Computer models to support scientific understanding in 7-12 students

Physics Examples

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Unit Introduction

Waves and wave terminology are introduced in middle school and secondary school instruction when topics of light and sound are presented. As important energy forms, light and sound are topics that students experience on a daily basis. While research studies report that teachers are familiar with the concepts presented in units on sound and light, testing of preservice middle school teachers demonstrated little knowledge about waves and wave properties (Mbewe, 2012). Previous work on students' conceptions of waves demonstrated that they often use an object-based reasoning approach when considering waves and wave motion (Caleon & Subramaniam, 2010). They perceive of light or sound as entities, but do not necessarily think about the transmission of light or sound (Driver, Squires, Rushworth, & Wood-Robinson, 2007).

Unit Objectives

At the end of this unit, the teachers should:

- Know the naive concepts that students have regarding the properties of waves.
- Describe simulations that model these concepts.
- Identify the strengths and weakness of those simulations, especially with regard to how the simulation helps students develop scientific understandings.
- Identify appropriate learning objectives for each simulation.

Unit Description

This unit introduces two different computer simulation sites, ExploreLearning, and PhET. Many other sites with wave related simulations are available on the Internet (see appendix). The unit consists of 3 lessons. Each lesson begins with a review of some naïve concepts identified in the science education literature that students have regarding properties of waves. Next, simulations are explored that address the science topics. Finally, rubrics for each simulation focus attention on how the images help students develop scientific understanding related to these concepts. In each lesson, you will identify appropriate learning objectives for classroom lessons for each simulation.

Unit Learning Objectives

Learning objectives are statements that define the expected goal of a lesson or activity in terms of demonstrable skills or knowledge that will be acquired by a student as a result of instruction. They consist of three parts, performance, condition and criteria. Performance defines what students will be able to do after instruction. Condition determines the means necessary to achieve the objective. Criteria sets up the level of success expected after instruction and are often assumed to be perfect mastery. For example,

- Performance: Students will draw an image representing a transverse wave and identify wavelength, amplitude, crest, trough, and frequency.
- Condition: given a paper and pencil,
- Criteria: with 100% success.

Naïve Concepts

Naïve concepts are commonly held views or opinions that are considered inaccurate by modern science often because they are based on incomplete understandings. Students perceive and interpret the world with their intuitions and personal experiences and those ideas may be very different from scientific views.

Next Generation Science Standards

Developing and using models is one of the Scientific and Engineering Practices identified in the *Frameworks for K-12 Science Education* (National Research Council (NRC), 2012). Computer simulations along with diagrams, physical models, mathematical models, and analogies are all included in the definition of models articulated in the *Next Generation Science Standards [NGSS]* (NGSS Lead States, 2013*).* The approximations and limitations that reduce the predictive power of models are characteristics of scientific modeling and important elements for students to recognize. The NGSS highlight the role of models as presentations of systems under study, as key to scientific explanations, and as data generators to support predictions. Models play an important role in the development of academic language and scientific communications. The Common Core English Language Arts Standard RST.6-8.7 articulates the importance of integrating quantitative or technical information with a visual representation such as a flowchart, diagram, model, graph or table (National Governors Association Center for Best Practices, 2010).

Figure 1 shows the disciplinary core idea progression in the NGSS related to wave properties for students from Kindergarten through twelfth grades. This unit focuses on the concepts identified for students in grades 6 through 12.

	K-2	3-5	6-8	9-12
PS4.A Wave properties	Sound can make matter vibrate, and vibrating matter can make sound.	Waves are regular patterns of motion, which can be made in water by disturbing the surface. Waves of the same type can differ in amplitude and wavelength. Waves can make objects move.	A simple wave model has a repeating pattern with a specific wavelength, frequency, and amplitude, and mechanical waves need a medium through which they are transmitted. This model can explain many phenomena including sound and light. Waves can transmit energy.	The wavelength and frequency of a wave are related to one another by the speed of the wave, which depends on the type of wave and the medium through which it is passing. Waves can be used to transmit information and energy.

