STEAM Activity – Metal Pipe Chimes

Music and the Arts Team Up with Technology
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Here is an activity that will incorporate many of the themes of STEAM (Science, Technology, Engineering, Arts and Mathematics). You'll need all these themes as you calculate, construct, assembly and perform with a unique set of tubular pipe chimes made from standard ½" metal conduit (found at most larger hardware stores that sell electrical wiring).

Let's start with a basic principle of science (physics to be exact) and engineering (acoustic vibration). When metal bars (hollow or solid) are struck, they vibrate in a specific manner that is dictated by such factors as the geometry (size and shape) of the bar, the material of the bar and several engineering constants (such as the acceleration due to gravity). The formula which describes this phenomena is:

$$\text{Pipe Chime Length} = \frac{Mode\ Factor^2 * g * E * I}{(w * f^2)^{1/4}}$$

Mathematical formulas are a bit like baking recipes. If you put all the right stuff in, in the right order, and follow the instructions, you end up with a final product that is just what you hoped for. The mathematical formula for calculating the length of pipes necessary to produce the middle octave of a piano is derived from free vibration beam theory and based upon what musicians refer to as the American Standard Pitch (A4 = 440 Hz). The following 'ingredients' are necessary for the formula above:

Pipe Chime Length is expressed in inches.

Mode Factor = 3.58, for the fundamental mode, which is generally the primary and loudest mode. I found this information from a book on the physics of musical instruments.

g = the acceleration due to gravity, which is 386 inches/second^2

E = the modulus of elasticity for the material of the pipe. For steel, this number is 30,000,000 psi (pounds per square inch).

I = the moment of inertia, an engineering calculation that is calculated from the shape and area of the cross section of the piping used. For a circular pipe, I = π * (OD^4 - ID^4)/64, where π is the mathematical quantity Pi, which equals 3.1416, OD is the outside diameter of the pipe (in inches) and ID is the inside diameter of the pipe (also in inches).

w = the weight per unit length of the material the pipe is made from. In this case, pounds per inch of length. For steel, this value is calculated by dividing the density of steel with the cross sectional area of the pipe. w(steel) = 0.0235 pounds per inch of length

f = the frequency of pipe chime desired. This number can be found in musical and engineering texts that define pitch. In the case of the pipe chimes presented here, the A4 note, found just below Middle C on a standard piano, has a frequency of 440 cycles per second.

By drilling a hole completely through each pipe at the ‘node point’ (through which a support string is attached to each pipe chime) the maximum free vibration is maintained and so is the best sound quality. The node position for the primary (fundamental) vibration frequency is 22.4% of the length of each pipe. For the A5 musical note (below), the node position is 0.224 x 13.86 = 3.10 inches (79mm). Invite your audience to calculate the node position for each of the following pipe chime lengths:

The results from the equation found on Page 1, starting with the octave 5 frequencies of a piano, are:

No.	Musical Note	Length (inches)	Length (millimeters)	Node Position (inches)	(millimeters)
0	A5	13.86	352	3.10	79
1	A#	13.46	342		
2	B	13.08	332		
3	C	12.71	323		
4	C#	12.35	314		
5	D	11.99	305		
6	D#	11.65	296		
7	E	11.32	288		
8	F	11.00	279		
9	F#	10.69	271		
10	G	10.38	264		
11	G#	10.09	256		
12	A6	9.80	249		
13	A#	9.52	242		
14	B	9.25	235		
15	C	8.99	228	2.01	51

Question: How many pieces of metal conduit will you need to create the 16 pipes listed here?
Answer: 2 pieces 10 feet long, with some extra just in case you make a mistake.

Write on each pipe chime (with a permanent marker) the number (No.) shown in the chart above. Then invite your group to play the following song and see if they can ‘name that tune.’ When two numbers are shown vertically together, play both of these pipe chimes at the same time.

