The Electric Marimba
Construction Instructions

Create It Lab

M^4-004 v0.8	**Title:** Electric Marimba	**Target Grade Level:** 7-12	
Categories	Physics / Waves / Sound / Music / Instruments / Piezoelectricity		**Pira** 3D
Standards	**US:** NSTA Science Content Std B, 5-8: p. 155, 9-12: p. 180		**VT:** S5-6:29
	Regional: McREL Science Standard 9, Levels II-IV		
Keywords	Resonance, Frequency, Pitch, Music, Idiophone, Wavelength, Unclamped Beam , nodes, Timbre, Reflected wave, Standing Wave, piezoelectricity		
Project Type: Workshop	**Complexity:** Challenging	**Materials:** Generally Available	
Project Duration: 2.0 hr Prep, 6.0 hr Build		**Recommended Team Size:** 6-9	

Note: optional material is highlighted in red.

e-Marimba: Construction Instructions

Purpose

The primary purpose of this project is to understand the connection between the length of an **unclamped beam** and its fundamental resonant frequency. This objective is accomplished by building and playing a marimba made with hardwood bars. An optional goal is to develop an intuitive understanding of the mathematical relationship between the beam length and the fundamental frequency. Extensions of the project could include a discussion of the structure of musical scales and piezoelectric materials.

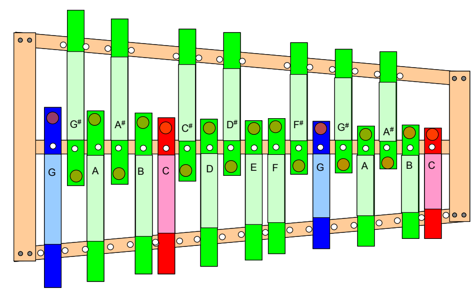


Fig. 1 Fully chromatic, 1 ½ Octave e-Marimba with Offset Bars.

Background

A marimba is a musical instrument in the **idiophone** (pronounced `*id·ē·ə·fōn*) category. The name idiophone comes from the Greek word *idios,* which means "one's own." Instruments of this kind are called idiophones because they make *their own* sound, depending on just the materials and shape of the object. Other idiophones include tubular bells, steel drums and the glockenspiel. The marimba in this workshop consists of a grouping of hardwood bars, each vibrating as an **unclamped beam**. Typically, marimbas are acoustic instruments and require long tubes to amplify the sound of the vibrating bars. However, in electric marimbas, the sound of the bars is detected by **piezoelectric** disks that are attached to the bars. Piezoelectric materials have the property that they generate electricity when they are vibrated, and conversely, electricity causes the material to vibrate. The electric signal generated by the vibrating disks is carried by wires to a simple **pre-amplifier circuit** and then into a standard microphone jack of an amplifier.

The **fundamental resonant frequency** of an object is the frequency that requires the lowest energy to cause the object to vibrate. If an unclamped beam is vibrated at frequencies that include the fundamental resonant frequency, the fundamental frequency will usually be the loudest sound produced. Assuming the fundamental frequency is in the audible range for humans, this frequency will usually be heard as the dominant **pitch** of the beam.

In idiophones, higher resonant frequencies (**overtones**) may also be produced. Unlike the instruments in some other categories, these overtones do not have to be multiples of the fundamental frequency. The human ear may hear the overtones, but usually identifies the primary pitch as that of the fundamental frequency. The combination of the resonant frequencies is heard as a small change that partially responsible for the **timbre** (pronounced `*tam·bər*), or [nearly] unique tonal quality, of the instrument.

Materials & Tools

Materials per marimba:

(1) Foam. medium density strips, 1" x ¼" (~2.5 cm x ~0.5 cm), totaling 120" (~305 cm)
(4) Softwood, (2x4 x 8' (~ 4 cm x ~9 cm x ~245 cm),
(40/60) Finish nails, 10d (2½" or ~6.5 cm long)
(1) Hardwood strips , total lengths dependent on desired notes
  Alto Marimba - 0.75" x 1.5" wide,
  Tenor Marimba - 0.75" x 2.5" wide,
  Bass Marimba – 0.75" x 3.5" wide
(20) Binder clips, medium
(20) Star washers, size 8
(20) Flat washers, size 8
(20) Hex head screws, size 8
(20) Solder Lugs
(20) Peizoelectric disks, 35 mm
(1) Bare wire, totaling 120"
(1) Insulated wire, 10"
(1) Preamp (see Electro-Sci, Preamp)
(1) Battery, 9V
(1) Battery clip
(3) Screws, size 6, ¾" long
(2) Dowel, 5/8" (~1.5 cm) OD, 30 cm long
(2) Rubber chair-leg caps, 5/8" (~1.5 cm)

Tools per team:
(7) Large C-clamps
(3) Hand saws
(3) Miter box(es), 90°
(3) Drum sander
(1) Drill press
(3) Hammer
(1) Hand drill with (1) each
  size 8 nut driver
  3/16" (~0.5 cm) bit
  ¼" bit
  1/16" bit

(8) Goggles
(8) Ear Plugs
(8) Dust Masks
(1) Masking tape, roll
(3) Tape Measure(s), English & metric
(3) Electronic tuner (or pitch-matching instrument)
(1) Hot Glue gun, with glue and glue station
(1) Soldering Iron, with solder and soldering station
(1) Wire cutters, small
(1) Needle nosed pliers

Tools for Instructor:
(1) Sheetrock knife and straight edge for cutting foam
(1) IPAD/IPOD Tuner APP, with FFT frequency display (e.g., Tuner!!)

