Intro to Waves: Acoustic Sensing

Overview
In this lesson, students will complete a Slinky activity to produce multiple forms of waves. This will provide a visual of different types of waves and various wave characteristics such as amplitude, wavelength, period, and frequency. Students will then visually represent these characteristics on a poster. A real-world, technological application of longitudinal waves will be explained in acoustic biosensors.

Key Search Words
9-12 grade, high school, physics, waves, longitudinal waves, transverse waves, wavelength, amplitude, pulse, periodic, wave speed, frequency, acoustic sensors, technology application

Learning Objectives
- Students will be able to differentiate between transverse and longitudinal waves.
- Students will be able to identify amplitude, pulse, periodic, longitudinal, and transverse waves.
- Students will be able to calculate the wavelength, period, frequency, and wave speed of a wave.

Curriculum Alignment
North Carolina Essential Standards
- Phy.2.2.1 Analyze how energy is transmitted through waves, using the fundamental characteristics of waves: wavelength, period, frequency, amplitude, and wave velocity.

Next Generation Science Standards
- HS-PS4 Waves and their Applications in Technologies for Information Transfer

Classroom time required
- One 90-minute block
    - 10 minute Warm-Up and Introduction to Waves
    - 20 minute Slinky lab part 1
    - 15 minute Slides 5-7
    - 10 minute explanation of acoustic sensor applications
    - 20 minute complete Slinky lab part 2 and poster
    - 15 minutes answer post-lab questions
        - Two 50-minute blocks may be appropriate
            - Day 1: Students complete Slinky lab part 1 and take notes on key terms
            - Day 2: Students learn about acoustic sensors, complete Slinky lab part 2 and present their posters to the class

Materials & Technology
Materials
- 5 large Slinkys (*OPTIONAL:* 5 Slinkys per class, students tend to overstretch these)
- 5 poster boards or personal whiteboards per class
- Markers
- Stopwatches or phones with timers
- 5 Metersticks

Technology
- Laptop with PowerPoint/Slides capabilities
- Projector
- Scientific calculators

Safety
There are no safety concerns in this lesson.

Teacher Preparation for Activity

Before class, teachers will need to organize materials in a way that is best suited for the given class. Each group will need a Slinky, meter stick, stopwatch, markers, and poster. Teachers should also review the supplementary resources regarding the acoustic sensor fabrication process and applications. This background research is mainly preparation for potential student questions regarding the acoustic sensors.

Student Preparation for Activity

Before starting this lesson, students should have an understanding of how to find speed from previous physics lessons in kinematics. Students should also be familiar with how to calculate an average value from a data set.

Procedure

- Project slide deck (Also included in the Appendix)
- Slide 2: Warm-Up Discussion
  - Ask students: How and where do we experience waves? Why is it important that we are able to analyze waves?
  - *OPTIONAL:* Get students moving: Create a stadium wave in the classroom!
    - Have students line up. Point/walk/run along the line and have students lift their arms and yell as you point at/pass them.
- Slide 3: Describe mechanical vs. electromagnetic waves
  - Electromagnetic waves range from 10^{-12} to 10^{-3} meters in wavelength (The University of Tennessee Knoxville)
    - X-rays and UV rays are on the nano-scale
    - The light we see has wavelengths of about 400 to 750 nm
  - Can light travel in outer space?
    - Allow students a moment to think and respond
    - Of course. We get light from the sun.
  - Can sound travel in space??
    - Allow students a moment to think and respond
    - No. Astronauts speak to each other through microphones/walkie talkies in their pressurized suits. The sound waves from their voices travel through the air in their suits. The radio waves from between the walkie talkies can travel through space.
- Slide 4: Allow students to collect materials and follow the instructions for the first part of the Slinky activity
  - Students should break up into five groups (or as many Slinky's are available)
  - Instructions are on Slide 4, which is included in the Appendix
- Slides 5-7: Introduce key vocabulary to students
  - Provide access to slides via an online portal or have students copy the vocabulary. It will be important for them to have a place to reference these definitions when they are completing their posters.
  - Slide 6: Ensure students copy down the equations for frequency and wave velocity
  - Slide 7: Allow them time to play with their Slinky to demonstrate transverse and longitudinal waves (Reference video in Supplemental Resources)
- Slide 8: Explain that sensors are used for a variety of applications in science and our daily lives.
  - Acoustic sensors measure the change in frequency of sound waves to give us information about whatever substance or object is being studied/sensed
  - The photo on Slide 8 was taken in the nanotechnology cleanroom that is a part of SMIF at Duke
- Slide 9: Lab Process
  - Step 1: Design and build the sensors
    - *OPTIONAL INFO:* Fabricated using evaporation of gold and other metals onto quartz, spin coating of resists on to wafer, and photolithography for creation of microfluidic channels (more info in Supplemental Resources)
  - Step 2: Find out at what frequency the sensors function best (aka "characterization")
    - *OPTIONAL INFO:* Using an analyzer that vibrates sensor in order to find the resonant frequency
- Slide 10: Students should complete part 2 of the Slinky lab
  - For wave speed, students can simply use speed = distance / time
    - They should have measured and recorded the distance of their wave (length of the Slinky) and how long it took for one pulse wave to travel along that distance.
  - Students should label their wave drawing on their poster with the key terms listed on Slide 10 and calculate the characteristics using the equations they learned earlier in the lesson (from Slide 6)
- As students finish their wave posters, have them display those posters around the room or in the hallway.
- Slide 11: Have students take the last bit of class to complete the post-lab questions online or on paper

