Battle of the Electric Marimba Bands

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Abstract
This paper describes a pilot project-based STEAM*[*] unit in which 7th/8th grade students explored the science, math and technology of electric marimbas by fabricating the instruments. Inclusion of requirements for artistic design, musical performance and a team competition resulted in the active participation of nearly all the students.

Introduction
The Battle of the Electric Marimbas was jointly developed by *Essex Middle School* and *Create It Lab,* working in conjunction with the *IBM Technical Education Outreach* program. The team also included N. Caiano, who provided both the musical instruction and the arrangements of the selections chosen for the marimba performances.

Marimbas are wooden xylophone-like instruments that have roots in various parts of the world. The chromatic marimba is the national symbol of culture for Guatemala, where it was believed to have been developed from an early Mayan instrument [1]. The heritage surrounding the marimba makes it a natural topic for historical study.

Modern marimbas are quite large and cover several octaves. For the purposes of this project, three marimbas were defined: (1) a 1½-octave alto, (2) a 1-octave tenor and (3) a 1-octave bass. Conventional marimbas also use tubes located below the center of each bar that are tuned to resonate at the bar frequency and thus provide acoustic amplification. Amplification is especially important for the tenor and bass notes. In this project, the resonator tubes were replaced with piezoelectric sensors located on the underside of one end of each bar. This method greatly simplified the construction of the marimbas as well as allowing electronic mixing of the music from the alto, tenor and bass marimbas.

Construction
The electric marimba unit was developed during the summer of 2011 and piloted during the fall semester. The target student population consisted of three 20-student teams. Each team was divided into three marimba design groups of 5-7 students. The design groups were selected to include a diverse set of skills and/or interests. Specific categories included music, art/culture, math/science, woodworking and electronics. The entire project spanned several weeks and consisted of five classroom sessions per team, several rehearsals and a “battle of the bands” finale.

Fig. 1 The prototype electric marimba.

The first session involved an introduction to marimba science, which reinforced the background in vibrations, waves and resonance that had been previously provided by the classroom instructor. In addition, piezoelectricity and the associated energy transformation concepts were presented as background for the operation of the marimba sensors. The format for the session was a series of hands-on demonstrations (e.g., piezoelectric devices, resonance and wave machines), which focused on the science involved in the generation and electrical sensing of marimba bar vibrations.

In the second session, the Design Cycle [2] was presented and compared with the Scientific Method as well as standard problem solving techniques. All three of these operations involve nearly identical processes. However, the Design Cycle methodology was emphasized because of the motivational benefits of the design process and the natural linkage to project-based learning.

[*] Science, Technology, Engineering, Art and Mathematics

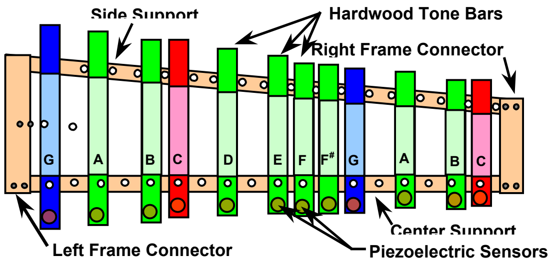

Fig. 2 Design of the production electric marimba.

To illustrate the cyclical nature of product design, an interactive, hands-on discussion of the continuous development of the telephone was used. A working electric marimba prototype was then provided for inspection by the students and used as the entry point in a design cycle. Students were asked to consider the design from a consumer perspective, and each design group held a brainstorming session to identify functional and/or artistic enhancements that would be desirable. Next, the students were challenged to focus on which design modifications could be implemented within the time, material and cost constraints of the project. A PICK chart [3] was introduced as a simple tool for accomplishing this goal. Design modifications that could easily be incorporated in the project were considered for implementation. Enhancements that were subsequently adopted for the prototype included painting, the addition of wheels, a handle, and marimba stick holders. One enhancement, the simplification of the wiring, was selected for the production marimbas.