Figure 1. Next Generation Science Standards disciplinary core idea progression. Retrieved from http://www.nextgenscience.org/sites/ngss/files/Appendix%20E%20-%20Progressions%20within%20NGSS%20-%20052213.pdf p.7

Lesson Description

Each lesson is composed of an introduction, naïve concepts that students often hold related to the topic covered in the unit, activities and explanation of the simulations used. The topics addressed by the three lessons in this unit are:

- Transverse and Longitudinal Waves
- Light Waves – Reflection and Refraction
- Sound Waves – Doppler Effect

Lesson 1: Transverse and Longitudinal Waves

Introduction

This lesson deals with transverse waves, in which the oscillations are perpendicular to the direction of the energy transfer, and longitudinal waves, in which the displacement of the medium is in the same direction as the direction of travel of the wave. Concepts such as amplitude, frequency and damping will be examined. A brief discussion of naïve concepts related to waves will take place at the beginning of the lesson. The PhET and ExploreLearning simulations offer students opportunities to explore the properties of waves in unique ways. Finally, after using the simulations, you will analyze how the presentations help students develop scientifically sound understanding of wave properties.

Naïve Concepts

Students may have the following naïve concepts about waves:

- As waves move, matter moves along them (Arons, 1997).
- Particle motion within a matter wave has the same velocity as the wave itself (Arons, 1997).
- Wave length and wave amplitude are sometimes confused.

Learning Objectives

- Students will draw a representation of a physical wave and name key components.
- Students will describe the effects on a wave when one or more of their characteristics are changed.

Transverse Waves - PhET Simulation

The Waves on a String (https://phet.colorado.edu/en/simulations/category/physics/sound-and-waves) Waves on a String simulation presents an image of a rope attached to a wrench on one end, and at the other end the rope is fixed to a wall. The viewer has several options: a) both ends of the rope can be changed from fixed to open to unending; b) a wave can be generated by moving the wrench up and down; and c) an oscillation or pulse can be created. Using the menu at the screen top, the viewer can change the damping of the system and the tension of the rope when selecting the manual setting. For the oscillating setting, you can also change the amplitude and frequency, while for the pulse setting you can change the pulse width instead of the frequency. In all three settings you can display the rulers and timer box by selecting them (Figure 2).

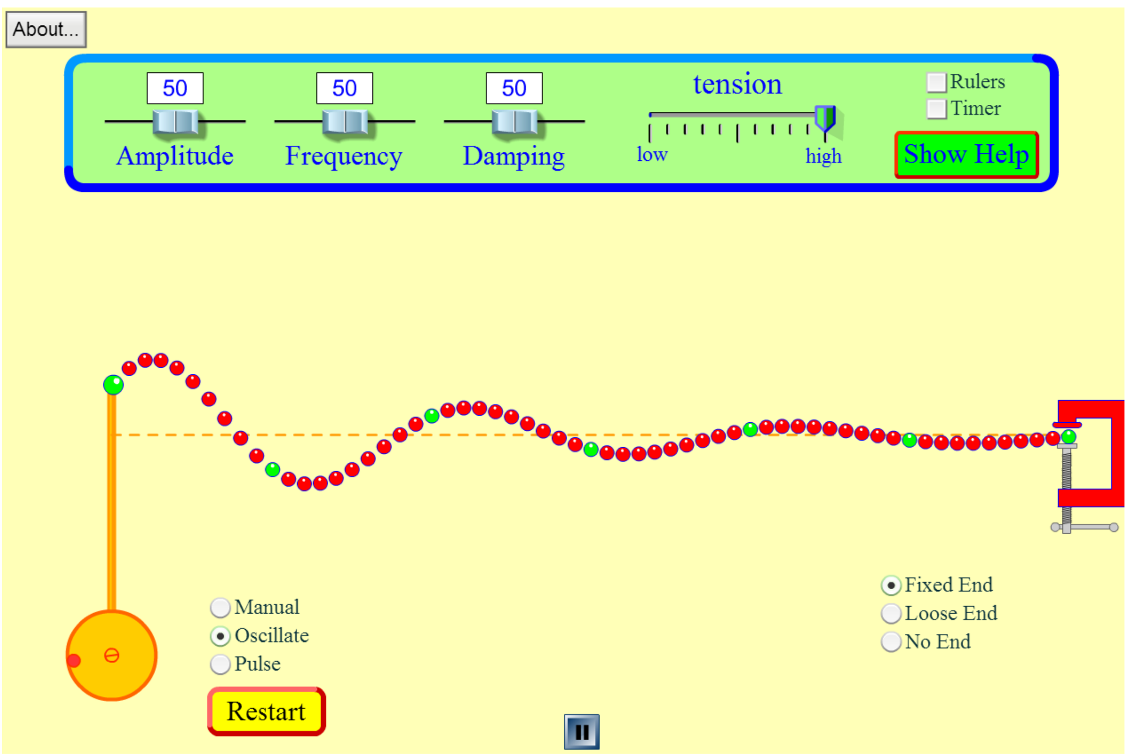

Figure 2. PhET simulation of generating a transverse wave.
https://phet.colorado.edu/en/simulations/category/physics/sound-and-waves