Procedure

The e-Marimbas can be made as fully chromatic, 2-sided instruments with the accidental notes (sharps & flats) offset from the regular notes, or as a 1-sided instrument with in-line bars. Furthermore, there is the option of constructing a reduced set of notes (e.g., for just a single key). The following procedure is written with the 1-sided version for the keys of C and G appearing in black text and additions for a fully chromatic, 2-sided version shown in red. Appendix A illustrates these two design choices.

Constructing an e-Marimba can be divided into three activities: I. Marimba Frame Construction, II. Marimba Bar Construction and III. Final Assembly. For large teams, it is recommended that two sub-groups work on activities I and II in parallel, with interactions between the subteams to allow the size of the frame to be established by the length of the tuned bars. Other activities, such as music selection, artistic/cultural enhancements and project documentation can also be performed in parallel. Appendix B illustrates the process flow for the project.

During the assembly process, all marks on the wood should be made in pencil.

I. Marimba Frame Construction

Building the Marimba Frame has 3 parts: Part A. Support Construction, Part B. Center Support Wiring and Part C. Frame Assembly.

The marimba bars are supported by foam strips on top of 2x4 supports. Finish nails are used to loosely hook the bars to the *center support* and to separate the bars on the *side support(s)*. Short lengths of 2x4s are also used as *left and right connectors* to link the supports together. The bar widths and the *bar periodicities* (bar width + the space between bars) for alto, tenor and bass marimbas are shown in the following table.

Table 1 Key Marimba Dimensions

Marimba	Alto	Tenor	Bass
Bar Width (in.)	1.5	2.5	3.5
Bar Periodicity (in.)	2.0	3.0	4.0
Center Support Length (in.)	44	47	60

Part A. Support Construction

□ (1) Cut a 2x4 to the appropriate length for the *center support* of the marimba under construction as shown in the table at the top of this section.

□ (2) Pick 1 narrow side of the 2x4 as the top side. Use a ¾" thick hardwood strip to draw a line down the center of the top side.

□ (3) Repeat step (2) for one (two) 2x4*(s)* that is (are) several inches longer to be used for the *side support(s)*.

□ (4) Use a *side support* to draw lines along both sides of the *center support* so that they are below the top surface by the width of the narrow dimension of the 2x4 (about 1 ½ in.).

□ (5) Drill 1/4 in. holes along the line on the side of the *center support*, 2 in. from each end.

Insert picture of marked center and side support

□ (6) On the top side of the *center support*, measure and mark the center point along the line.

□ (7) For the alto marimba, mark 2 points at half the *bar periodicity* at mid-width on either side of the center mark and erase the center mark so it will not cause confusion.

□ (8) On either side of the marked point(s), continue to measure & mark points, separated by the *bar periodicity* until there are 18 marks for the alto marimba or 13 marks for the tenor & bass marimbas.

□ (9) At each of the marks, use a hammer to drive 2 ½ inch finish nails into the *center support* at the marked points until the heads are slightly shorter than the height of the narrow dimension of a small 2x4 block placed next to the nails (about 1 3/8 inches). It may be necessary to put the *center support* on the floor during nailing, to reduce the noise level.

□ (10) Leaving 3 ½ in. on each end, place 1-in. wide foam strips on the top of the *center support* by centering them over the heads of the nails and pushing them on. Make the foam strips slightly longer than necessary where they meet, so that there are no gaps. Also, make sure that each foam strip is held in place by at least 2 nails.

Insert picture of center support with nails and foam strips

Part B. Center Support Wiring

☐ (1) Set the *center support* on its side. Measure & mark the midpoint on the drawn line. For tenor and bass marimbas, mark 2 points on either side of the center point, offset by half the *bar periodicity* and erase the center mark to avoid confusion.

☐ (2) From the marked point(s), continue to measure & mark points, separated by the *bar periodicity* until there are 19 marks for the alto marimba or 14 marks for the tenor & bass marimbas.

☐ (3) Place a binder clip on its side with one of its loops around the mark at the far left. With either a nut driver or a drill with a nut-driver bit, drive a hex-head screw thru a star washer, a flat washer, the binder clip loop and then into the wood. Do not tighten completely. Repeat this operation, skipping every other mark, until there 10 clips mounted on the support for alto marimbas or 7 clips mounted on tenor & bass marimbas.

Insert picture of center support with mounted binder clips

☐ (4) Turn the center support over, supporting each end with a small 2x4 block to keep it flat. Repeat steps (1) and (2) for this side.

☐ (5) Repeat step (3) for those marks that do NOT have clips mounted to the opposite side. There should be 9 new clips for alto marimbas and 7 new clips for the tenor and bass marimbas.

☐ (6) Starting at the right-most clip, wrap the end of the bare wire between the star and flat washer and tighten the hex screw with the mouth of the clip facing the foam side of the *support*.

☐ (7) Keeping the wire reasonably tight, repeat step (6) for each clip in succession.

☐ (8) Flip the center support over. Starting from the same end of the support as on the other side, wrap the wire around the binding clips as in steps (6) and (7).