Fabrication and tuning of the hardwood marimba bars dominated both the third and fourth sessions. The procedure involved cutting the bars to length to obtain tones that were 3 notes above the desired note, and then sanding the center third of the backside of the bars to bring the pitch down to the correct note. This procedure was used to reduce the level of higher order harmonics and was particularly important for the tenor and bass bars that were more subject to torsional modes. The bars for the alto marimbas probably could have been

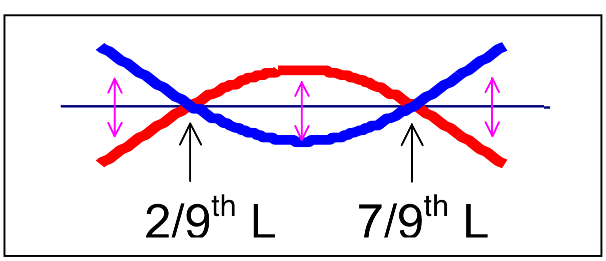

Fig. 3 Diagram of the fundamental vibration mode for a marimba bar of length L, showing the location of the nodes

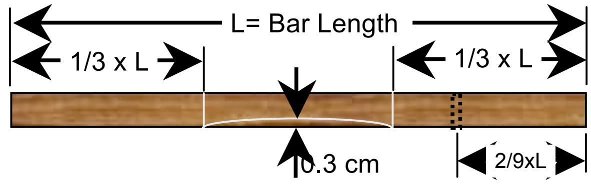

Fig. 4 Edge view of a marimba tone bar illustrating the hole location and the approximate region removed from the underside during tuning.

tuned simply by adjusting length. After a bar was tuned, a 3/16" hole was drilled mid-width and 2/9ths of the bar length from the end. This distance from either end of the bar corresponded to the node locations for the fundamental frequency, and thus defined the locations used for supporting the bar. Electronic chromatic tuners were used to check the tones of the bars. Tuning apps for smart phones and tablets were also used and had the advantage of detecting the actual tone frequency (i.e., which octave), rather than just the note. However, after sensors were added to the marimbas, the dedicated tuners had the advantage that they could be connected directly to the output bus and used to rapidly check all of the notes in a complete set of marimbas.

While one set of students was cutting and tuning bars, other groups were working in parallel to build other parts of the instrument. One group constructed the basic supports for each marimba. The supports consisted of two lengths of 2x4 softwood placed on edge, which were cut extra long so they could be adjusted to fit the tuned bars later. Finish nails, 3" long, were driven into the top edge of the support along the center line. The nails on one support were located at the midwidth point for the bars. On the other support the nails were located so they would fall between the bars. Narrow foam strips were pushed over the nails along the length of the

Fig. 5 Tuning by sanding the middle section of the underside of a marimba bar.

supports. The foam provided vibration isolation for the bars. Next, binder clips were screwed to both sides of one of the supports, with the clips located below the bar edges, on alternating sides of the support. The binder clips on each side were connected electrically by looping an uninsulated wire sequentially around each screw. The binder clips served as the connection points for the piezoelectric sensors and the two wires on the sides of the support formed the output bus. A pair of 9-V battery clips, recycled from the tops of dead batteries, were soldered to the ends of the bus and used to attach to external wires connected to a mixer or amplifier.

Another group was taught how to solder lugs to the piezoelectric sensor wires for the connection to the wire bus. After attaching all the lugs, the soldering group was taught how to use hot glue guns and then tasked with gluing the piezoelectric sensors to the underside of the ends of tuned bars. Glue was used just under the edges of the discs, and not under the center region to allow that region to vibrate freely. For the alto bars and to a lesser extent the tenor bars, the mass of the sensors was sufficient to alter the pitch of the bar. Therefore, tuning of these bars was stopped about a musical half-step short of the desired tone. Fine tuning correction of the bars was sometimes needed after the sensors were mounted.

During the fourth and fifth sessions, the frames for the marimba bars were assembled. The tuned bars were set on the supports at the nodal points ($2/9^{th}$ of the bar length from either end) with the hole in the bar over a nail on one support. The bars were placed between the nails on the other support. Short 2x4 connecting pieces were then cut to length and laid flat across each end of the supports. Power drills and 2½" screws were used to attach the connectors to the supports. The supports were then trimmed with a hand saw to match the outside dimension of the connecting pieces.

Fig. 6 Soldering lugs onto the piezoelectric sensors for connection to the output bus.

