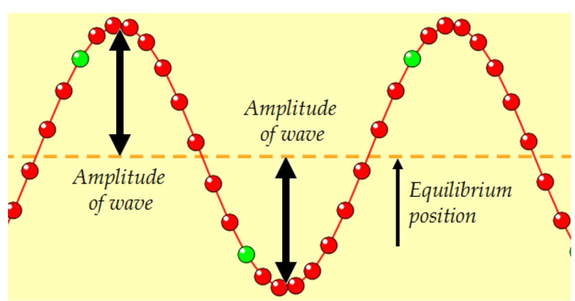
How does the motion of the **oscillating source** change as you increase and decrease the amplitude?

How does the motion of the **oscillating source** change as you increase and decrease the frequency?

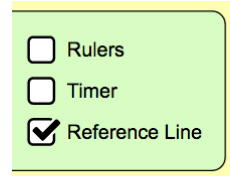
The ***frequency*** of the source is a measure of how often it completes one full cycle of its motion. The value of the frequency is actually a count of how many cycles it completes in a particular period of time. Usually this fixed period is taken to be one second and then the frequency is given units of Hertz (Hz). To make the motion of the source easy to follow, in this exploration, we are using a frequency of 1.00 Hz, which means the source completes exactly one cycle of its motion in one second. (Often the letter '*f*' is used to represent frequency.)

Let us now consider what effect varying the amplitude and frequency of the source have on the continuous wave that it is generating.

STEP 4. The amplitude of a wave pulse is the maximum distance any part of the string moves away from its equilibrium position as the wave pulse passes. We can similarly regard the amplitude of a continuous wave as the height of the peaks above the equilibrium position (which is the same as the depth of the valleys below the equilibrium position).

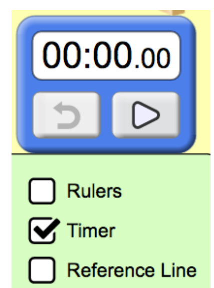


Does the amplitude of the wave seem to be the same as, or different from, the amplitude of the source that is creating it? (If you are not sure, use the **Reference Line** tool to check.)



Sketch a 'snapshot' of the wave on the simulator and mark the amplitude of the wave at two peaks and two valleys.

As well as the source oscillating up and down (with the frequency you have set), each part of the string is also oscillating up and down. In order to measure the frequency of both the source and some parts of the string, click the **Timer** checkbox to display a timer tool.



The **Frequency** of the oscillating source should still be set at 1.00 Hz. Start the timer just as the source reaches the top of its motion and stop it after it has completed **ten** whole down and up cycles.

Approximately how long does it take the **source** to complete ten cycles? Why does this make sense?

Now focus your attention on one particular part (or dot) of the string. (You may find that one of the green dots is easier to follow.) Reset the timer; start it just as your dot reaches the top of its motion and stop it after it has completed **ten** whole down and up cycles. Make a note of the timer reading, reset it, and repeat this for some other parts of the string. Answer the following questions based on your results.

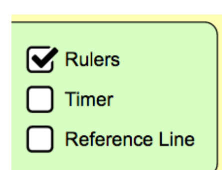
Does the amount of time it takes each part of the string to complete ten down and up cycles seem to be close to the same as that for the source, or is it very different?

What does your answer to the previous question imply about the frequency with which each part of the string is oscillating up and down? Is it the same as, or different from, the frequency at which the source is oscillating up and down?

Since the string is attached to the oscillating source, each part of the string moves up and down at the same frequency and amplitude (assuming there is no damping) as the source. Thus, we can also talk about the frequency and amplitude as a characteristic of a continuous wave itself. For example, when a continuous wave is being produced by an oscillating source that has an amplitude of 3 cm and frequency of 5 Hz, we can also say that the wave it generates also has an amplitude of 3 cm and a frequency of 5 Hz.

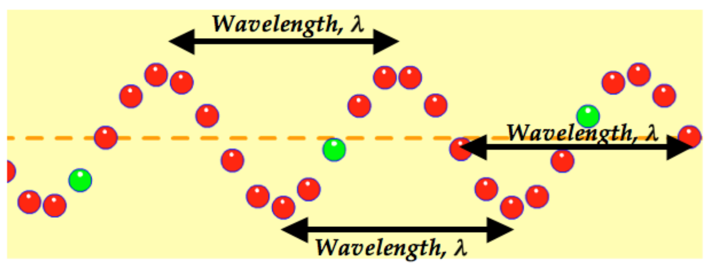
STEP 5: Return the amplitude and frequency controls to their original values (0.40 cm and 1.00 Hz) and wait a few seconds for a regular pattern to form again.

As the wave moves along the string, it traces out a repeating pattern of peaks and valleys. Pause the simulation and select **Rulers** and use the horizontal ruler to answer the following questions about this pattern.



Does the distance between successive (neighboring) peaks seem to be about the same, or is it very different depending on which two successive peaks you look at?