Insert picture of wired center support

☐ (9) Use wire clippers to trim the excess wire to make it 2 in. long on only one side of the center support.

☐ (10) *Tin* the free end of the *bare* wire with solder as well as both ends of the 10 in. long piece of *insulated* wire.

☐ (11) Wrap one end of the *insulated* wire around bare wire and solder the two wires together.

☐ (12) Push the free end of the *insulated* wire thru the ¼ inch hole in the *center support*.

☐ (13) Clip the *bare* wire on the other side of the support so that it is even with the *insulated* wire and *Tin* the end of the *bare* wire with solder.

□ (14) Twist the *insulated* and *bare* wires together and then solder each wire to a different terminal of the same recycled battery clip. The wires can go to either terminal on the clip.

□ (15) Put a small amount of hot glue over the spots where the wires are soldered to the battery clip.

Insert picture of wired center support, from the battery clip side

Part 3. Frame Assembly

Several of the bars, cut to their final length, will be needed temporarily to determine how large to make the frame in this part of the assembly process.

□ (1) Clamp the ends of the *center support* into *plywood fixture*, with the wire and battery clip on the left-hand side. Arrange the *side support(s)* in front of (and behind) the center support so both ends extend beyond the ends of the *center support.*

□ (2) Set several short, middle and long bars, cut to their final length, on the marimba in the appropriate positions as shown in Appendix A.

□ (3) Adjust the *side support* position so that the foam sits approximately under the 2/9th line drawn on the top surface of the bars. Make sure the ends of the *side support* still extend beyond those for the *center support.*

Insert picture of supports in the fixture and supporting several bars

□ (3b) Use a protractor to check the angles between the *side supports* and the edges of the underlying plywood *fixtures*. If necessary, make small adjustments to the make the front & back angles nearly the same for both the left and right ends of the instrument.

□ (4) While holding the supports in this position, clamp another 2x4, wide side down, across the left-hand side of the supports so that it is even with the end of the *center support* and the left end of the side support*(s)* extends slightly beyond it. This 2x4 will become the *left frame connector*. The foam strips probably will have to be trimmed slightly so they are not trapped underneath the *connector*. Place small 2x4 blocks under the ends of the *connector* so that it holds the supports in place, but does not bend very much when it is clamped. The ends of the *connector* should nearly align with the edges of the support fixture.

Insert picture of supports with left connector clamped in place.

□ (5) While the *connector* is clamped to the supports, mark the locations for two holes to be drilled thru the *connector* where it aligns with <u>each</u> underlying support. Use a hammer and nail to make small indentations at each mark.

□ (6) Use a drill to make a 1/16th hole at each mark and then countersink (recess) the tops of the holes to fit the top of a flat-head screw.

□ (7) Apply moistened bar soap or a soft wax to the threads of 2 ½-inch deck screws. Use a drill with a Phillips driver bit to insert the screws into the holes until the top of the screws are even with the top surface of the *connector*.

Insert picture of supports with left connector screwed in place.

□ (8) Place a short section of 2x4, wide side down, over the right-hand side of the instrument so that the end of the *center support* is aligned with the edge of the 2x4 and the right end of the side support*(s)* extends slightly beyond it. This 2x4 will become the *right frame connector*.

□ (9) Measure the distance between the *connectors* near both ends of the *right connector*. Make any small adjustments to keep the distances nearly equal.

□ (10) While holding the *right connector* in position, use a long 2x4 at an angle (about 30 degrees) over the middle of the *connector* so that there is access to both ends. Small 2x4 blocks should be placed under the *2x4 clamp* near the ends, so it does not become excessively bowed.

□ (11) As in steps (6) and (7), drill, countersink & attach the *right connector* with 2 deck screws to both ends of the *side support(s)*.

□ (12) Remove the *2x4 clamp* and repeat step (11) to attach the *right connector* to the end of the *center support* with 2 deck screws.

□ (13) With a pencil, mark lines on the frame *connectors* along the outside edges of the side support*(s)* and on the *side support(s)* along the outside edge of the *connectors*.

□ (14) Temporarily remove the marimba bars and carefully set them aside. Also, remove the foam strips and double-sided tape <u>only</u> from the *side support(s)*.

□ (15) Use a tape measure to the find the perpendicular distance between *the left and right connectors.* Mark half this distance at mid-width on the *side support(s)*, as measured from the *left connector*. At mid-width of the support for <u>tenor</u> and <u>bass</u> marimbas, mark points on either side of the center point, offset by <u>half</u> the *bar* spacing as measured <u>perpendicularly</u> to the *connectors.* Erase the center mark for the <u>tenor</u> & <u>bass</u> marimbas, so it will not cause confusion. From the marked point(s), continue to measure & mark points at mid-width on the *side support(s)*, separated by the *bar periodicity* as measured <u>perpendicularly</u> to the *connectors* until there is no room left. <u>Alto</u> marimbas should have 19 marked points and <u>tenor</u> & <u>bass</u> marimbas should have 14 marked points.

□ (16) The locations of these marks can be checked by temporarily setting the marimba bars back into position. The bars should be parallel to each other with the marks on the *side support(s)* showing in between the bars. Correct the location of the marks, if necessary.

□ (17) Remove all marimba bars and carefully set them aside.