3	**3**	**5**	**3**	**8**	**7**	**3**	**3**	**5**	**3**	**10**	**8**	**3**	**3**	**15**	**12**	**8**	**7**	**5**	**13**	**13**	**12**	**8**	**10**	**8**
				3	**1**			**1**		**3**	**3**			**12**	**8**	**3**	**3**	**1**	**8**	**8**	**8**	**3**	**7**	**3**
														8	**3**				**5**	**5**	**3**		**3**	

All engineered products, including these pipe chimes, have tolerances associated with their manufacture, construction and assembly. These tolerances can alter the pitch of your pipe chimes and are a function of the frequency of each pipe. The longer the pipe chime, the larger the permissible variation. The shorter the pipe chime, the smaller the permissible variation. A 10 Hz variation in pitch (detectable by humans) can be produce by these tolerances at each octave level:

A5 = +/- 0.08” (2.0 mm)   A6 = +/- 0.03” (0.7 mm)

Simply stated, if you are making the A5 pipe chime above, you need to cut the length of the pipe as close to the 13.86 inches (352mm) dimension as possible. If you make it 2 mm longer than necessary, this pipe will vibrate at 10 Hz lower than expected, which will affect the quality of the music you produce (like playing a song on a piano that needs tuning!)

Electrical conduit, which can be purchased at most larger hardware stores or electrical supply dealers, is perfect for making a set of pipe chimes. It comes in 10 foot (3 meter) lengths. Engineering values for standard 1/2” electrical steel conduit (which oddly enough has an outside diameter of 11/16” inch) has been used to calculate the pipe chime lengths provided here. You will need 2 pieces of 10 foot long 1/2” electrical steel conduit to make the pipes calculated in this paper (and have a few feet left over, just in case you make a mistake). We recommend cutting these pipes with a standard pipe cutting tool (found at most hardware stores). This tool cuts easily and does not leave the ragged edge that a hack saw will produce. After cutting each pipe to length, use a pipe reamer (also available in the same section of the hardware store) to

remove any sharp edge left on the pipe. Ream both the inside and outside diameters of both ends of the pipe chime. Then, drill a hole through each pipe chime at the node point and pass a string through these holes. Hold each pipe by this string loop and strike with a spoon or nail to produce a tone.

If you are interested in a more extensive list of pipe chime calculation lengths (75 of the 88 piano keys covering the frequencies from A1-C7) email me at jimcain@teamworkandteamplay.com and I’ll send you the list. But it’ll cost you! You’ll need to share (via email) a photo or activity description of one of your own favorite STEAM activities, along with your request for the pipe chime lengths.

* Disclaimer – The metal conduit used to create these simple pipe chimes is an inexpensive substitute for the substantially more expensive materials used to create commercial tubular bells and chimes. It also has a much wider tolerance on diameter, wall thickness and density, and often is coated with a plating that also varies in thickness. As such, the calculated dimensions provided in this paper are only reasonable estimates. Also, commercial tubular bells include in their length calculations an ‘end effect’ which modifies the length of the pipe. I have not included this additional effect in my calculations.   The good news is, since all pipe lengths are calculated from the same equation (and typically made from metal conduit purchased from the same vendor), the musical quality of the pipes compared to each other is pretty good (but may vary slightly from the notes of other well-tuned musical instruments).

I first wrote about pipe chimes in the book *Teambuilding Puzzles* (ISBN 978-0-7575-7040-7), available from Kendall Hunt Publishers (1-800-228-0810 or www.kendallhunt.com). If you enjoy constructing things with your young scientists, the book *Teamwork & Teamplay* (ISBN 978-0-7872-4532-0) also from Kendall Hunt Publishers, not only includes dozens of unique teambuilding activities, but also instructions to build the equipment for each of these activities. You can find more information about all my books (16 so far!) and teambuilding props at www.teamworkandteamplay.com

I hope you enjoy this activity. Please email me and let me know how it is going. I’d love to hear from you.

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