Calculating Pitch

OVERVIEW

ESSENTIAL QUESTION

How do musical instruments produce different pitches, and what variables allow you to calculate the pitch of an instrument?

OVERVIEW

In this lesson, Mickey Hart's beam instrument is used as a model to calculate how strings produce pitch. After creating and playing a model version of the beam, students are introduced to the variables that determine the fundamental frequency a string produces, and manipulate a mathematical equation to solve real-world problems related to the construction and performance of the beam.

In the lesson **The Mathematics Behind Sound**, students calculated and visually represented the differing sound qualities of various musical instruments. Yet, anyone who has sat in front of a piano or listened to a guitar solo knows that even a single instrument is capable of producing a wide variety of sounds.

This lesson focuses particularly on pitch or frequency, and the variables in a single instrument's construction that contribute to the pitches it is capable of producing.

The instrument that will serve as a case study for this lesson is the "beam" or "blaster beam." Measuring over 8 feet in length and capable of playing some of the lowest pitches humans are able to hear, the beam is a metal construction beam with 13 bass piano strings stretched over it, and a pickup to amplify their sound. The instrument was invented by John Lazelle and refined by Craig Huxley in the 1970s, and its otherworldly sound has been featured in multiple science fiction, fantasy, and horror films, including the Star Wars and Star Trek series, 2010, and 10 Cloverfield Lane. Mickey Hart first discovered the instrument while working on the soundtrack to the film *Apocalypse Now*.

Despite the immensity of the beam's size and the sound it produces, it is a relatively simple instrument. The 13 bass piano strings on the beam are all tuned to the same note, making it an electrified version of the monochord - an open stringed instrument that traces as far back as the ancient Sumerian civilization (ca. 5500-1900 BCE). By experimenting with the monochord, Greek philosopher Pythagoras (c. 570- c. 490 BCE) developed mathematical principles and early scientific concepts not only related to music, but the entire universe. The fact that the beam serves as a sort of present-day monochord makes it the ideal instrument to examine the mathematics behind pitch, in the same way Pythagoras did millennia ago.

OBJECTIVES

Upon completion of this lesson, students will:

1. KNOW (KNOWLEDGE):

- The musical instrument the beam
- The definition of pitch
- How pitch can be represented mathematically
- How to define and calculate for an instrument's fundamental frequency
- What variables dictate the pitch an instrument produces (tension, mass, size/length)
- How different pitches are created by manipulating the variables of an instrument

2. MASTERY OBJECTIVE:

- Students will be able to analyze and explain how the variables of an instrument affect the pitch it produces by experimenting with the calculation for fundamental frequency.

ACTIVITIES

MATERIALS NEEDED FOR THIS LESSON:

- Pushpins
- Rubber bands of various sizes and thicknesses
- Empty tissue boxes

MOTIVATIONAL ACTIVITY:

1. Play **Clip 1, Mickey Hart Playing The Beam**. Ask students:

- According to Mickey Hart, what is The Beam?
- Who is credited for developing the monochord, which is an ancestor to The Beam?
- Based on what you heard and saw in the video, how Does Mickey Hart play The Beam?
- Can you describe how this instrument is constructed?
- What factors might determine the frequency of an instrument, or whether an instrument sounds high or low?

PROCEDURE

1. Tell students that in class they will be using the beam as a way to calculate how an instrument produces particular pitches, or frequencies (Teachers may refer to the lessons **The Science of Sound** and **The Mathematics of Sound** that introduce frequency or pitch.)

2. Tell students that the pitch or pitches an instrument produces depend on how the instrument is constructed and how the musician manipulates the instrument. Play **Clip 1** once again. While they watch the video, ask students to make notes on which variables might be determining the pitch this instrument produces. (If needed, encourage students to think about what material is vibrating to produce the sound [the strings], and what variables go into that material's construction.) Ask students to share their observations with the class, and list student responses in a place that can be seen by the entire classroom.

3. Tell students that while large, the beam is a type of monochord, which is a relatively simple instrument. The only material that determines the pitch is the string being struck; everything else on the instrument is built to support and amplify the sound of the string. The monochord is in fact so simple that it can be constructed from household materials.

4. Pass out to individual students or student groups a collection of various rubber bands, an empty tissue box, and a handful of push pins. Using the push pins as anchors, tell students to stretch 3-4 rubber bands over the hole in the tissue box. Encourage students to use different sized rubber bands, and use the push pins to stretch the rubber bands at different lengths, and remind them to be careful with the push pins. Once their "beam" instrument is completed, ask students to pluck the rubber bands and observe how the sounds between the rubber bands differ. (The video "Creating a Tissue Box Instrument provides a tutorial of the activity). Then ask students:

   - Did the rubber bands produce different sounds when you plucked them?
   - Did you observe any relationship between the thickness or length of the rubber band, and the resulting sound? For instance, did some rubber bands sound higher in pitch than others?
   - Based on your observations, what variables of the rubber band might contribute to the resulting pitch it produces?

