THE MATHEMATICS BEHIND SOUND

Est. Time: 60-120 minutes

Subjects: Math

Age Range: Middle School

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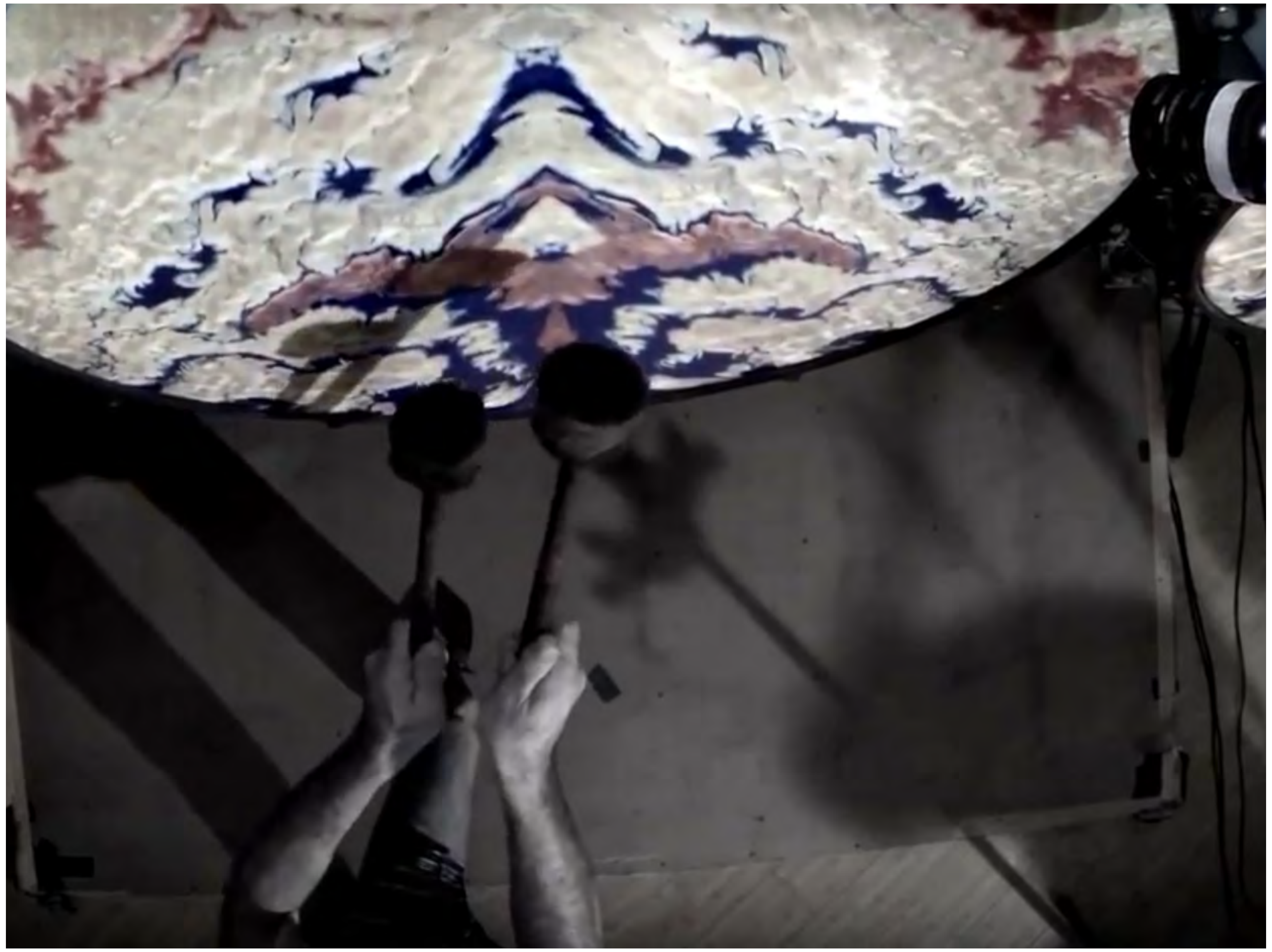
TEACHROCK

What are the mathematical variables that give a sound its particular quality, and how can these variables be measured, visualized, and calculated?

In this lesson you will:

- Identify sound as the perceived result of the compression and rarefaction of air molecules
- Examine sound elements: amplitude, envelope, frequency, and spectrum
- Identify decibels and hertz as a unit of measuring sound's qualities
- Identify wavelength and wave speed as attributes of a sound wave determining its frequency
- Examine the crest, trough, and period of a sound wave

Before starting these activities, it may be helpful to review **The Science of Sound DLP**, since it introduces some of the terminology and basic concepts used here.