To being exploring the site, select the oscillate button. The initial settings for the amplitude, frequency and damping are 50, and the tension of the string is set as high as shown in

Figure 2. Change those settings and see how they affect the waves on the string. Are those changes what would you expect? Finally change the fixed end to a loose end and no end and observe what happens to the wave.

How does the simulation represent the characteristics of a wave? How can a teacher design in inquiry activity using this simulation to help students develop sound conceptual understanding of transvers waves? Does the simulation help students develop scientifically sound understanding about the properties of waves, especially transverse waves? How does this simulation help students overcome their naïve concepts?

Longitudinal Waves - ExploreLearning Simulation

When you run the ExploreLearning simulation *Longitudinal Waves*, (http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=610) a window is displayed with a Cartesian coordinate system in two dimensions. The *y* axis indicates the amplitude of the wave and the *x* axis shows the position of the particles. Below it you will observe a tube with several dividers evenly distributed. Finally, a control menu is located at the bottom, which let you choose between continuous and pulsed waves, closed or open tube, as well as the strength and frequency of the wave (Figure 3).

For this activity select the continuous wave and open tube options and run the simulation with the initial settings for strength and frequency. Record your observations. Change the strength and frequency and observe how these changes affect the wave. Are those changes what would you expect?

How does the simulation display the characteristics of a longitudinal wave? When you change one or more characteristics, does the simulation help students develop scientific understandings of longitudinal waves? How does the simulation help students learn about the properties of waves? For those with a license to the materials there are questions underneath the simulation for the students to answer. The questions center on student recognition of the relationships between the displacement graphs at the bottom of the gizmo and the simulation graphs produced by the application. How could you compose or use such questions to test the impacts of the simulation on student learning?

