Activity Outline: Monochord

Overview
A monochord is a simple musical instrument with one or two strings (the latter more correctly called a duochord) and a moveable bridge. Unlike most musical instruments, the monochord was designed primarily for scientific experimentation and teaching. It is used to demonstrate the relationship of string division to pitch, and the various systems of temperament that can be derived this way.

[Image: Monochord]

Materials
Artec Educational offers a complete kit (one instrument) for $11.99. Their design incorporates two strings—one to act as a drone and the other to be tuned with the bridge. This allows the student to hear the interval produced by dividing the string without removing and replacing it. If you want finished instruments, Artec offers packs of five for $49.99.

Eric Leonardson’s design gives thorough instructions for a scratch build, as well as some background information on the instrument. Once the basic principles are understood it is possible to adapt the cheapest and most abundant materials into serviceable instruments, which may be more educational as well as more cost effective.

Teaching Concepts
The monochord is ideal for teaching both about the physics of string division, the harmonic series, and the mathematics of temperament. This exercise also provides an opportunity for some ear training. The primary function of the instrument is to demonstrate different methods of dividing an octave and the systems of temperament that are produced in this way. The mathematics of temperament span a wide range of difficulties, from extremely rudimentary (a basic octave) to relatively advanced (twelve-tone even temperament).

If multiple monochords are built (and perhaps amplified) they can be used to compose simple music in various temperament systems—including those devised by the students themselves. Because each instrument has at most two strings, students will have to collaborate to create complex harmony or textures.

Additional Terms and Concepts
- Vibration
- Frequency
• Scale
• Interval
• Temperament
• Harmonic
• Harmonic series
• Intonation

• Pythagorean scale
• Ptolemaic scale
• Just intonation
• Equal temperament
• String mass vs. tension vs. pitch

Further Reading
http://www.sfu.ca/sonic-studio/handbook/Interval.html

http://prezi.com/lg-p5r5mhj8b/copy-of-how-to-build-a-monochord/

http://www.hps.cam.ac.uk/whipple/explore/acoustics/monochord/
Monochord Lesson 1: Building the Monochord

The class participates in building several monochords, learning some basic physics and acoustics along the way. Once built, the monochords can be used individually or in combination to teach temperament and (with some additions) perform music.

Materials
Artec Kit: $11.99 per kit

Eric Leonardson’s design: Cost dependent on materials selected.

The Artec kit seems to call for piano wire, where Leonardson’s design specifies guitar strings. Motorcycle brake cables (assuming they are not otherwise in use) can be disassembled, and their individual strands used as high pitched strings.

The primary concern for a two-string design is that both strings be the same gauge. If they are not, they will sound and intonate differently even if tuned to the same pitch. For reliability and ease of use, guitar strings are probably the best option. Individual steel strings can be purchased here.

Student Level
6-9

Terminology
- Vibration
- Wave
- Frequency
- Pitch
- Tension
- Mass
- Harmonic
- Scale
- Interval

Suggested Plan
Introduce the monochord explaining that its purpose is primarily experimental rather than musical. Nonetheless, the principles involved in its construction and operation apply to all stringed instruments.

Despite the simplicity of the instrument, building it can be a good introduction to basic instrument engineering. Encourage students to fit parts carefully and use glue
and fasteners economically. Correct scale length and string alignment are the most important concerns here.

A major weakness of the Artec design is the dowel used as a bridge. The dowel is tall enough to stretch the string upward—thus sending it sharp with respect to the visual position of the dowel. Whether working from a kit or from scratch, make sure that your bridge is tall enough to effectively stop the string with as little extra stretching as possible.

A second weakness of the round dowel is that the center is hard to see, making exact placement more difficult. A visit to the hardware store will reveal numerous options better suited for this purpose, many of them quite cheap. The best result will be obtained by selecting a stock that is slightly too tall for the instruments and carefully shortening it (by sanding or cutting) until it is exactly the right height.

Once the instruments are built, carefully tune them and check all bridges, making adjustments as needed. Your monochords should now be ready for use, both for the lessons included in these materials and for many other possible activities relating to temperament and string vibration.

**Safety concerns:**
Strings can snap with great force during tuning, so keep faces well away from the monochord when changing pitch. Also take care to clean up any trimmed string ends—they are stiff wire and do have the ability to puncture skin.

**Related Concepts**
- Temperament
- Intonation
- Modes
- End effects
- Fundamental

**Extensions**
More advanced students can study the monochord in terms of equations regarding scale length, string mass, tension, and pitch. Instruments of different sizes can be built to experiment with these parameters. Very advanced students can venture into the territory of end effects and wave equations should they so desire.

*This article* offers a fairly detailed design for a scratch-built instrument as well as two separate amplification circuits; one magnetic, one optical.
Additional Resources

'How to Build a Monochord' video

Eric Leonardson Monochord Prezi

HPS CAM Article

SFU Acoustic Ecology Handbook: Intervals

Wikipedia has articles on the mathematics of string vibration, which may be of interest to advanced students.

