The Physics of Music

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Date: March 1, 2023

Duration: 3 to 5 hours (3 to 5 sessions of one hour each)

Introduction

This is a free resource for teachers and students and is part of the Callysto project, a federally-funded initiative to foster computational thinking and data literacy in Canadian Grade 5-12 classrooms.

In this lesson, we will explore how musical instruments produce sound and how these sounds can be reproduced on a computer. We examine what “sound” is, what makes a sound appear musical, the physics of sound waves and musical instruments, and how sounds are created on a computer. The lesson is presented as a collection of Jupyter notebooks including demos and simulations of instruments in Python code. The topics are organized as follows:

- What is sound?
- How do we simulate sound on a computer?
- What is music and what makes a sound musical?
- The physics of musical instruments
- Some sample instruments
    - tuning fork, penny whistle, slide whistle, didgeridoo, plucked strings
- More complicated instruments
    - Drum, trumpet, clarinet, violin
- Harmonics and musical notes

There are also several auxiliary notebooks that are referred to in the notebook, including detailed information on many of the examples.

Grade Level and Audience

Grades 7 to 12, adapting as appropriate
Suitable for Physics and for Music curricula

Necessary Background Knowledge

1. Students should know how to log in to the Callysto Hub as well as run a notebook prior to interacting with it. Teachers, to get started with Callysto notebooks and running material on the Callysto Hub, see our Starter Kit.
2. To log in to the Callysto Hub you and your students will need a Google or Microsoft account. This can be a school division-provided account or a personal account. Callysto does not collect any personal information about accounts.
3. Teachers can review with their students basic characteristics of sound such as amplitude, pitch, timbre and quality of tones, harmonics and the limits of human hearing. Students and teachers might like to review our other lesson plan on The Physics of Sound

Learning Outcomes

- Students will learn what a “sound” is
    - Vibrations in air as the basis for real sound
    - Characteristics of sound, with pitch, amplitude and timbre
    - How sound is simulated on the computer with lists of numbers
- Students will learn the three components of producing a note in a musical instrument
    - The initiator of the note (e.g. drumstick hitting, guitar plucking, mouth blowing)
    - The vibrating member (e.g. drumhead, guitar string, lips vibrating)
    - The resonating/transmitting body (e.g. drum shell, guitar body, trumpet tube)
- Students will learn details of the physical basis for sound waves arising in music
    - Standing waves and traveling waves
    - Reflection of waves in instruments
    - Connection between frequency, pitch, and wavelength
- Students will learn about harmonics and harmonic synthesis
    - Harmonics are multiples of a given fundamental frequency
    - Harmonics arise naturally in vibrating objects like musical instruments
    - By adding various harmonics one can synthesize the sounds of musical instruments
- Students will see the physics of several instruments
    - Tuning fork, penny whistle, slide whistle, stringed instruments, drums
    - Animations and simulations of these instruments on the computer

Required Materials

Required materials

1. A charged computer.
2. Access to the internet.
3. An installed internet browser, preferably Google Chrome.
4. A Google or an Outlook email account.

Optional additional materials

5. Headphones or external speakers for the computer
6. A few simple musical instruments: penny whistle, slide whistle, tuning fork, ukulele
7. A 3-foot long cardboard tube, such as from a roll of wrapping paper
8. A steel tuning fork and small neodymium magnets to attach to the fork

Modifications

There are up to five lessons that can be covered. The teacher may choose to do just the first three lessons, or give an overview of the lessons and allow students to explore on their own.

Preparation

The Jupyter notebooks for this lesson all use the computer's speaker to create sounds for the teacher and students to hear. It is a good idea to test the computer's sound system to ensure that it is loud enough for the class to hear, but not too loud. Please set up your computer in advance and try out the notebook, to ensure that the sound works and the volume set to a comfortable level.

In-Class Activities

Activity 1: Musical Sounds - (One hour)

- Link to the notebook **physics-of-music.ipynb** and cover the following sections:
    - What is sound, What is music, What makes a sound musical?
    - Simulating sound and music on the computer
    - The basic physics of how a musical sound is produced
    - Experiments with a real tuning fork: pure tones, pitch, slowing the vibration

- Extra notebook on tuning forks: **tuning-fork.ipynb**

Activity 2: Wind Instruments - (One hour)

- Link to the notebook **physics-of-music.ipynb** and cover the following sections:
  - Physics of a penny whistle, slide whistle, didgeridoo
  - Traveling waves in a hollow tube
  - Frequency, wavelength and the speed of sound in air
- Extra notebook on penny whistle: **penny-whistle.ipynb**
- Extra notebook on slide whistle: **slide-whistle.ipynb**

Activity 3: Stringed Instruments - (One hour)

- Link to the notebook **physics-of-music.ipynb** and cover the following sections:
  - Physics of plucked strings: ukulele or guitar
  - Traveling waves and standing waves on a string
  - Frequency, wavelength and the speed of sound in a string
  - Computer simulation of a plucked string
- Extra notebook on plucked strings: **plucked-string.ipynb**
- Extra notebook on standing waves: **standing-waves.ipynb**

Activity 4: Harmonics - (One hour)

- Link to the notebook **physics-of-music.ipynb** and cover the following sections:
  - Fundamental frequency and harmonics, definitions and examples
  - Integer harmonics and the Western musical scale
  - Combining harmonics to create musical tones
  - Computer simulation to imitate musical instruments
- Extra notebook on harmonics: **harmonics.ipynb**
- Extra notebook on a numerical keyboard: **keyboard.ipynb**

Activity 5: Additional instrument - (One hour)

- Link to the notebook **physics-of-music.ipynb** and cover the following sections:
  - Physics of other instruments: drums, trumpets, clarinets, violin
  - Visualizations and computer simulations of these instruments
  - Simulation challenge for simulating brass instruments
- Extra notebook on drums: **drums.ipynb**
- Extra notebook on violins: **violin.ipynb**

Reflections

Some suggested questions:

- *How would you describe the three main characteristics of sound: **amplitude**, **pitch** and **timbre?***
- *What makes a sound seem like it is musical, or produced by a musical instrument?*
- *How would you describe in more detail the three components of producing a musical sound? The **initiator**, the **vibrator**, and the **resonator**.*
- *For the other musical instruments not covered in the lesson, what are the initiators, the vibrators and the resonators? (e.g. a piano, a xylophone, a trombone, a kazoo, etc.)*
- *In the harmonic simulator, how well can you simulate the sound of particular instruments, like a flute, clarinet, violin, or drum? Are some easier to simulate than others?*
- *We have not discussed how a musical note develops over time. What do you think the **attack**, **sustain** and **decay** portion of a note could mean? How could you simulate this on the computer?*
- *Are there other characteristics of musical sounds that are important to the listener? How would you describe them? How might you produce them on a computer?*

Next Steps

For more information, you can check out our YouTube videos, online courses, or callysto.ca for learning modules, tutorials, lesson plans, exercises and events.

Contact

If you encounter any issues or have any suggestions, please get in touch with us at contact@callysto.ca or twitter.com/callysto_canada.