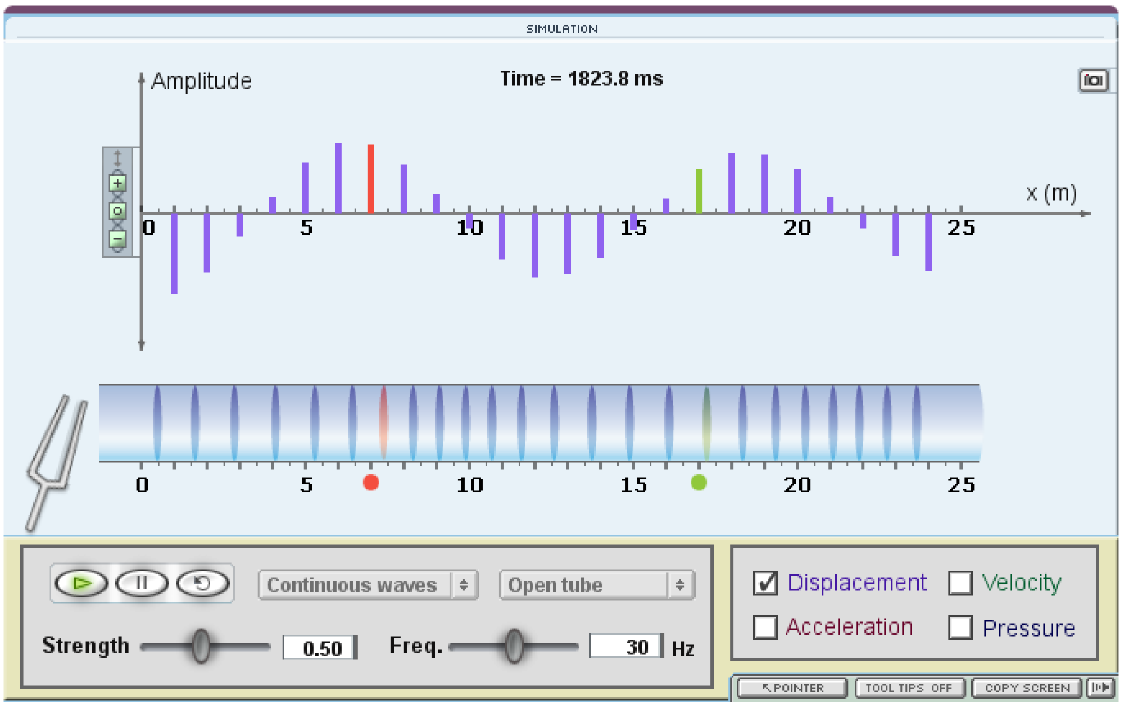

Figure 3. ExploreLearning longitudinal wave simulation.

Summary

Students have naïve concepts about the notion of waves and their characteristics and those should be addressed in class for them to fully understand this physics concept. After exploring the simulations, identify how the simulation represents the characteristics of transverse and longitudinal wave behavior and how the representations help students develop sound scientific understandings. Now that you have explored the simulations that address some of the characteristics of a wave, complete the following table to report your findings (Figure 4).

Learning Objectives before using the simulations	How do the simulations address the learning objectives?
Students will draw a representation of a physical wave and name key components.	
Students will describe the effects on a wave when one or more of their characteristics are changed.	

Figure 4. Rubric for waves.

Lesson 2: Light Waves – Reflection and Refraction

Introduction

This lesson focuses how a light wave reacts when it goes from one medium to a different one. Depending on the indices of refraction of the media and the incident angle, the light wave can demonstrate total internal reflection, or both reflection and refraction. Both phenomena reflection and refraction of light will be examined. A brief discussion of naïve concepts related to reflection and refraction will take place at the beginning of the lesson. Next, the viewer will explore the ExploreLearning and PhET simulations in order to consider how the images highlight the learning objectives. Finally, after using the simulations, you will analyze how the simulations address the learning objectives identified at the beginning of the lesson

Naïve Concepts

- Students may think that when an object is viewed through a transparent medium, the object is seen where it is located (Driver et al., 2007).
- Students struggle to understand that waves at a boundary can be partially reflected, transmitted, or absorbed. Students often believe the example of complete reflection represents the natural condition rather than an idealized circumstance (Arons, 1997).
- Students may believe that light stays on the surface of a mirror during reflection (Driver et al., 2007).

- Students may believe that the pitch of a sound source rises as a sound source approaches, the pitch falls dramatically as it passes the observer, and continues to gradually fall as the object recedes (Neuhoff & McBeath, 1996).

Learning Objectives

- Students will be able to draw and explain what happens when a beam of light goes from one medium to a different one.
- Students will be able to explain the differences between refraction and reflection.
- Students will illustrate that light can be reflected or refracted by a medium.

ExploreLearning Simulation

The ExploreLearning *Refraction Simulation* *http://www.explorelearning.com/index.cfm?method=cResource.dspView&ResourceID=552* depicts a window with a beam of light going across two different media. A series of sliders allow the viewer to change the indices of refraction of the media as well as the angle of incidence of the light ray. Check boxes provide tools to let the viewer measure lengths and angles (Figure 5).

Run the simulation with the initial settings to observe how the simulation works. Then change the indices of refraction and the angle of incidence and observe what happens. Is this simulation an accurate representation of what occurs when a light ray goes from one medium to a different one? This simulation does not show any partial reflection. Under what conditions does the simulation demonstrate reflection? Under what conditions does the simulation demonstrate refraction? How does the simulation help students build scientifically sound understanding of refraction and reflection? Underneath the simulation are questions for the students to answer for those with a subscription. The questions center on the relationships between the angle of incidence and angle of refraction. How could you compose or use such questions to gauge your student's learning.