5. Explain to students that while much bigger, the beam uses the same physical principles to produce sound as the instruments the students created. Tell students that the specific pitch produced on the beam is determined by the tension (amount of force applied to the string), mass (the amount of matter or substance that makes up an object), and length of the string. While the mass of the string is determined when it is manufactured, the tension and length of the string can be altered by tightening the string or through the use of a bridge, which splits the string in two —like the marker did in the homemade monochords.

6. Pass out **Handout - Calculating Pitch**, and tell students they will be referring to the handout regularly throughout the lesson.

7. Show **Image 1, Equation for Determining a String's Fundamental Pitch**. Tell students the equation displayed shows how to calculate the pitch of a note that a string instrument produces. Ask students to fill in the missing information on page 1 of **Handout - Calculating Pitch**.

PROCEDURE

8. Using **Handout - Calculating Pitch (Teacher's Guide)**, think aloud with students and walk through the guided practice on page 1 of the handout

9. As a class, review the standard specifications of the beam with the students by reading aloud the first paragraph on page 2 of the handout.

10. Individually or in groups, ask students to complete some or all of the three word problems presented in the handout. If necessary, use **Handout - Calculating Pitch (Teacher's Guide)** to help students work through problems they may have difficulty with.

SUMMARY ACTIVITY

1. Ask students to form groups and work together to summarize what they have learned about how tension, length, and mass per unit length of a string affect pitch. Students will write out their understanding on the final page of **Handout - Calculating Pitch**.

2. Play **Clip 2, Mickey Hart Playing The Drums**. Ask students as a class:

    - Based on what you are seeing in the video, what variables might contribute to the pitch created by a drum? Why do the different drums featured create different pitches?

3. Create a list of student responses in a place that can be seen by the entire classroom (note to teacher: the pitch of a drum is affected by its diameter, depth, the tension of the membrane that is being struck, the thickness of the membrane being struck, and the area of the membrane being struck.) Ask students:

    - Do you think drums have more or less variables that contribute to their pitch than string instruments? Why or why not?

    - Do you think it would be easier or more difficult to calculate a drum's pitch based on variables, compared to a string instrument? Why or why not?

EXTENSION ACTIVITIES

1. Ask students to hypothesize the variables of a wind instrument or percussion instrument other than a drum (bells, xylophone, etc.) which define the produced pitch, then conduct research to see if their hypotheses are accurate.

STANDARDS

COMMON CORE STATE STANDARDS

Expressions and Equations

CCSS.Math.Content.7.EE.B.3: Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies.

Creating Equations

CCSS.Math.Content.7.CED.A.4: Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange Ohm's law V = IR to highlight resistance R.

College and Career Readiness Reading Anchor Standards for Grades 6-12 for English Language Arts

Reading 1: Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.

Craft and Structure 4: Interpret words and phrases as they are used in a text, including determining technical, connotative, and figurative meanings, and analyze how specific word choices shape meaning or tone.

Integration of Knowledge and Ideas 7: Integrate and evaluate content presented in diverse media and formats, including visually and quantitatively, as well as in words.

Range of Reading and Level of Text Complexity 10: Read and comprehend complex literary and informational texts independently and proficiently.

College and Career Readiness Anchor Standards for Writing for Grades 6-12

Text Types and Purposes 2: Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.

College and Career Readiness Anchor Standards for Speaking and Listening for Grades 6-12

Comprehension & Collaboration 1: Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

Comprehension & Collaboration 2: Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.

Presentation of Knowledge 4: Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

College and Career Readiness Anchor Standards for Language for Grades 6-12

Language 1: Demonstrate command of the conventions of standard English grammar and usage when writing or speaking.

Vocabulary Acquisition and Use 4: Determine or clarify the meaning of unknown and multiple-meaning words and phrases by using context clues, analyzing meaningful word parts, and consulting general and specialized reference materials, as appropriate.

Vocabulary Acquisition and Use 6: Acquire and use accurately a range of general academic and domain-specific words and phrases sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when encountering an unknown term important to comprehension or expression.

RESOURCES

VIDEO RESOURCES

- Clip 1, Mickey Hart Playing the Beam
- Clip 2, Mickey Hart Playing The Drums
- Creating a Tissue Box Instrument

HANDOUTS

- Handout - Calculating Pitch
- Handout - Calculating Pitch (Teacher's Guide)