☐ (18) Mark the inside facing surfaces of the *side and center support(s)* to identify where each piece belongs. Make sure the each end of both *connectors* and the *side support(s)* have been marked as described in step (13). Then, unscrew both *connectors* and save the screws for later.

☐ (19) Clamp one end of a *connector* over the edge of a table with a C-clamp and cut along the line marking the edge of the *side supports*. **CAUTION: The hand saws are very sharp, so avoid touching the blade with your hands.** A C-clamp can be used to clamp a small wooden block next to the cutting line on the connector for a cutting guide. Repeat for the remaining ends of both *connectors and side support(s)*.

☐ (20) Use a hammer to drive 2 ½ inch finish nails into the *side support(s)* at the marked points until the heads are slightly shorter than the height of the narrow dimension of a small 2x4 block placed next to the nails (about 1 3/8 inches). It may be necessary to put the *side support(s)* on the floor during nailing, to reduce the noise level.

☐ (21) Leaving 3 ½ in. blank on each end, replace the foam strips on the *side support(s)* by carefully pushing them on over the heads of the nails. Make the foam strips slightly longer where they meet, so that there are no gaps. Also, make sure that each foam strip is held in place by at least 2 nails.

☐ (22) Place the *side support(s)* back in position around the *center support* with the correct inside marks facing each other. Place both *connectors* over the ends of the supports and screw them back in place using a drill with a Phillips-head bit. The foam strips will need to be slightly trimmed to fit between the *connectors*.

II. Marimba Bar Construction

Marimba bar construction requires three parts: Part A. Cutting Marimba Bars to tune them to a *Starting note,* Part B. Sanding Marimba Bars to form a bottom-side arch to tune them to the *Final notes* and Part C. Attaching Piezoelectric Sensors to the bottom of the bars. Building a musical instrument using a natural material such as wood causes Parts A and B to be iterative (requiring re-checking and adjusting), with some possibility of wasted wood. However, this challenge makes the creation of a musical instrument a special and rewarding achievement.

Part A. Cutting Marimba Bars

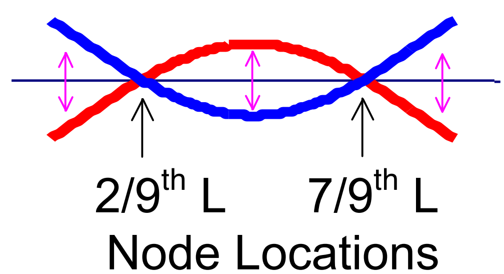
☐ (1) Slide a rubber chair-leg cap on the end of the wooden dowel or PVC pipe to make the marimba "beater." Other types of marimba beaters can be made later, to optimize the sound.

☐ (2) Acquire a supply of hardwood with the same width and from the same source, if possible (preferably without many knots or defects). This is an important step since small variations in the mechanical properties of the wood (esp., density and elasticity) make a big difference in the tone of the bars.

☐ (3) Select a reasonably defect-free strip of hardwood. Pick a bar length in the expected mid-range for the marimba. Measure and mark a line across the strip at this length with a straight edge. Using *C-clamps*, fasten the strip and *miter box* to a table such that the mark lines up with the 90° slot in the box. Cut the strip at the mark using a hand saw by pushing the saw back and forth, but not pressing down very hard. Care should be taken to make sure the blade stays in the same track during the entire cut and that the miter box itself is not damaged.

☐ (4) Check the tone of the bar by supporting it at the approximate node locations (i.e., at $2/9^{ths}$ of the length of bar from each end) on a temporary foam-covered base. Hit the center of the bar with the beater made in step (1) and use an electronic tuner to determine the approximate note.

The vibration of an unclamped beam at its fundamental frequency is illustrated at right. For an unclamped beam, the **nodes**, or the points that remain stationary, are located at 2/9ths of the beam length from either end. Why would these be good places to support the beam?



☐ (5) If the tone is more than 20 *cents* away from a *starting* note (there are 100 *cents* between adjacent notes). trim the bar slightly until its tone is within this range. The list of starting notes for each marimba size appear in the Marimba Tables in Appendix C.

☐ (5) Once the tone of the bar is near the *starting* notes, measure the length of the bar and enter it into the table. Calculate the lengths needed for each of the remaining *starting* notes using the equation:

$$\text{Length}_{\text{NEW BAR}} = \text{Length}_{\text{OLD BAR}} * \text{Square Root}(\text{Frequency}_{\text{OLD}} / \text{Frequency}_{\text{NEW}})$$

Add ½ cm to the length of these bars and record both calculated lengths in the Table.