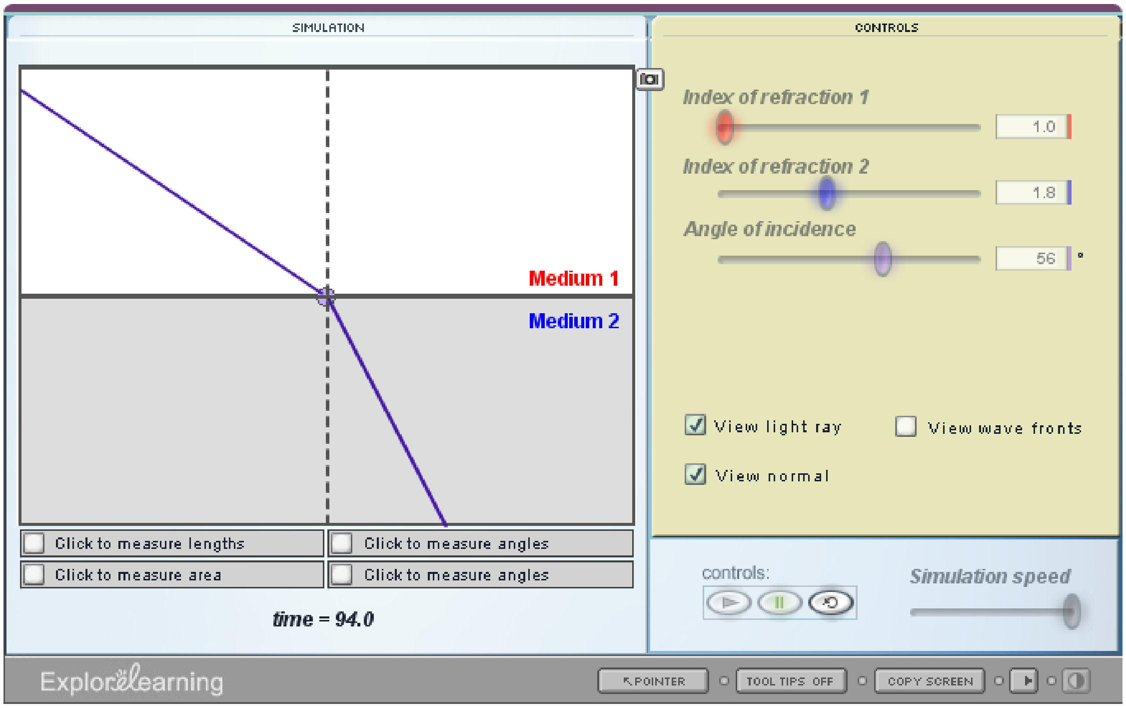

Figure 5. ExploreLearning refraction simulation.

PhET Simulation

http://phet.colorado.edu/en/simulation/bending-light

When you view the PhET *Bending Light* simulation, you will see a window with a laser pointer and two different media with their respective refraction indices. The original settings are air (n=1) for medium 1 and water (n=1.33) for medium 2. On the bottom left corner a toolbox is located in where you can find a protractor and a photo-device to measure the intensity of the light. There are three tabs with different simulations, but for this activity only the first tab entitled "Intro" will be used (Figure 6).

Turn on the laser by clicking on the red button using the initial parameters and observe what happens. If the Show Normal box is clicked, a dashed normal line appears in the simulation. Grab the laser pointer and move it to change the angle of incidence. After that, change the refraction indices of both media and move the laser in order to change the incidence angle of the light ray. Use the protractor in order to measure the incidence, reflected and refracted angles. Consider how this simulation might be used for a guided inquiry exercise in class to help students understand both reflection and refraction.