Watch **this video** demonstrating a single note being played on four different instruments, then consider or ask a partner:

- What were the instruments you saw in the video? If you can't name them, how would you describe them?
- Using your own words, can you describe how some of these instruments sounded?
- How would you compare the sound of one instrument to another?
- Would it be possible to "measure" the characteristics of these sounds in order to better describe and analyze them? What variables of sound might be able to be measured?

Let's examine the mathematics behind sound by investigating four ways sound can be mathematically measured and shaped: **amplitude**, **envelope**, **frequency**, and **spectrum**.

To better understand these characteristics of sound, let's compare and contrast the four instruments featured in the clip.

As you go through the DLP, fill out what you learn about each characteristic on **this handout**.

Hint: examples of filled in tables can be found* **here.

Before analyzing the instruments, review this info from **The Science of Sound DLP**:

- **Longitudinal wave** - Sound operates as a longitudinal wave and occurs when a vibrating object displaces air molecules surrounding it, which expand and contract in a regular wave-like motion.

- **Compression** - When air molecules are close together.

- **Rarefaction** - When air molecules are far apart.

- **Transverse wave** - Sound is represented visually as transverse waves, which move up and down like ocean waves due to compressions and rarefactions. This visual representation makes them easier to analyze. Compressions are shown by positive numbers on the y-axis. Rarefactions are shown as negative numbers on the y-axis. The x-axis represents time.

Amplitude measures the volume of a sound. Use **this handout** to explore this variable of measuring sound.

Fill out the graphic organizer handout with the pertinent information, then complete the questions on the **handout**. Finally, consider or ask a partner:

- How would you describe the difference in decibels between these instruments, and how many times louder they are between each other?

**Hint:* notice that, while the instruments only vary by a few decibels, they differ greatly on how much louder they are to the quietest perceptible sound. This reflects the logarithmic scale of decibels.*

Envelope measures the changes in amplitude of a sound over time. Use **this handout** to explore this variable of measuring sound.

Fill out the graphic organizer handout with the pertinent information, then complete the questions on the **handout**. Finally, consider or ask a partner:

- How would you describe the attack, sustain, and decay of each sound?
- How might the way an instrument is constructed and played contribute to the instrument's envelope?

Frequency measures the “highness” or “lowness” of sound. Use this **Sound Waves Tech Tool** to study this variable of measuring sound.

Set the tech tool to the “Sine” wave option. Experiment with the tool by pressing the numbers 1-8, then consider or ask a partner:

- How does the sound differ when selecting different numbers?
- What is the relationship between the numbers, the sound wave graph, and the resulting sound?
- How many peaks are present in the graph when the number 1 is pushed? How many peaks are present when the number 8 is pushed? What might these peaks represent?

