**NGSS-Aligned PhET Lesson: Introduction to Wave Properties**

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| **Lesson Topic** | * Introduction to Wave Properties * Equation for speed of a wave * Variables that affect speed of a wave |
| **Level** | High School Physics (9th-12th; Conceptual; Algebra-based) |
| **Key Words/Vocab** | Wave; wavelength; frequency; period; speed; medium; media; amplitude; sine graph; cosine graph; oscillation; s=d/t; s=fλ; f=1/T; T=1/f; transverse; longitudinal; sound wave; electromagnetic wave; light wave; energy; tension; damping |

**Part A: Gather and Filter Information from NGSS and PhET Interactive Simulations**

**Step 1*:*****Select PEs and PhET Simulation(s) that work together.**

**1a. Select PEs and Identify the associated Clarification Statements and Assessment Boundaries.**

**Step 2: Collect and Filter NGSS specifics for lesson**

**2a. Identify the three dimensions that are coded to the PEs.**

**2d. Select related Common Core Mathematics Standards (CCSS-M) and Common Core Literacy Standards (CCSS-L) related to the PEs selected.**

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| **Performance Expectations (PE)** | **Clarification Statement** | | **Assessment Boundary** |
| **[HS-PS4-1](http://standards.nsta.org/DisplayStandard.aspx?view=topic&id=44)**  [Use mathematical representations to ­support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.](http://standards.nsta.org/DisplayStandard.aspx?view=topic&id=44) | Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth. | | Assessment is limited to algebraic relationships and describing those relationships qualitatively. |
| **Science & Engineering Practices** | **Disciplinary Core Ideas (DCIs)** | | **Crosscutting Concepts (CCs)** |
| **Using Mathematics and Computational Thinking**  Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations. | **PS4-A:** The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. | | Cause and EffectEmpirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. |
| **CCSS-English** | | **CCSS-Math** | |
| **RST.11-12.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-PS4-1), (HS-PS4-4)  **WHST.9-12.2** - Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS4-5) | | **HSA-CED.A.4** - Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. (HS-PS4-1), (HS-PS4-3)  **HSA-SSE.A.1** - Interpret expressions that represent a quantity in terms of its context. (HS-PS4-1), (HS-PS4-3)  **HSA-SSE.B.3** - Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. (HS-PS4-1), (HS-PS4-3)  **MP.2** - Reason abstractly and quantitatively. (HS-PS4-1), (HS-PS4-3)  **MP.4** - Model with mathematics. (HS-PS4-1) | |

**1b. Evaluate PhET sims for alignment with PEs, Clarifications, Boundaries.**

**Table 1b: PhET Sim Selection**

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| **Sim Name** | **Main Topics** | **PhET Sample Learning Goals** | **Reflection and reasoning** |
| Wave on a String | * Waves * Frequency * Amplitude | * Discuss wave properties using common vocabulary. * Predict the behavior of waves through varying medium and at reflective endpoints. | \* Included in Lesson  Sim allows student to determine speed of a wave & investigate variables affecting speed of a wave on a string (amp, tension, damping) |
| Bending Light | * Snell's Law * Light * Refraction | * Explain how light bends at the interface between two media and what determines the angle. * Apply Snell’s law to a laser beam incident on the interface between media. * Describe how the speed and wavelength of light changes in different media. * Describe the effect of changing wavelength on the angle of refraction. * Explain how a prism creates a rainbow. | \* Included in Lesson  Sim allows students to investigate the affect of different media on speed of an electromagnetic wave (move from air to denser material; move from denser material to air) |
| Sound | * Sound * Waves | * Explain how different sounds are modeled, described, and produced. * Design ways to determine the speed, frequency, period and wavelength of a sound wave model. | \* Possibly included in Lesson:  Sim allows student to measure the frequency, period and speed of a wave. Students can compare speed of a sound wave to the speed of a wave on a string. |
| Fourier: Making Waves | * Waves * Sines * Cosines | * Explain qualitatively how sines and cosines add up to produce arbitrary periodic functions. * Recognize that each Fourier component corresponds to a sinusoidal wave with a different wavelength or period. * Mentally map simple functions between Fourier space and real space. * Describe sounds in terms of sinusoidal waves. * Describe the difference between waves in space and waves in time. * Recognize that wavelength and period do not correspond to specific points on the graph but indicate the length/time between two consecutive troughs, peaks, or any other corresponding points. * Become comfortable with various mathematical notations for writing Fourier transforms, and relate the mathematics to an intuitive picture of wave forms. * Determine which aspect of a graph of a wave is described by each of the symbols lambda, T, k, omega, and n. * Recognize that lambda & T and k & omega are analogous, but not the same. * Translate an equation from summation notation to extended notation. * Recognize that the width of a wave packet in position space is inversely related to the width of a wave packet in Fourier space. * Explain how the Heisenberg Uncertainty principle results from the properties of waves. * Recognize that the spacing between Fourier components is inversely related to the spacing between wave packets, and that a continuous distribution of fourier components leads to a single wave packet. | \*\* Not included in Lesson  Sim allows students to look at waves of different frequencies and harmonics. More advanced wave functions than needed for intro activity. |
| Radiowaves and Electromagnetic Waves | * Radiowaves |  | \*\* Not included in Lesson:  Sim shows radiowaves, allows user to modify several variables (eg, frequency, amplitude) but does not have tools for measuring speed. Also cannot alter medium through which wave is traveling. |
| Wave Interference | * Waves * Sound | * You can watch water, sound, and light waves move and see how they are related. All can be represented by a sinewave. * What does this sinewave represent for these three different phenomena? * Use multiple sources with different spacing and see a changing interference pattern. * Find points of constructive and destructive interference by eye, and by using the detectors. * Put up a barrier to see how the waves move through one or two slits. What sort of pattern do the slits create? How can you change this pattern? * In the light panel, predict the locations of the fringes that appear on the screen using d sin(θ) = mλ. Use the tape measure to verify your predictions. | \*\* Not included in Lesson:  Sim allows students to look at interference patterns for different types of waves (water, sound, light). Although the sim does have tools for measuring speed of a wave for different types of waves, the units are not as user-friendly for an introductory lesson. Qualitatively, it was not explicitly obvious that the different types of waves had different speeds. |

