Instructor Guide: Pulse Propagation

This instructor guide gives detailed guidance for teaching the ACORN Physics waves. For more general guidance on facilitating ACORN Physics Tutorials, see our facilitator guide.

Overview & learning goals

This ACORN Physics Tutorial provides open-ended scaffolding for students to construct a qualitative model for a pulse propagating on a spring or string, based on research on students' generative ideas about wave mechanics. This Tutorial supports learning goals related to both scientific practices and disciplinary content.

Students will practice:

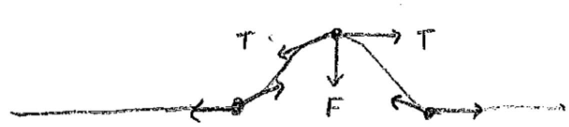
- Constructing scientific explanations
- Generalizing their observations, prior knowledge, and explanations to construct a conceptual model
- Developing hypotheses and predictions based on a conceptual model, and then testing these predictions
- Refining a conceptual model on the basis of tests
- Recognizing that they already have ideas relevant to physics understandings of mechanical waves

Students will articulate a model that supports them to:

- Predict and explain how changes to the medium (i.e., tension, mass density) affect pulse speed
  Predict and explain how changes to the source motion (i.e., amplitude, duration) affect pulse speed
- Predict and explain how changes to the medium (i.e., tension, mass density) affect the shape of a pulse
- Predict and explain how changes to the source motion (i.e., amplitude, duration) affect the shape of a pulse

This worksheet focuses on the process of constructing a model from one's own ideas, rather than a particular canonical model. We encourage instructors to guide students to test and refine their ideas as emerging scientists, rather than to guide students toward a specific set of ideas. Students will construct a variety of models that are appropriate. Example models that students have articulated at the end of this worksheet include:

> "If we think of waves as forces moving throughout the spring/string then we can use $\overrightarrow{F_{net}} = m\vec{a}$. Using this we can conclude that using a greater tension force will increase acceleration (speed) + using a spring/string with greater mass will decrease acceleration (speed)."

> *"A pulse propagates along a spring or string at a constant velocity and constant shape. This velocity is $v = \sqrt{T/\mu}$. This can be seen in the diagram below:*
>
> 
>
>
> *The higher the tension, the more force is acting on the string in the pulse to bring each point on the string back to equilibrium and the faster the pulse will propagate down the string. "*

Possible supplements to this worksheet:

Students are asked to conduct at least two experiments in this worksheet, and for this they will need springs or strings of different mass densities and a scale or force meter to measure tension in a spring or string. PhET's Wave on a String simulation can be a helpful supplement to this worksheet, though it cannot be used to test every experiment that students might design.

What is this ACORN Physics Tutorial designed to do?

This Tutorial has three major sections, each focusing on a different wave propagation experiment. In the first section, students examine how the tension of a spring affects the motion of a pulse; in the second, students apply and extend the ideas elicited in the first section to explain how changing the mass or mass density affects the motion of a pulse; in the third, students design their own experiment to test and extend the ideas they used in the first two sections.

<u>Section 1: Tension</u>

In this section, students explain why a pulse propagates faster on a higher-tension spring. Students first individually answer an **explain** question about the tension scenario. Common ideas that students have used to explain the tension scenario include:

- *Properties of the medium either impede or facilitate the motion of the pulse.* Students respond as though the pulse is a macroscopic entity moving on or through the medium, and the tension and/or mass density affects how the medium responds to the pulse or causes it to move. The nascent mechanistic model for propagation suggested by this idea is: the pulse is a pseudo-object that is pulled and/or pushed through the medium, and the strength of the push/pull is affected or determined by the properties of the medium.
- *The speed or duration of transverse motion affects pulse speed.* Students respond as though the pulse is a propagating disturbance of parts of the string, where propagation speed is linked to the transverse motion of the medium. The nascent mechanistic model for propagation suggested by this idea is: particles or segments of the medium are sequentially displaced and return to equilibrium at a rate that depends on parameters of the pulse and/or medium.
- *The speed of the pulse is affected by its energy.* Students respond as though the speed of the pulse is explained or predicted by energy accounting (i.e., considering how energy is increased, decreased, transferred, or transformed). This idea may fit with either of the models implied by the ideas above, or other models, depending on the energy transfers/transformations that the student describes.