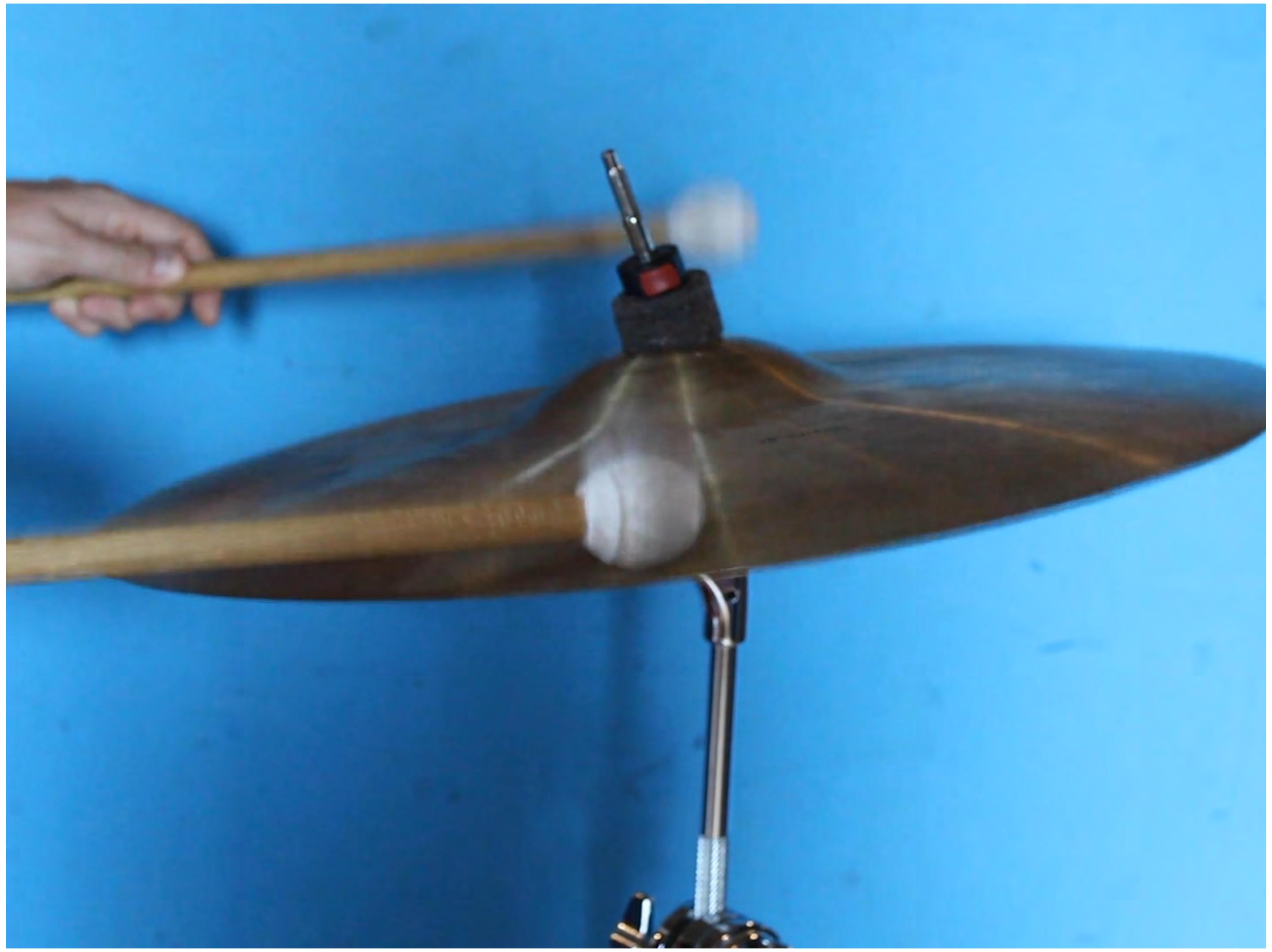
Remember that **frequency** measures the “highness” or “lowness” of sound. Now, use **this handout** to explore this variable of measuring sound.

Fill out the graphic organizer handout with the pertinent information, then complete the questions on the **handout**. Finally, consider or ask a partner:

- How would you describe the relationship between the frequency and the wavelength, based upon your answers?

Watch **this video** again. Pause the video after each demonstration of a single note being played and hum the frequency being created by the instrument. Finally, consider or ask a partner:

- Was it easier to match the frequency of some instruments over others?
- Which instruments were easier to match the frequency? Which were harder?
- Scientifically speaking, why might some instruments make a clearer frequency than others?



Spectrum is the amount and amplitude of different frequencies a sound creates. Sometimes it's referred to as the "sound spectrum." It's the final variable that you'll be exploring.

So far, you've been calculating the fundamental frequencies of the instruments, or the frequencies that the instruments produce most strongly. However, most sounds contain multiple vibrating frequencies.

Remember that **spectrum** is the amount and amplitude of different frequencies a sound creates. Now, use **this handout** to explore this variable of sound.

Fill out the graphic organizer **handout** with the pertinent information, then complete the handout by plotting frequencies to create a spectrogram of each instrument. Finally, consider or ask a partner:

- How do the spectrograms you created represent the sounds of individual instruments? For example, are the lower frequencies more prominent in the lower sounding instruments?

SUMMARY

- There are mathematical variables that give a sound its particular quality
- **Amplitude** measures the volume of a sound
- **Envelope** measures the changes in amplitude of a sound over time
- **Frequency** measures the “highness” or “lowness” of sound
- **Spectrum** is the amount and amplitude of different frequencies a sound creates

BE CREATIVE

Experiment with the interactive **Soundwave** and **Spectrogram** tools at the **Chrome music lab**, then write a brief paragraph explaining what scientific or mathematical principle each tool is based upon.

BE CURIOUS

Check out a real-world application of the "Mathematics Behind Sound" calculations. Watch percussionist Mickey Hart's brain be "sonified" in the **"Sonifying Brain Waves" video**. Then, use the **Sonifying Brain Waves Activity handout** to explore more deeply and answer questions.

BE CURIOUS

Watch **this video** of sound engineer and producer Stella Gotshtein describing equalization, then write a brief reflection considering what acoustic aspect discussed in the lesson relates to equalization, and why equalization is an essential tool to mixing music.

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