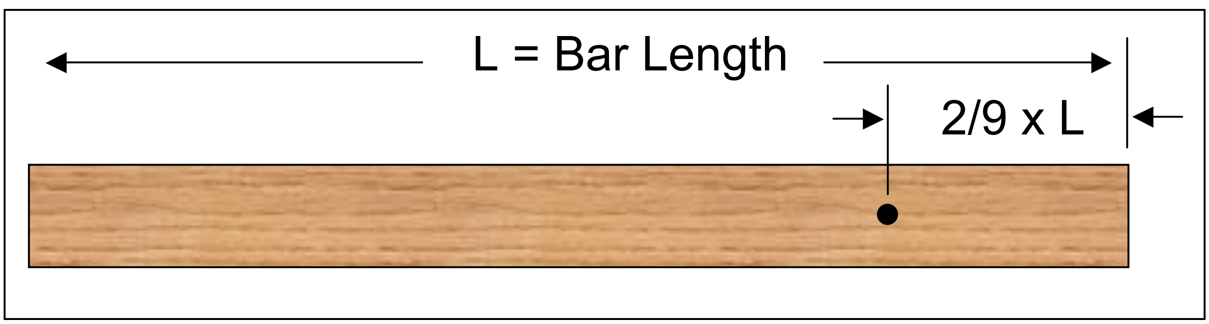
□ (5) Cut a few new bars to the longer length as in step (3), being efficient with usage of the hardwood strips. Check the tones of these bars and trim them, if necessary, to make their tones within 20 cents of one of the *starting* notes. If no problems are encountered, repeat this process until bars for all the desired *starting* notes are produced.

Part B. Sanding Marimba Bars

□ (1) Measure the final lengths of the marimba bars and enter them into the table. Calculate 2/9th and 1/3rd of these lengths and also add them to the table in the appropriate columns.

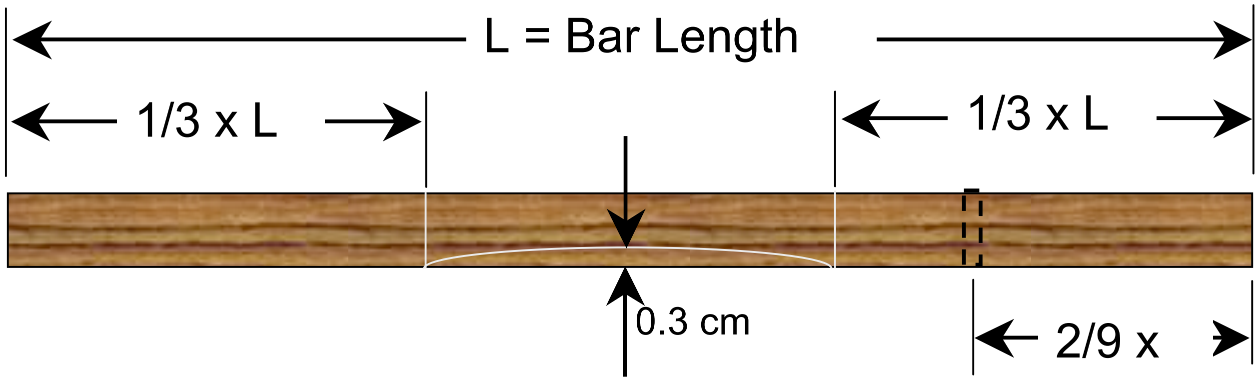
□ (2) The 2/9th-length value is the distance from the each end of the bar where the node for the fundamental frequency is located (where the vibration is minimal). Pick the best looking side of the bar to be the top side and write *Bottom* on the other side, near one end. On the top of each bar, use a straight edge to lightly draw a pencil line across the bar at the 2/9th-length distance from both ends.

□ (3) Using a drill press, drill a 3/16th in. hole thru the bar at the mid-width point along the 2/9th –length line on one end of the bar.



□ (4) The vibration of the bar at its fundamental frequency can be emphasized by modifying the bar between the 1/3rd–length distances from both ends. Place the bar on its side and draw lines across the sides at these points. Turn the bar over and repeat for the other side.

□ (5) With the bar on its side, mark a point and at the center of the bar, 0.3 cm from the *Bottom* edge. Turn the bar over and repeat this operation on the other side, making sure that the point is measured from the *Bottom* edge.



 (6) Use a flexible strip of material (e.g., rubber or plastic weatherstripping), draw a smooth curve on <u>both</u> sides of the bar, which connects the two 1/3rd–length points on the bottom edge and passes thru the 0.3 cm mark at the center of the bar. The resulting arc will be used as a guide for creating an arch into the bottom surface of the bar for the final tuning.

 (7) One team member should use a drum sander mounted on a drill press to make the arch. **CAUTION**: **Before this operation, remove all rings, bracelets & necklaces and put on ear plugs, goggles and a dust mask.** Turn on the sander, put the bar on its side with the bottom edge toward the sanding drum. Holding the ends of the bar securely, start from the right-hand 1/3rd-length mark, push the bar gently against the drum and move it until the left-hand 1-3rd–length mark is reached. Repeat this operation 5 times and then flip the bar over and do the same thing from the other side. When repeating this operation, us the drawn arc as a guide and make more sanding passes for the very middle of the bar than the rest. As the desired note gets closer, make fewer sanding passes between checking the tone. e

 (8) Next, have another team member check and record the note and the number of + or - *cents* (sharp or flat) for the bar. There should be a slight lowering of the tone after each sanding operation. The goal is to stop sanding when the tone is 25 cents higher than the *Final note* for the bar shown in the marimba bar table in Appendix C. Return the bar to the sander and report to the operator how close the bar is to the desired tone.

 (9) Repeat steps (7) and (8) until the tone is approximately 25 cents higher than the *Final note* for the bar, as shown in the marimba bar tables in Appendix C. Write the note on a small piece of masking tape and put it on the top of the bar near the nail hole.