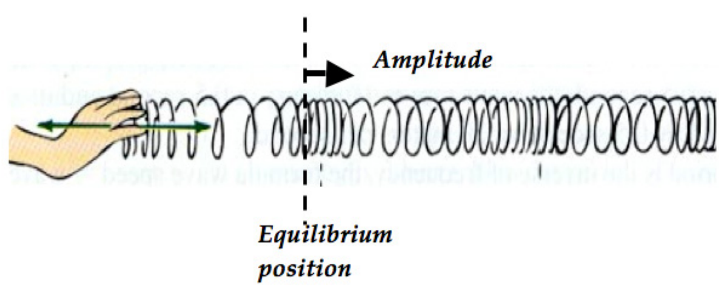
Does the distance between successive (neighboring) valleys seem to be about the same as that between successive peaks, or is it very different?



Another characteristic of a continuous wave is its ***wavelength***. This is a measure of the distance between two successive, but otherwise identical, points on the wave; for example, the distance between two successive peaks or two successive valleys. (Often the Greek letter *lambda* (λ) is used to represent wavelength.)

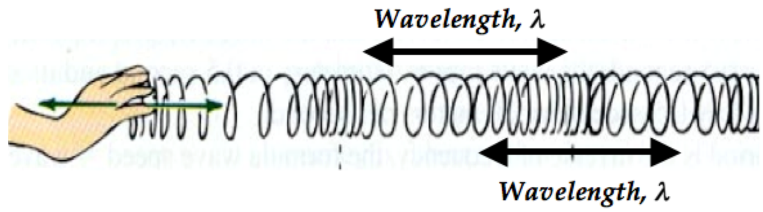
Providing the continuous wave is a series of identical pulses, any of these ways of measuring the wavelength should give the same result.

STEP 5: Though we have defined all of these characteristics from examining continuous transverse waves, they can also be used to characterize continuous longitudinal waves in a very similar way.



In this case, the amplitude of the wave is the maximum distance a part of the medium (such as a single coil on the spring) moves forward or backward from its equilibrium position, and the frequency is how many times it moves backward and forward in one second.

For a longitudinal wave, the wavelength is the distance between two successive regions of compression or extension (stretching).



Exploration #3: What determines the wavelength of a continuous wave?

STEP 1. You have seen it is the amplitude and frequency of the oscillating source that determines the amplitude and frequency of the continuous wave it creates. However, what determines the wavelength of such a wave?

Do you think changing the amplitude of the wave will change its wavelength? Briefly explain your thinking.

Do you think changing the frequency of the wave will change its wavelength? Briefly explain your thinking.

You will now check your thinking using the simulator.

Without changing anything else, create some waves with different amplitudes. For each one, pause the simulation and use the 'Rulers' tool to measure their wavelength.

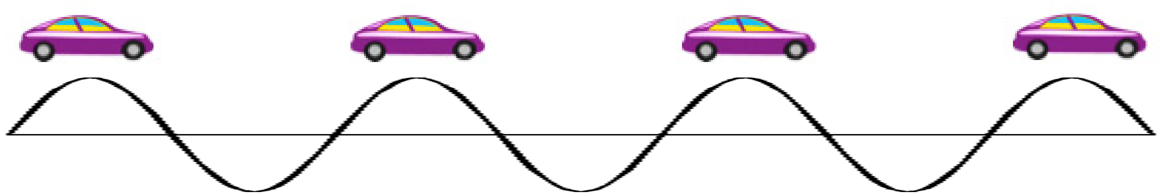
When the amplitude of the wave is changed, what happens to its wavelength (if anything)?

Now create some waves with different frequencies (keeping everything else the same). If you are not sure about what effect this has on the wavelength, you can again pause the simulation and use the ruler to measure the wavelength.

When the frequency of the wave is increased, what happens to its wavelength, (if anything)?

STEP 2. Let us now consider why this relationship between wavelength and frequency makes sense. To do so it may help to consider an analogy.

Consider a situation in which a series of identical cars leave a depot at regular time intervals, say every 30 seconds, and drive along the same long straight road at the same speed, say 30 mph. This would result in a line of cars moving along the road that are all the same distance apart. An observer standing by the side of the road would also see one car go by every 30 seconds.



In this analogy, the depot represents the source of a wave, and the **frequency of this source** is represented by how often cars leave the depot, which is one every 30 seconds. The **frequency of the wave** is represented by how often an observer sees a car go by (also one every 30 seconds). The cars themselves represent the peaks of a wave and the distance between them represents the wavelength.

Now suppose the cars were to leave the depot more often, say one every 10 seconds, but still **drive at the same speed**. Since the cars are leaving the depot more often this is analogous to a source with a higher frequency. (It happens more often.) The observer would now also see one car go by every 10 seconds, representing a wave with a higher frequency.

Under these circumstances, would the distance between successive cars be greater than, smaller than, or the same as it was before? Explain why this is in terms of how far each car would travel before the next one left the depot.

What does your answer to the previous question suggest about what happens to the wavelength of a wave when the frequency is increased? Would the wavelength be longer, shorter, or remain the same?

Explain why this is in terms of how far each peak travels before the next one is created.

