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The sound of STEAM: Acoustics as the bridge between the arts and STEM

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This paper describes the development and presentation of a Science, Technology, Engineering, Arts, and Math (STEAM) workshop for elementary school teachers designed to provide ideas and tools for using acoustics in the classroom. The abundant hands-on activities and concepts in acoustics naturally link science and music in an intuitive way that can assist teachers in moving forward on the STEAM initiative. Our workshop gave teachers an introduction to acoustics principles and demonstrations that can be used to tie in STEAM techniques with Utah State Education Core standards. These hands-on demonstrations and real-world applications provide an avenue to engage students and support learning outcomes. Feedback indicated that the participants learned from and enjoyed the initial implementation of this workshop, though many elementary school teachers did not immediately see how they could integrate it into their curriculum. While additional efforts might be made to better focus the training workshop for the K-6 level, curriculum developers need to appreciate how acoustics could be used more broadly at the elementary school level if the emphasis changes from STEM to STEAM.

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1. BACKGROUND

The need to create enthusiasm for science in young children has been emphasized in the United States through the science, technology, engineering and math (STEM) initiative. STEM has been fueled largely through a desire to increase US economic growth and global competitiveness by generating more interest in the rising generation in the STEM fields.[1] The results of STEM education are beginning to be observable, as the generation who was first educated during the STEM push is entering the workforce and beginning to influence the economy. Many are saying that more creative and analytical thinking is needed to keep US innovation competitive; STEM education appears to leave a gap in this area. Studies have been done which show that participation in the arts increases creativity and innovation.[2,3] Drawing on this concept, a proposed solution is that an "A" be added to STEM to represent the arts, creating the acronym STEAM.[4] This type of integrative program has already been implemented with some success in multiple universities, and support is growing for STEAM across the nation.[5,6]

Acoustics is a natural fit for STEAM, as it is so closely related to music. There has been much published on the overlap between acoustics and music,[7-10] as well as publications on using musical acoustics in instruction.[11-13] The Acoustics Research Group at Brigham Young University (BYU) has taken an interdisciplinary approach through an introductory acoustics course designed to give those in music and speech fields a scientific view of their disciplines.[14] As the course has been further developed, it has transitioned to focus on creating an active learning environment through discovery-based activities. Active learning is an instructional method that engages students in their own learning by involving them in hands-on activities that require them to think about what they are doing and the concepts being taught. Descriptions of the gains in student learning are described in Refs [15] and [16].

These efforts to foster integrated learning have extended to the outreach program of the Acoustics Research Group at BYU. Student volunteers give tours of research facilities, run interactive booths at STEM fairs and similar locations, and put on acoustics demonstration shows. The "Sounds to Astound" demonstration show is focused on creating an understanding of and excitement for the basic principles of sound in elementary school children. These shows have been publicized through flyers sent to schools and emails to teachers and historically have been able to reach as many as 750 participants per year.[17]

BYU recently began participating in the move from STEM to STEAM through their arts partnership with the local schools. The arts partnership was created in 2005 with several local school districts as a result of an endowment they received to increase arts instruction in the schools. The Arts Express conference is a yearly summer conference run as part of this initiative to train elementary school (K-6th grade) teachers on how to integrate arts into their instruction.[18] The conference has had a variety of themes, including literacy and assessment. Teachers who attend the conference leave with a greater ability to weave arts into the subjects they already teach, thus increasing the exposure that children have to arts while still giving just as much time to those subjects specified by the curriculum. In the last two years the themes of the conference have been focused on STEAM, as a result of a STEM initiatives in the schools. The BYU Acoustics Research Group was asked to present an adapted version of their demo show at the 2015 conference to provide ideas to teachers on using acoustics to integrate arts into STEM in an elementary school classroom. This paper summarizes the preparations and implementations of our first STEAM teacher workshop.

2. PREPARATION

Building upon previous active learning efforts, we created a presentation that involved the teachers in hands-on activities demonstrating the integration of music and acoustics. It also provided resources to the teachers allowing them to immediately implement the concepts in their own classrooms.