Once the students understand the basic principles involved in building a monochord and the results obtained by doing so, they may be interested in designing their own instruments. By doing so they can demonstrate their understanding of the temperament system they have chosen.
Monochord Lesson 2: The Harmonic Series

The monochord is used to demonstrate the harmonic series as it relates to string division.

Materials
• 1 complete monochord
• Measuring tape
• Projector or other visual aids
• Handouts
• Electronic tuner/app (optional)

[Image: Harmonic series chart]

Student Level
6-12

Terminology
• Vibration
• Wave
• Fundamental
• Harmonic
• Octave
• Scale

Suggested Plan
Introduce the monochords and make sure that they are tuned to the same starting pitch, or to whichever pitch you have chosen for each instrument. Demonstrate the first harmonic by placing your fingertip gently in the center of the string and plucking on one side of it. If you’re touching the right point you will hear a tone an octave above the fundamental. This is the first essential lesson of the monochord: You have divided the string in half to double the frequency. This can be expressed in the following equation: \[ f_1 = \frac{1}{2L} \sqrt{\frac{T}{\mu}} \]

Repeat this procedure dividing the string into thirds, quarters, and fifths. Further harmonics may or may not be audible on your instrument. The ratios are 2:1 (octave), 3:2 (perfect fifth), 4:3 (perfect fourth), and 5:4 (major third).
This demonstrates that harmonic nodes are a property of all strings, regardless of instrument.

Once the natural harmonics have been found, the bridge can be used to divide the string in the same places to produce the same tones. Show the students (or allow them to discover) that some harmonics can be found in more than one place on the string, but always at the same ratio.

The harmonic series can be expressed in fractions, ratios, frequencies, or musical intervals. Combined with the formulas, this offers many possibilities for additional exercises and evaluation.

### Related Concepts
- Hertz
- Cents
- Steps
- Intervals
- Intonation
- Pythagorean tuning
- Ptolemaic tuning
- Equal temperament
- Harmony
- Scale degree
- Sharp/flat
- Consonance/dissonance

### Extensions
Students advanced enough to do basic calculus can be given the formula for the series and taught to derive the harmonics of given frequencies.

A slightly different approach to the lesson would be to have students locate the positions of the natural harmonics on their instruments and determine the string division that produces each one. In this way they can discover the formula (or at least elements of it) for themselves.

The physics of string tension and vibration are may also be of interest to classes where equations are relevant.

### Additional Resources
- Harmonic series video
- Monochord readings:
  - HPS CAM Article
SFU Acoustic Ecology Handbook: Intervals
Monochord Lesson 3: Early Temperament

The monochord is used to demonstrate just intonation as it relates to string division. The introduction of the third can provide a starting point for discussing the concepts of consonance and dissonance.

Materials

- 1 complete monochord
- Measuring tape
- Projector or other visual aids
- Electronic tuner/app (optional)

Iphone tuner app

Android tuner app

Student Level

6-12

Terminology

- Vibration
- Wave
- Fundamental
- Harmonic
- Octave
- Scale
- Interval
- Hertz
- Cents
- Steps
- Intonation
- Pythagorean tuning
- Ptolemaic tuning
- Equal temperament
- Harmony
- Scale degree
- Sharp/flat
- Consonance/dissonance

Suggested Plan

Tune all instruments before beginning.

Early music physicists—possibly including Pythagoras—built their scales on the 3:2 ratio, or perfect fifth. This is an easy interval to tune by ear, and sounds very stable. If you have more than one string available you can use the bridge to tune one to the fifth of the other and demonstrate this.
As explained in the example above, the Pythagorean scale is mathematically simple but lacks a usable major third—a vital part of western music. In order to obtain the third and other intervals, Just Intonation was devised. Systems of Just Intonation alter some tones of the Pythagorean scale in order to create consonant intervals, but still rely only ratios that can be expressed in relatively small whole numbers.

Individually or in groups, invite students to devise their own justly intonated scales. Assembling intervals that are all simple ratios and (ideally) neat multiples of one another can be challenging. Their knowledge of the harmonic series should provide a good starting point. Once everyone is happy with what they have on paper, try the results on the instrument and see how they sound.

**Related Concepts**
- Tonality
- Mode

**Extensions**
This online synthesizer and accompanying article (with many diagrams) are good resources for further exploring the sound and theory of Just Intonation.

Students could be assigned to design and build a simple musical instrument (based on the principles of the monochord) according to their own temperament system.

**Additional Resources**
Overview of temperament systems with string ratios:


Frequency graphs and audio of many ancient scales, including Ptolemaic:

http://www.nonoctave.com/tuning/scales/Ptolemy's_Scale_Catalog.html

Monochord readings:

http://prezi.com/lg-p5r5mhj8b/copy-of-how-to-build-a-monochord/
http://www.hps.cam.ac.uk/whipple/explore/acoustics/monochord/

SFU Acoustic Ecology Handbook – Intervals:

http://www.sfu.ca/sonic-studio/handbook/Interval.html

SFU Acoustic Ecology Handbook – Just Intonation:

http://www.sfu.ca/sonic-studio/handbook/Just_Tuning.html