Part C. Attaching Piezoelectric Sensors

Attaching the piezoelectric sensors with hot glue to the bars requires 2 people. The operation is simplified with the use of two tools: an *applicator* and a *glue spreader*. The *applicator* is a section of PVC pipe with the same diameter as the piezo sensors. One end is used as a template to draw where the sensor will be mounted and the other end is used to gently push the piezo disk into the hot glue. The *gluing* end has a notch that fits over the sensor wires. These wires are fragile and easily ripped off the sensor, so they should be treated very carefully. The glue spreader is used to quickly spread the glue over the very edge of the sensor to hold it in place.

□ (1) Use a soldering iron to connect each of the wires from the piezo sensors to a solder lug. These wires are fragile, so they must be handled carefully. **CAUTION: Soldering irons are extremely hot and can cause severe burns if not used safely. Goggles should always be worn during soldering and it is important to wash your hands after handling solder.**

□ (2) Use the *drawing* side of the *applicator* to draw a circle mid-width on the bottom side of the end of the bar with the drilled hole. The edge of the circle should be about 0.5 cm from the end of the bar.

□ (3) To apply the sensor:
- One person should use a hot glue gun to apply a very thin layer of glue along the circle.
- A second person should immediately place the sensor over this circle with the wires toward the hole and use the applicator to gently push it into the glue with the notch over the wires.
- The first person should quickly use the glue spreader to push excess glue over the very edge of the sensor, being careful to keep the glue out of the center region.
- If necessary, a small amount of glue can be applied by one person and spread over the edges of the sensor by another person to attach it more robustly to the bar.
- A small amount of glue should also be applied and spread over the sensor wires to attach them to the bar and provide strain relief in case they are inadvertently pulled.

III. Final Assembly

□ (1) Replace all the bars on the base in order of length, with the accidental notes (sharps / flats) on the far side and the regular notes on the near side.

□ (2) Identify good locations inside the frame for the preamp and switch units. Use a screwdriver to mount both the battery holder for the preamp and the switch with small screws. This may require temporarily removing a few of the bars and care should be taken not to damage the sensors or their wires.

□ (3) Connect the preamp to a good 9V battery and clip them into the battery holder. Make sure the switch is in the OFF position, so that the LED light is off.

□ (3) Connect the recycled battery clip from the piezo sensors to the the preamp clip marked "PIEZO".

□ (4) Replace any missing bars and connect solder lugs from the piezoelectric sensors to the binder clips on either side of the bars. Run the wire that crosses the *center support* under the foam strip. One of the sensor lugs from each of two adjacent bars will be stacked together inside the same binder clip.

□ (5) Ta-Da! You are done! Please have your marimba checked out by one of the facilitators before connecting it to an amplifier.