### 2b. Use DCI grade band progressions and/or Appendix E for previous and future grades.

**2.  What background knowledge should students bring to this activity?  (Previous Grades for DCI)**

**[K-2](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)**

* [Sound can make matter vibrate](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)
* [Vibrating matter can make a sound](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)

**[3-5](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)**

* [Waves, which are regular patterns of motion, can be made in water by disturbing the surface. When waves move across the surface of deep water, the water goes up and down in place; there is no net motion in the direction of the wave except when the water meets a beach.](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)
* [Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks).](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)

**[6-8](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)**

* [A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)
* [A sound wave needs a medium through which it is transmitted.](http://standards.nsta.org/DisciplinaryCoreIdeas.aspx?id=11&detailid=110)

**2c. Select additional Science and Engineering Practices that support your chosen DCIs and CCs.**

Additional Practices that might fit lesson:

* **Developing and/or Using Models**
  + Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
* **Planning & Carrying Out Investigations**
  + Select appropriate tools to collect, record, analyze, and evaluate data.
  + Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
* **Developing and/or Using Models**
  + Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

# B: Plan your lesson using steps in Part A and PhET’s teacher tools

## Step 3: Refine lesson focus

### 3a. Break the DCI into lesson segments

**Table 3a: DCI Analysis for grade level**

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| --- | --- | --- | --- |
| **DCIs** | **DCI Components Previously Covered in this Unit** | **DCI Components Targeted in this Lesson** | **DCI Components Still to Be Addressed in Unit** |
| **HS-PS4-A:** | ~~The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing.~~ | The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on ~~the type of wave and~~ the medium through which it is passing. | ~~The wavelength and frequency of a wave are related to one another by~~ the speed of travel of the wave, which depends on the type of wave ~~and the medium through which it is passing.~~ |

**Table 3b: Develop Lesson Level PEs**

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| --- | --- | --- | --- | --- | --- |
| **Lesson Segment** | **Sci and Eng Practices** | **DCI** | **CCs** | **Lesson Level Performance Expectation** | **Brainstorming Lesson Ideas** |
| **Part 1: Method for determining speed of a wave** | **Planning & Carrying Out Investigations**  Select appropriate tools to collect, record, analyze, and evaluate data. | The wavelength and frequency of a wave are related to one another by the speed of travel of the wave | Cause & Effect | Develop a method for using the tools in the Wave on a String sim to determine the speed of a wave.  [Develop a method, including identification of tools and variables to be measured, for determining the speed of a wave on a slinky.] | Station 1: Students use tools in sim to determine speed of a wave on a string  Station 2: Students use physical tools to determine speed of a wave on a slinky |
| **Part 2: Predict and test variables affecting wave speed** | **Planning & Carrying Out Investigations**  Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.  **Using Mathematics and Computational Thinking**  Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. | The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on ~~the type of wave and~~ the medium through which it is passing. | Cause & Effect | Make a prediction about the variables that impact speed of a wave, then write a hypothesis that clearly states the relationship between the variable and the wave speed, and the reasoning used to develop hypothesis.  Design an experiment (using the simulation or the physical equipment) to test hypothesis about the variables that impact wave speed.  Write a claim about the correctness of your hypothesis, using evidence from your lab to support your claim. | * Students make and share out predictions & hypotheses about variables impacting speed of a wave. * Students use sim or slinky to test their hypotheses * Students evaluate data to determine whether or not it supports their hypothesis, then revise their claim about the variables affecting wave speed using evidence from their lab to support their conclusion |
| **Part 3:**  **Equation for Speed of Wave** | **Developing and/or Using Models**  Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. | The wavelength and frequency of a wave are related to one another by the speed of travel of the wave | Cause & Effect | Develop a computational model that shows the relationships between wavelength, frequency, speed and tension for waves traveling on a string. | * Identify relationships (direct, inverse, none) between speed, wavelength, frequency, and tension for waves on a string based on data/observations from their experiment * Substitute values for wave quantities into speed equation to build speed of wave equation |
| **Part 4: Effect of Medium on Wave Speed** | **Developing and/or Using Models**  Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. | The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on ~~the type of wave and~~ the medium through which it is passing. | Cause & Effect | Use the Bending Light PhET simulation to investigate the impact of different media on wave speed, then use your observations to revise your model about speed of a wave. | Students extend investigation of wave speed/wave behavior by looking at effect of medium (air, water, glass, oil) on speed of a light wave, then use observations to further revise their model about the speed of a wave. |