- *OPTIONAL:* If time is built in, have students present their poster-board to practice presentation skills and promote higher quality work.

Differentiation

- Adaptations for students with learning difficulties:
  - Provide printed copies of a guided worksheet with a blank data table for students to complete throughout the Slinky activity
  - Provide a printed list of key terms with guided definitions for students to fill in during notes
  - Actively walk throughout the classroom as students work on Slinky activity
  - Allow for additional wait time when asking questions during discussions
- Adaptations for students with gifts and talents:
  - Have students present their posters and responses to the post-lab questions
  - Allow for additional wait time when asking probing questions
- Adaptations for English learners:
  - Provide language supports for the key terms with phonetic pronunciation and scaffolded definitions
  - Repeat instructions and questions multiple times using different wording
  - Allow for additional wait time when asking probing questions
  - Physically demonstrate the Slinky activity while explaining instructions

Assessment/Check for Understanding

Formative Assessment

- Questions and discussion throughout the Slinky activity
- Questions asked during note-taking on key vocabulary and formulas for characteristics of waves
- *OPTIONAL:* Poster presentations

Summative Assessment

- Wave posters: Groups should have 90% of the labels correct on their posters.
  - *OPTIONAL:* Check students' calculations for accuracy
- Answers to the post-lab questions – students are not expected to get most of these questions correct based on this lesson, but their responses will provide insight to their understanding.
  - 1. A higher energy wave produces a higher amplitude and/or a higher frequency
  - 2. Either they cancel each other out or bounce off of each other
  - 3. Lack of precision in measurement of distance and time, etc.
  - 4. The higher the mass of an object touching the sensor, the lower the resonant frequency, which will lead to a greater change in frequency measured by the acoustic sensor.

Required resources

The EM spectrum – This source was used for referencing wavelengths on the electromagnetic spectrum. It also contains potentially helpful diagrams and charts.

Supplemental resources

Waves Background Resources

- Longitudinal wave using slinky coil
- 6.3 How is energy related to the wavelength of radiation? | METEO 300: Fundamentals of Atmospheric Science

Nanotechnology Sources

- Duke SMIF
- What is Photolithography in Nanotechnology?