At this point, the lugs from the sensor on each bar were connected to the binder clips, one on each side of the support. The marimbas were then tested to verify functionality by attaching the output bus to the microphone input of a standard PA system. Any problems were then identified and corrected.

Most of the marimba mallets were constructed using 12" long, 5/8" diameter dowels or ½" diameter CPVC pipe. Soft chair leg tips were used for the mallet heads. This type of mallet was used for the alto and tenor marimbas. A softer head material was needed for the bass marimbas. Drilling a hole in a bouncy ball and inserting a dowel was found to be an effective design choice. For some songs, a harder head was desirable for the alto mallets. Experimentation with hardwood knobs showed that they produced an excellent tone, but tended to make indentations in the hardwood bars. Softwood or yarn-wrapped hardwood knobs were proposed as suitable replacements.

Art and Music

Prior to construction of the marimba, the 2x4 supports and connectors were painted with a white primer. After completion of the frame, the artists from each design team used acrylic paint to decorate it, generally choosing colors and designs of cultural significance to Mexico and Central America.

The musically inclined members of the three design groups within each team collaborated on selection of the music and in leading the performance. The songs chosen were the adaptation of *La Bamba* by Ritchie Valens, *The Lazy Song*, by Ari Levine and *Tequila*, by Daniel Flores. Since the electric marimbas were not conventional instruments, special arrangements of the selections were created. These arrangements were instructive for many of the students by illustrating how the alto, tenor and bass marimbas were matched with

Fig,. 7 The artistry and music of Team 1 on the alto, tenor and bass marimbas.

the melody, harmony and bass lines of the music. Two rehearsal sessions were arranged for each of the three teams prior to the competition. In most cases, the students chose to use their free time for additional rehearsals.

Presentation

Each team prepared a presentation containing an introduction of the design groups, a brief discussion of marimba science, the design of the different marimbas and the construction process. Unique features of the team's marimbas, including the artwork, were noted. As a specific example, one group described their choice to mount a sensor on the top of one of the bars (instead of on the underside) in order to highlight the technology being used. Photographs, taken during the sessions and stored in a special Facebook group, were particularly helpful in assembling these presentations. An introduction to the team's musical selection concluded the presentation.

Discussion

The electric marimba pilot program was very successful in engaging a complete cross-section of the students. The application of science and math to marimba construction was also clearly an effective educational tool. However, a laboratory version of the project would provide an opportunity to develop a deeper level of understanding. In particular, more quantitative modeling of the tuning process could be employed to strengthen the view of mathematics as a useful tool.

Fabrication of the marimbas was observed to be very empowering for many of the students. New experiences such as using power tools and soldering rapidly became familiar skills and resulted in increased confidence. However, as in most pilot construction projects, the assembly process would have benefited from several key procedural changes. For example, providing a sample of pre-tuned bars for each size marimba would have made the process more efficient. In addition, having a larger number of parallel operations, such as construction of the mallets, would have maintained a more continuous focus.

Acquiring the skill to play the marimbas in front of a large audience was similarly energizing. A sample of the enthusiasm for the project was clearly demonstrated when two of the teams woke up early on a cold winter's day when school was not in session just to play their selections at a teachers' convention.

The process for selecting the music for the performance was found to be much more time consuming than expected. Despite much prompting on the part of the educators, it was very difficult to excite interest in this aspect of the project until the students had working marimbas. This delay in picking the song resulted in very tight schedules for creating the necessary arrangements and rehearsing the music. Having a complete set of pre-built marimbas may have allowed the musical portion of the project to occur in parallel with the instrument construction.

Awards

An independent panel of judges, representing all STEAM disciplines, evaluated the presentations and performances of the three teams. A project rubric was used to award trophies for the overall champions, the most artistic and the most entertaining team.

Conclusion

Overall, the electric marimba project was very successful, engaging nearly all the students throughout the project and energizing them to apply their knowledge and gain new skills. Several procedural changes were identified that could improve the efficiency of the construction and music selection phases of the project. In addition, a laboratory version of the project was proposed to allow greater appreciation of the role of mathematics and science in real world applications.

Acknowledgement

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