**Step 4**: **Determine evidence for formative and summative assessment**

**Table 4: Assessment Evidence**

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| --- | --- | --- | --- | --- |
| **Lesson Segment** | **Lesson Level PE** | **PhET Learning Objectives** | **Evidence** | **Cues, Prompts & Lesson Ideas** |
| **Part 1: Method for determining speed of a wave** | Develop a method for using the tools in the Wave on a String sim to determine the speed of a wave.  [Develop a method, including identification of tools and variables to be measured, for determining the speed of a wave on a slinky.] | Develop an experimental method to determine the speed of a wave on a string. | * Brief description of method (written, audio or video recorded) that includes tools, measurements, number of trials | * Challenge cue during free explore |
| **Part 2: Predict and test variables affecting wave speed** | Make a prediction about the variables that impact speed of a wave, then write a hypothesis that clearly states the relationship between the variable and the wave speed, and the reasoning used to develop hypothesis.  Design an experiment (using the simulation or the physical equipment) to test hypothesis about the variables that impact wave speed.  Write a claim about the correctness of your hypothesis, using evidence from your lab to support your claim. | Write a hypothesis about how changing a specific variable will affect speed of a wave on a string.  Design and implement an experiment to test your hypothesis.  Write a claim that evaluates your hypothesis, using evidence from your lab to support your claim. | * Prediction: variables that might affect wave speed * Written hypothesis for variable that team will test (If…then…because…) * Clearly recorded data * Conclusion written in form of “Claim, evidence, reasoning” | * Brainstorm variables that might affect wave speed: How could you increase the speed of a wave? * How are other variables related? (What happens to the wavelength when you change frequency?) |
| **Part 3:**  **Equation for Speed of Wave** | Combine background knowledge of speed with observations from the Wave on a String simulation to develop a computational model (equation) that demonstrates the relationship between wavelength, frequency and speed of a wave | Develop a computational model (equation) that demonstrates the relationship between wavelength, frequency and speed of a wave | * Labeled diagram of wave anatomy * Work showing combination of speed equation with wave quantities (f or T, wavelength) * Equation: s=fλ | * Which wave variables relate to the variables in the speed equation? Which wave variable represents distance (length)? Which wave variable represents time? |
| **~~Part 4: Effect of Medium on Wave Speed~~** | ~~Use the Bending Light PhET simulation to investigate the impact of different media on wave speed, then use your observations to revise your model about speed of a wave.~~ | ~~Test your claim about how specific variables influence speed of a wave using a different types of wave medium.~~ | * ~~Observations about impact of media on wave speed~~ |  |

**Step 5**: **Develop a Big Idea and Lesson Plans**

***Note: See accompanying Teacher Notes and Student Handout for lesson plans.***

**Brainstorming Notes**

What is a wave? What are key characteristics of a wave? Ie, what is the anatomy of a wave? (amplitude, frequency (how many times per min), period (how long per cycle), wavelength (distance traveled during 1 cycle)

What graphical shape do we observe on a position vs. time graph for an object that is oscillating up and down or moving in a circle?

How can we mechanically create a wave? How does the period of a wave compare to the period of an object moving in a circle?

What variables can you control in the sim? (damping, freq, amp)

What effects do each variable have on the wave? (amp-gets bigger; freq-changes how frequently waves form/complete; damp-causes wave to get smaller over time)

What tools do you have for measuring? Timer, ruler/meter stick

What variables affect the speed of a wave?

What are common wave “behaviors”?

**Step 6**: **Re-examine lesson**