Instructors are encouraged to listen for and highlight ideas like these in students' conversations, and to ask open-ended questions to understand students' thinking more clearly. Instructors should encourage students to write down their relevant ideas in the "model-building box" on the first page of the worksheet. It is not important that students' ideas are completely correct or fully fleshed out at this stage of the worksheet, because they will spend significant time testing and revising their thinking in the following section. However, it is essential that students recognize what force, energy, motion, and propagation ideas they *are using* so that they can test and refine them.

Next, students share their explanations with group members and write down a second explanation that is different from their own. This guidance serves two purposes: by articulating their own explanations to group members, students may solidify, modify, or extend their own explanation, and listening to group members' explanations may elicit new ideas for students. Thus, students gain access to a broader set of ideas with which to articulate a conceptual model in the upcoming sections of the tutorial. In the third and final question of this section, students articulate a mechanism for *how the pulse propagates on the string* that is implied or stated in each explanation that they have written down in the previous two questions; that is, we assume students are relying on a (possibly unarticulated) mechanism to answer the previous questions, and we ask them to reflect on their work so far and articulate what that mechanism is. This task is challenging for students, and instructors can support students by highlighting important ideas that students have written or by giving examples of physical mechanisms and explanations that students may be familiar with.

Section 2: Mass density

This section supports students to extend, test, and refine the ideas elicited in the previous section. First, students **predict** how the speed and/or shape of a pulse will change when the pulse is generated with the same motion on a heavier spring or string. This question is designed to support students in applying the ideas they used to explain the tension scenario in Section 1, now extending to this new experiment. Once students have articulated a prediction that is consistent with their thinking, they test their ideas with an experiment. Instructors should provide students with springs or strings of different mass densities (or a string and a rope) and a scale or force meter to ensure that tension is the same in both tests. If the results of the experiment are not what students predicted, they revise their mechanism from Section 1 to account for their new observations. Instructors should encourage students to write down their relevant ideas in the "model-building box" on the first page of the worksheet, and to check that students' ideas can explain the effects of both tension and mass density on the speed and shape of the spring.

Section 3: Student-designed experiment

In this section students reflect on their mechanistic explanations (or models) of pulse propagation, determine a question about pulse propagation that they still have, and choose an experiment to address that question. Choosing an experiment and interpreting the results to test and refine a scientific model is challenging for students, and instructors can facilitate this process by highlighting important or recurring ideas they have heard students discussing and suggesting ways to test these ideas. This section suggests an experiment – changing the hand motion used to generate a pulse – which is relevant for questions about how the source motion affects pulse speed. We expect that this experiment is relevant for many, but not all students. If this experiment isn't relevant for a group's questions, they should design a different experiment. It is important that students develop models from their own ideas (rather than instructors' suggestions), but instructors can encourage students to add to or refine their model if it does not accurately predict or explain the behavior of an experiment that they test.

What are specific strategies to help students with this worksheet?

- Keep track of questions that students express and suggest ways they can test their questions using equipment or simulations.
- Suggest new experiments to clarify what a student is thinking or to resolve inconsistencies in their ideas.
- Ask students to draw diagrams to illustrate their ideas or suggest representations that may help students make sense of their observations.
- Once students have articulated a detailed mechanistic model, help them to examine connections between their model and equations that describe pulse or wave propagation (e.g., $v = \sqrt{T/\mu}$ or $v = \lambda f$).
- See the *Facilitator Guide* for general strategies that apply to all ACORN Physics Tutorials.

What research has been done to develop and/or test this worksheet?

We developed this tutorial based on our analysis of hundreds of students' ideas about wave mechanics and tested it in university physics courses, where students used the tutorial in small groups during regular class sessions. Learn more about the research involved in this worksheet here: https://www.physport.org/curricula/ACORN/research#waves