Appendix A: Marimba Design Options

Figure 1 Fully Chromatic Alto Marimba with Offset Bars

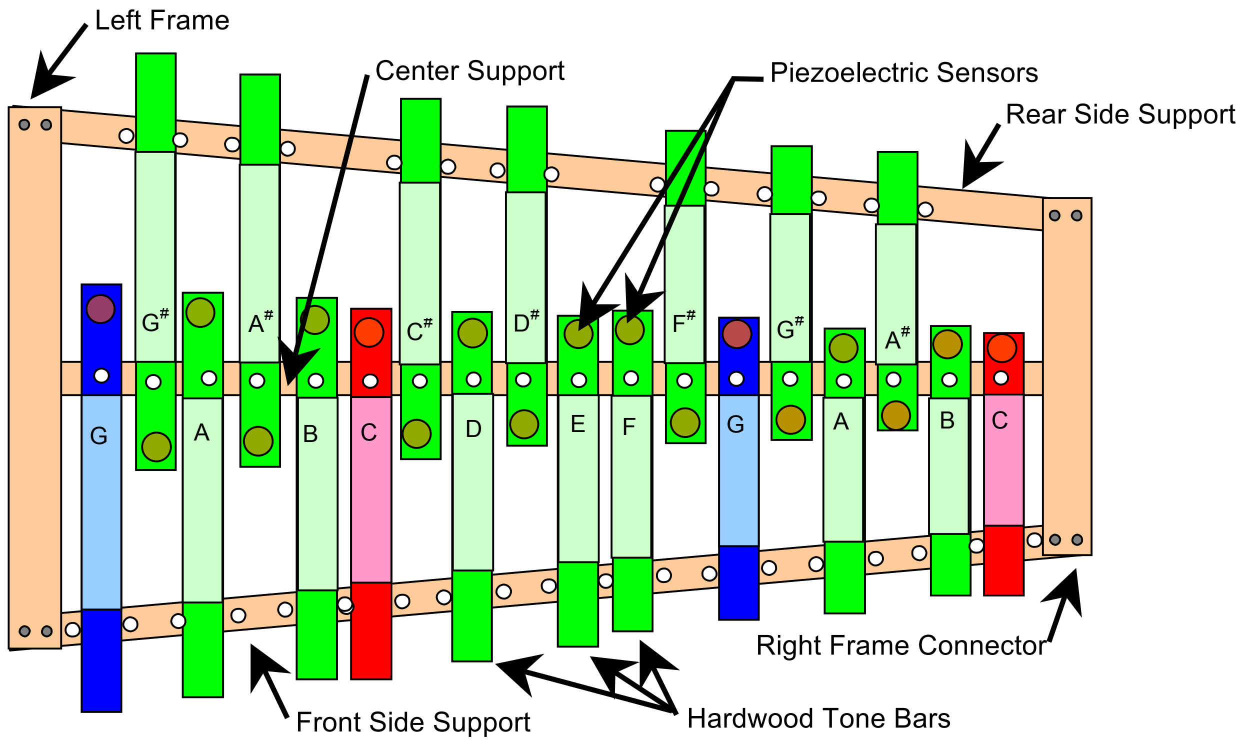
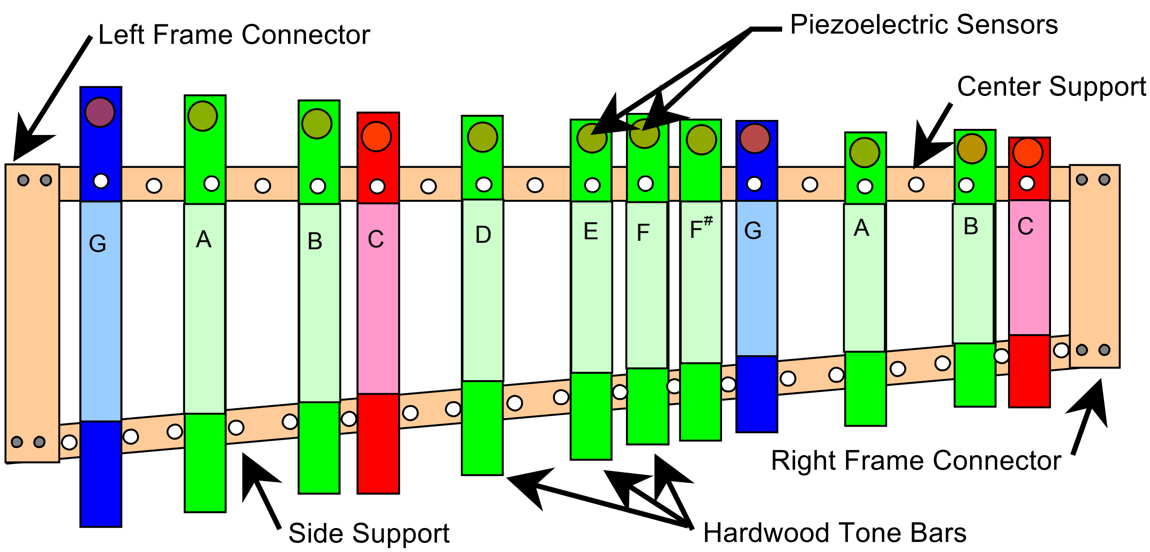
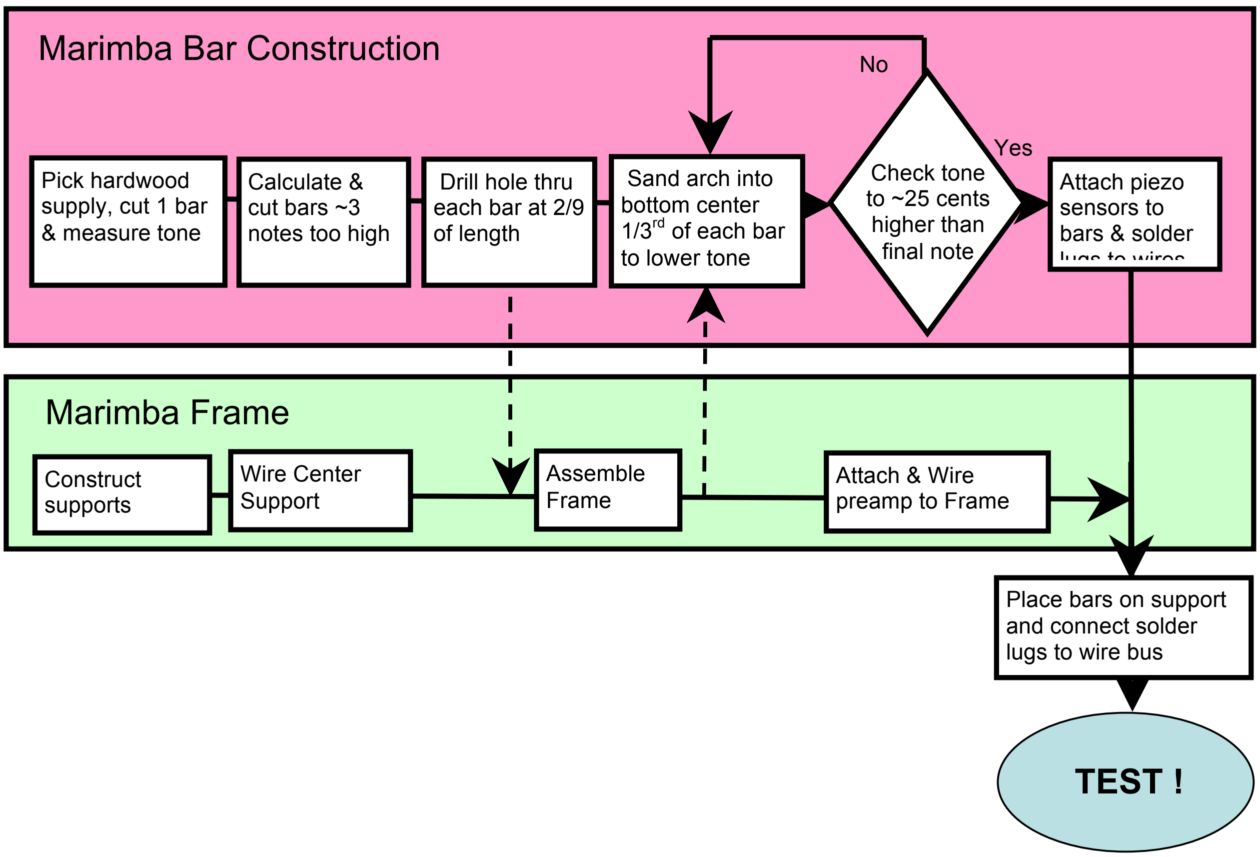