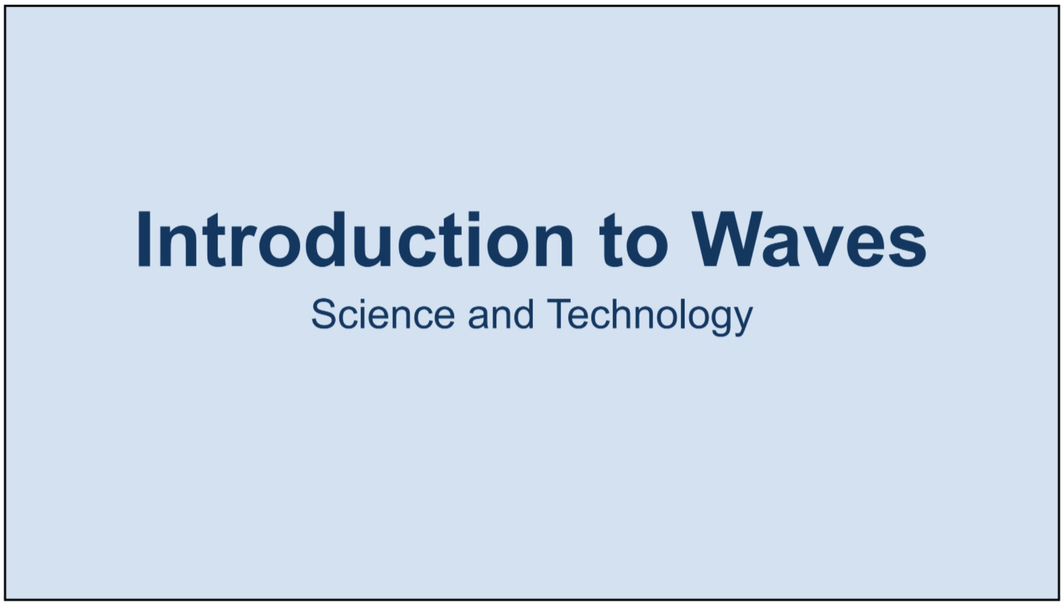
Author comments

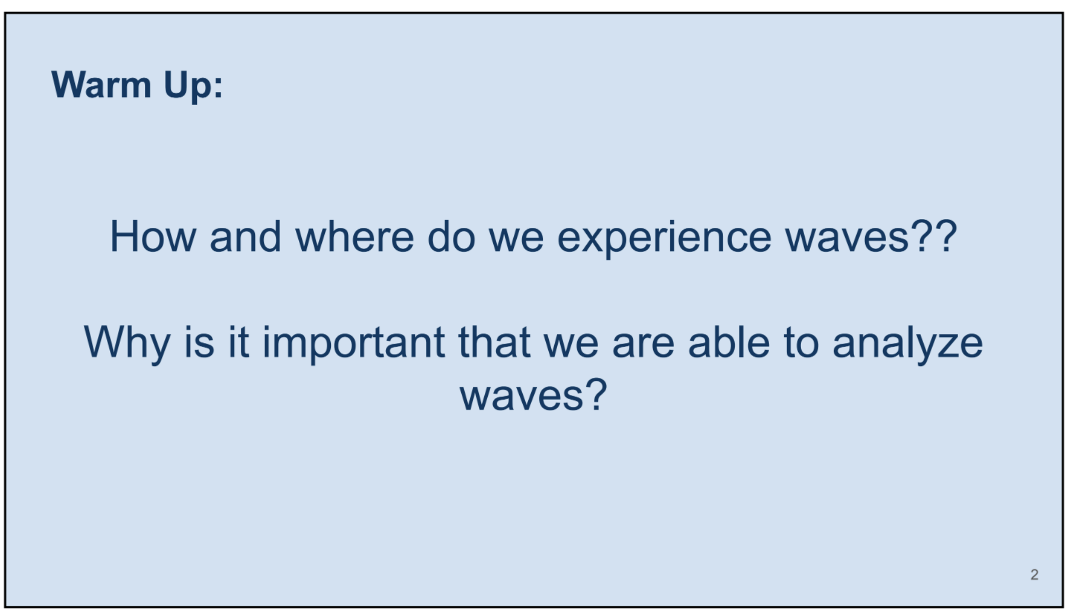
- This lesson plan was developed after spending a month in a lab that fabricated and characterized Quartz Crystal Microbalance (QCM) sensors. This Duke University lab is trying to figure out how to modify the design of the QCM to lead to more accurate measurements.
  - It is recommended that teachers do their own supplemental research on this type of acoustic sensor, if they plan to emphasize this portion of the lesson. The resources provided are a starting point but not comprehensive.
  - An understanding of resonant frequency may be helpful in explaining this process to students.
- Guided language supports and worksheets may be created to complement the notes and activity in this lesson.
  - When taught in an Honors Physics 1 class, no additional support was provided, and the lesson ran smoothly. Students enjoyed playing with the Slinkys and were comfortable asking questions when needed.
- Active monitoring of the Slinky activity is encouraged to ensure students are correctly labeling their posters and to be readily available should any questions or issues arise.