STEP 3. Finally, consider what would happen if the speed of a wave were changed (by changing something about the medium). Would this have any effect on its wavelength or not? To think about this, consider the 'line of cars' analogy again. In this analogy, the speed of the cars represents the speed of the wave.

Suppose the cars were again to leave the depot once every 30 seconds, but drive along the road at a constant speed of 60 mph (instead of 30 mph as before)?

Would the distance between the cars be less than, greater than, or the same as when they drove at 30 mph? Explain why in terms of how far each car travels before the next car leaves.

You determined in the previous exploration that the speed of wave pulses on a string depends on the tension in the string. (How tightly it is pulled end-to-end.)

Suppose you were to increase the tension in the string in the simulator, would you expect the wavelength of the wave to increase, decrease, or stay the same? Why do you think so?

To check your thinking, reset the simulator amplitude and frequency to the original values (25 each) and generate a continuous wave. Then increase the speed of the waves by increasing the tension in the string to its maximum value.

Does the wavelength behave as you predicted? If not, try to explain what does happen.

Exploration #4: What determines the wave speed of a continuous wave?

If you keep your eye on a particular peak in a wave, it moves along the wave at a certain speed called the **wave speed**. In this exploration, you will use the wave simulation to determine what property or properties of a wave determines the wave speed.

First, watch the simulation movie **(UWS L1 Mov10),** where the amplitude of the wave is increased. A clock will allow you to compare how long it takes the peak to move from the source to the other end for different values of amplitude.

Does the **wave speed** seem to change (increase or decrease significantly) as the **amplitude** increases, or does it remain about the same? How do you know?

Second, watch the simulation movie **(UWS L1 Mov11),** where the frequency of the wave is increased. A clock will allow you to compare how long it takes the peak to move from the source to the other end for different values of frequency. Also pay attention to what happens to the wavelength as the frequency is increased.

Does the **wave speed** change (increase or decrease significantly) as the **frequency** increases, or does it remain about the same?

When the wave speed remains the same (as it did in the last movie), what happens to the wavelength as the frequency is increased?

The last property we will consider is the tension or tautness of the string. There is a slider in the simulation that can change the tension of the string. Watch the simulation movie **(UWS L1 Mov12),** where the tension of the string is increased. Also pay attention to what happens to the wavelength.

Does the **wave speed** change (increase or decrease significantly) as the **tension in the string** increases, or does it remain about the same?

When the frequency remains the same (as it did in the last movie), what happens to the wavelength as the wave speed is increased?

The tension in the string is a property of the medium through which the wave travels; changing the tension changes the wave speed. ***It is a general property of waves that move through a medium that the wave speed depends only on the properties of the medium, and does not depend on either the frequency or amplitude of the wave.***

Relating wavelength to speed and frequency

You saw in the previous exploration that the ***speed*** at which waves move through a medium is determined ***only by the properties of the medium***. (For waves on a string the relevant properties are the tension and the thickness of the string.)

Also, the ***frequency*** of a wave is completely determined ***only by the motion of the source of the wave***. Whatever frequency the source oscillates at will be the frequency at which the different parts of the medium oscillate as the waves pass.

However, you have now seen that the wavelength of a continuous wave depends on both the frequency **and** the speed. (***So it depends on both source and the medium.***)

When the frequency of a wave is increased (by increasing the frequency of the oscillating source), does the wavelength increase or decrease?

When the speed of a wave is increased (by changing some property of the medium, e.g. the tension in a string), does the wavelength increase or decrease?

Careful measurements would show us that the wavelength of a continuous wave is related to its speed and frequency by the expression[1]:

$$Wavelength\ of\ wave = \frac{Speed\ of\ wave}{Frequency\ of\ wave}$$

Explain how this relationship is consistent with your answers to the two questions above.

We will call all the ideas we have developed about waves in the first two activities of this unit, together with the expression above, our ***model for continuous mechanical waves***.

Summarizing Questions

S1: A boy and girl stretch a long rope between them in midair. Their pull results in a tension that makes the wave speed 4.5 meters per second (m/s). The girl then moves her end of the rope up and down with an amplitude of 20 cm and at a frequency of 3 Hz (three times per second).

[1] In this expression, if speed is measured in units of meters per second (m/s) and frequency in Hertz (Hz), then the wavelength will be in units of meters (m).

a) Calculate the wavelength of the continuous wave created by the girl's motion.

b) If the girl were to change the amplitude of her up and down motion to 40 cm, but keep the frequency at 3 Hz, would the wavelength of the wave now be less than, equal to, or greater than the value you calculated above? How do you know?

c) If the girl were to move her end up and down at a frequency of 6 Hz, would the wavelength of the wave be less than, equal to, or greater the value you calculated in part a)? Explain how you know.

d) Suppose the girl again moves her end of the rope up and down at a frequency of 3 Hz, but the boy at the other end pulls harder on his end (increasing the tension in the rope). Would the wavelength of the wave now be less than, equal to, or greater than the value you calculated in part a)? Explain how you know.