Figure 2 Alto Marimba with In-line Bars for the keys of C and G



Appendix B: Marimba Construction Flow Diagram



Appendix C: Marimba Bar Tables

$$\text{Length}_{\text{NEW BAR}} = \text{Length}_{\text{OLD BAR}} * \text{Square Root}(\text{Frequency}_{\text{OLD}} / \text{Frequency}_{\text{NEW}})$$

Table 2 Alto Marimba Bars

~Start Note	Freq (Hz)	Meas/Calc Length (cm)	Length +0.5 cm (cm)	Final Length (cm)	2/9th Length (cm)	1/3rd Length (cm)		Final Note	Freq (Hz)	No-Sensor Deviation (±cents)	Final Deviation (±cents)
A#	466.16						Sand bar to lower tone to 25 above desired note	G	392.00		
B	493.88							G#	415.30		
C	523.24							A	440.00		
C#	554.36							A#	466.16		
D	587.32							B	493.88		
D#	622.24							C	523.25		
E	659.24							C#	554.36		
F	698.44							D	587.33		
F#	739.98							D#	622.25		
G	783.98							E	659.25		
G#	830.60							F	698.46		
A	880.00							F#	739.99		
A#	932.32							G	783.99		
B	987.77							G#	830.61		
C	1046.5							A	880.00		
C#	1108.7							A#	932.33		
D	1174.7							B	987.77		
D#	1244.5							C	1046.5		

Notes in black are for an in-line bar marimba design for the keys of C and F

Notes in red are additions for a fully chromatic marimba which can be used either for an in-line or offset bar marimba

3 Sanding Worksheet

Note	Deviation (±cents)		Note	Deviation (±cents)		Note	Deviation (±cents)		Note	Deviation (±cents)

$$Length_{NEW\ BAR} = Length_{OLD\ BAR} * \text{Square Root}(Frequency_{OLD} / Frequency_{NEW})$$

Table 4 Tenor Marimba Bars

~Start Note	Freq (Hz)	Meas/Calc Length (cm)	Length +0.5 cm (cm)	Final Length (cm)	2/9th Length (cm)	1/3rd Length (cm)	Sand bar to lower tone to 25 above desired note	Final Note	Freq (Hz)	No-Sensor Deviation (±cents)	Final Deviation (±cents)
A#	233.08							G	195.99		
B	246.94							G#	207.65		
C	261.62							A	220.00		
C#	277.18							A#	233.08		
D	293.66							B	246.94		
D#	311.12							C	261.62		
E	329.62							C#	277.18		
F	349.22							D	293.66		
F#	369.99							D#	311.12		
G	391.99							E	329.62		
G#	415.30							F	349.22		
A	440.00							F#	369.99		
A#	466.16							G	391.99		

Notes in black are for an in-line bar marimba design for the keys of C and F

Notes in red are additions for a fully chromatic marimba which can be used either for an in-line or offset bar marimba

5 Sanding Worksheet

Note	Deviation (±cents)		Note	Deviation (±cents)		Note	Deviation (±cents)		Note	Deviation (±cents)

$$Length_{NEW\ BAR} = Length_{OLD\ BAR} * \text{Square Root}(Frequency_{OLD} / Frequency_{NEW})$$

Table 6 Bass Marimba Bars

~Start Note	Freq (Hz)	Meas/Calc Length (cm)	Length +0.5 cm (cm)	Final Length (cm)	2/9th Length (cm)	1/3rd Length (cm)	Sand bar to lower tone to 25 above desired note	Final Note	Freq (Hz)	No-Sensor Deviation (±cents)	Final Deviation (±cents)
A#	116.54							G	98.00		
B	123.47							G#	103.83		
C	130.81							A	110.00		
C#	138.59							A#	116.54		
D	146.83							B	123.47		
D#	155.56							C	130.81		
E	164.81							C#	138.59		
F	174.61							D	146.83		
F#	185.00							D#	155.56		
G	196.00							E	164.81		
G#	207.65							F	174.61		
A	220.00							F#	185.00		
A#	233.08							G	196.00		

Notes in black are for an in-line bar marimba design for the keys of C and F

Notes in red are additions for a fully chromatic marimba which can be used either for an in-line or offset bar marimba

7 Sanding Worksheet

Note	Deviation (±cents)		Note	Deviation (±cents)		Note	Deviation (±cents)		Note	Deviation (±cents)