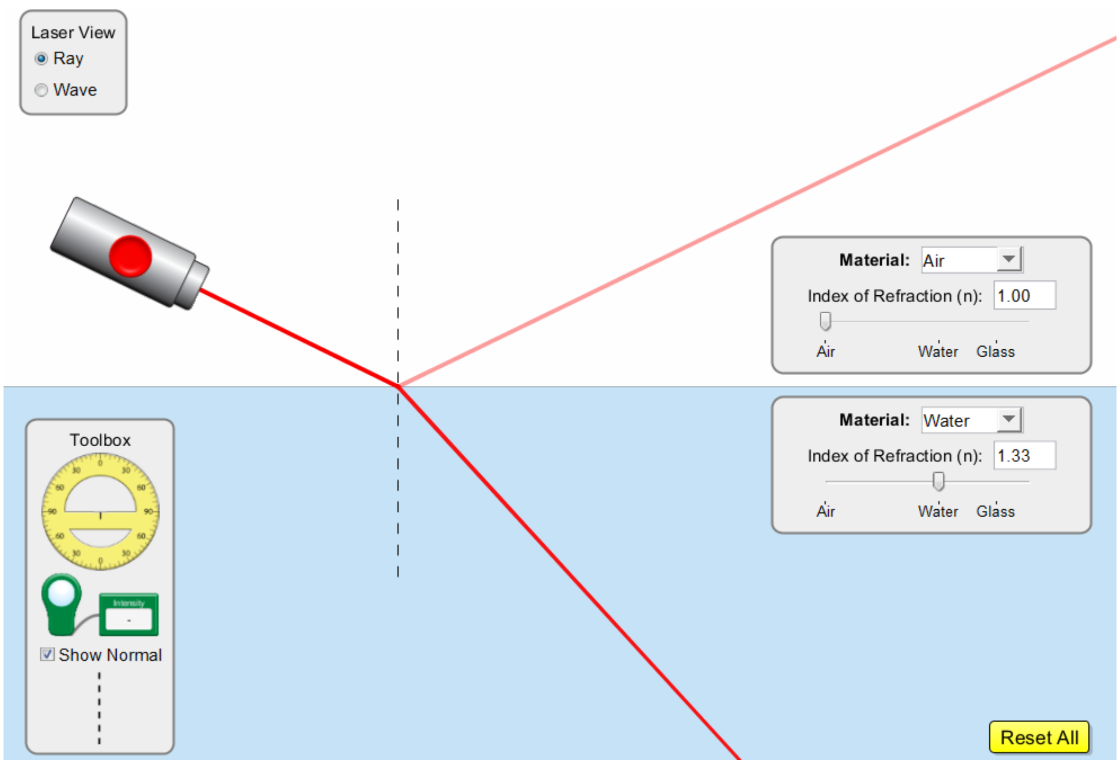

Figure 6. PhET refraction simulation.

Do you think the simulation does a good job showing the phenomena of reflection and refraction? Does the simulation help students to achieve the learning objectives? Does this simulation help students overcome their naïve concepts?

Summary

Students have naïve concepts about reflection and refraction of light and those should be addressed in class for them to fully understand these physics concepts. After exploring the simulations, consider how the simulations show reflection and refraction. Use the rubric in Figure 7 to summarize your thoughts.

Learning Objectives before using the simulations	How does the simulation address the learning objectives?	
	ExploreLearning	PhET
Students will be able to draw and explains what happens when a beam of light goes from one medium to a different one		
Students will be able to understand the concepts of reflection and refraction of light		
Students will illustrate that light can be reflected or refracted by a medium.		

Figure 7. Refraction rubric.

Lesson 3: Sound Waves – Doppler Effect

Introduction

This lesson introduces the Doppler Effect, one of example of which is the change in frequency of a wave for a stationary observer relative to a moving sound source. A brief discussion of naïve concepts related to the Doppler Effect will take place at the beginning of the lesson. Next, you will examine an ExploreLearning simulation in order to consider how the representations help students develop scientific understanding of this complex concept. Finally, after using the simulation, you will analyze how the simulation addresses the learning objectives identified at the beginning of the lesson

Naïve Concepts

Although when a sound source traveling at a constant velocity past a stationary observer drops in observed frequency both during its approach and its departure, students may believe that a rise in pitch occurs for the passing sound as it approaches the observer (Neuhoff & McBeath, 1996). With a sound source moving at a constant velocity, the frequency of the waves projected in any given direction remains constant. Waves in front of the moving source will have an observed frequency higher than the sound source; waves behind the moving source will have an observed frequency lower than the sound source. However, at no point of observation, does a rise in frequency of the observed sound source occur (Neuhoff & McBeath). When the listener first notes the moving sound source, the higher pitch (than the actual source frequency) is heard. As the object moves closer, the frequency and pitch first gradually decrease, then decrease rapidly as the course passes the observer, and finally continue a gradual decline as the source moves away.

Students may not recognize that the Doppler Effect occurs when either the sound source or the listener is moving.

Learning Objectives

Students will correctly describe the change in frequency of a sound source moving at a constant speed relative to a stationary observer.

Students will compare and contrast the effect of position of the observer relative to the sound source on the frequency of the sound.