Sources

The University of Tennessee Knoxville. (n.d.). *The EM Spectrum*. Department of Physics and Astronomy. Retrieved July 6, 2022, from http://labman.phys.utk.edu/phys222core/modules/m6/The%20EM%20spectrum.html

Appendices





What is a wave?

A wave is a disturbance that transfers energy from one location to another

Mechanical Waves: Travel through a medium (matter such as water, rope, air, etc.)

- Sound waves
- Seismic waves
- Waves in the ocean

Electromagnetic Waves: Don't need a medium to travel through

- Light waves
- Radio waves

Slinky activity (pt. 1)

1. One person holds each end of stretched out slinky/spring
2. Measure length of slinky/spring
3. One person produces one wave pulse
4. Time how long it takes for wave to travel across medium
5. Repeat for 5 trials

Creatively display your wave and a table of measured values on a poster.

Key Terms

Crest: relative/absolute high points in a wave, "above" equilibrium

Trough: relative/absolute low points in a wave, "below" equilibrium

Propagation: direction in which wave is traveling

Disturbance of the medium: direction in which the medium (matter) vibrates due to the wave of energy

Key Terms

Period (T): time it takes for one complete wave to pass a certain location

Frequency (f): number of waves that pass a given location in a certain amount of time

$F = 1 / T$, unit = Hertz (Hz)

Amplitude: maximum displacement from a position of equilibrium

Wavelength (λ): distance between a point on a wave and the same point on the next wave

Wave velocity (v): speed and direction that a wave is moving

$v = f * \lambda$ $v = \lambda / T$

Other waves to define waves

Pulse vs. Periodic

Pulse: a single disturbance of a medium

Periodic: (aka continuous) connected series of wave pulses

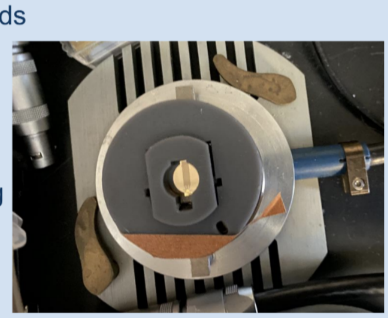
Transverse vs. Longitudinal

Transverse: propagation of wave is perpendicular to disturbance

Longitudinal: propagation of wave is parallel to disturbance

Technology Application: Acoustic Sensors

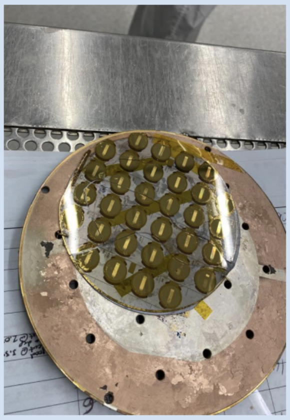
- Used for biosensing and a variety of other needs
- Measure the change in frequency of sound waves to tell something about what is being studied or sensed
- The photo shows a micro-QCM, which is being developed in the Zauscher lab at Duke.
  - Fabricated using nanotechnology
  - Potential applications include: virus detection and analysis of DNA

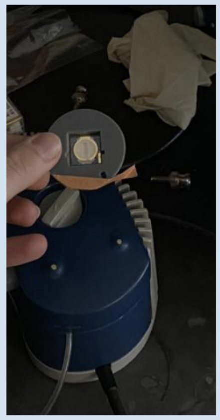


Lab Process

1. Build sensors

2. Analyze and characterize sensors





Slinky activity (pt. 2)

1. One person holds each end of stretched out slinky/spring
2. Measure length of slinky/spring
3. One person produces one wave pulse
4. Time how long it takes for wave to travel across medium
5. Repeat for 5 trials
6. Label the crest, trough, propagation, amplitude, and other wave characteristics on your poster
7. Use the formulas and prior knowledge to calculate wave speed and frequency and add these calculated values to your table
8. Find the average wave speed for all five trials combined and include on your poster

When you are finished, grab some tape and hang your poster on the classroom wall.

Post Lab Questions

1. How do relative amplitude and frequency relate to the energy of the wave?
2. Investigate interference by sending two wave pulses at the same time. What happened to the waves when they meet?
3. What might be some sources of error in your team's measurements for this lab?
4. How do you think the change in frequency of the sound waves in an acoustic biosensor informs scientists about the particles it's touching?