ExploreLearning Simulations

The Doppler Shift simulation

(http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=363)

presents a representation of a car in a road and a person far ahead next to the road. The menu allows the viewer to change the frequency of the sound source, the speed of the source and the speed of sound. Also the motion of the source can be selected between linear, circular and oscillating. The observer can be grabbed and moved to different positions in the representation. Finally options allow the viewer to display additional waves and to see the observed frequency (Figure 8).

Check the “display additional waves” and “observed frequency” boxes before running the simulation. Run the simulation with the initial settings and observe what happens. In a later trial, change the settings on the menu above and observe. How does the frequency of the wave observed by the stationary observer change as the sound sources approaches, draws even with the listener and moves past? Grab the observer and move him/her so that s/he is standing in the road in the path of the oncoming sound source. Move the observer to a position to the right or left of the sound source path. How does the change of position for the observer affect the perceived sound?

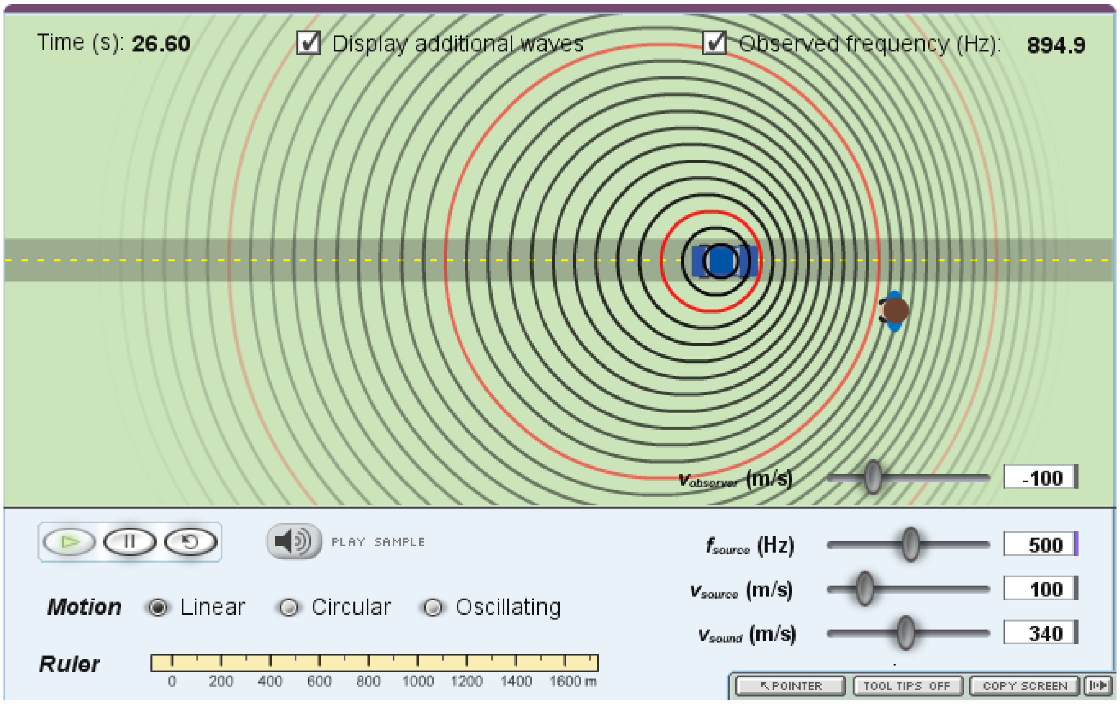

Figure 8. ExploreLearning Doppler Effect simulation.

The second simulation entitled *Doppler Shift Advanced* is similar to the previous simulation, but in the later one you can change the speed of the observer as well as the source. Run the simulation this time changing the speed of the observer. Does the simulation provide a scientifically acceptable representation of the Doppler Effect? How does this simulation help students overcome their naïve concepts?

Summary

Students have naïve concepts about the Doppler Effect and those should be addressed in class for them to fully understand this physics concept. The rubric below provides opportunity for the viewer to consider the contributions made by the model to student conceptual understanding of the Doppler Effect.

Learning Objectives before using the simulations	How do the simulations address the learning objectives?
Students will correctly describe the change in	

frequency of a sound source moving at a constant speed relative to a stationary observer.	
Students will compare and contrast the effect of position of the observer relative to the sound source on the frequency of the sound.	

Figure 9. Rubric Doppler Effect.

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