A. HANDOUT DEVELOPMENT

In order to fill the goals of the conference, we turned to the Utah State Science Core standards. Sound is addressed in the curriculum in sixth grade, where students are introduced to basic principles of sound production and acoustics vocabulary along with light and heat concepts (see Table 1). Many parts of the United States have adopted the next generation science standards (NGSS), which, though different from what is shown here, contain similar concepts and ideas, introducing them earlier in the curriculum.[19] Our goal was to enable the teachers to create learning activities that encouraged discovery of these concepts, while allowing the children to be creative musically.

Table 1: Utah 6th grade sound-related science core concepts

Objective:	**Describe the production of sound in terms of vibration of objects that create vibrations in other materials**
a.	Describe how sound is made from vibration and moves in all directions from the source in waves.
b.	Explain the relationship of the size and shape of a vibrating object to the pitch of the sound produced.
c.	Relate the volume of a sound to the amount of energy used to create the vibration of the object producing the sound.
d.	Make a musical instrument and report on how it produces sound.

For the workshop, we made a lesson plan that combined typical acoustics hands-on experiences with an emphasis on music. It also encouraged an active-learning experience where students are able to hear and touch the activities. The creation of a complete lesson plan provided an example to the educators of how to put the concepts together in a cohesive way with each concept building upon the prior ones. We chose learning activities that could easily be implemented in the conference and in their classrooms. This lesson plan was given to the teachers for reference during and after the presentation and is included here as Appendix A.

Also given to the teachers was a listing of other activities that could fit into the core curriculum concepts. These could be substituted for those in the example lesson plan, or simply added to create a longer plan that could extend over several class periods. These activities related to other musical instruments or acoustical phenomena, allowing the teacher to have the flexibility to adapt to student interests (see Table 2).

Table 2: Additional activities that could be integrated into a lesson plan about acoustics. Links were included to give the teachers a resource to investigate the activities.

Candy Wave Machine *https://www.youtube.com/watch?v=RCbf9_4xN_E* Candies, such as Dots, are attached to the ends of short sticks that are laid in parallel across a long piece of duct tape. The duct tape is stretched across two supports, and students move the first stick to send waves along the wave machine. This activity is great to show the students how waves travel and reflect. Possible questions include 'what happens to the wave when it reaches the end of the wave machine?' and 'can you make the wave travel any faster or slower?'
Bottle Flute Take a bottle and blow over the top of it. What do you hear? This is similar to how blowing over a flute causes sound, as the air inside vibrates. Add water to the bottle. What changes? Why?
Finger on a Glass Rim Take a glass and, after getting your finger wet, rub your finger around the rim. Try different speeds until you get the glass to sing. What is vibrating to create the sound? Now add some water to the glass. What changes? Why?
Rubberband Guitar Take several rubber bands and stretch them around a tissue box, or another box with a hole cut out of it. Using different sizes of rubber bands works well after introducing the concepts of string weight and/or tension. Play your guitar by strumming the rubber bands. Which strings make the lowest pitch? Why? https://www.youtube.com/watch?v=dr4oDIMbi_E
Hose Trumpet Take a short length of garden hose and attach a funnel to one end using duct tape. Buzz your lips on the other end as you would a brass instrument. What is vibrating to cause the sound? Where is the sound the loudest, or where is it coming out of the instrument? If available, a trumpet mouthpiece can be attached to the free end of the tube. (The lip buzz can be difficult on the first try; here is a short clip that demonstrates how to do it: https://www.youtube.com/watch?v=1OXpAvgKY3Y)
Carrot Clarinet Create your own clarinet out of a carrot by drilling out the center of a carrot, as well as finger holes, and attaching a funnel and a saxophone mouthpiece to either end. What is vibrating to cause the sound in this case? Why does covering more or less of the holes change the pitch? https://www.youtube.com/watch?v=BISrGwN-yH4
Vibration Speaker: Feel the difference in sound level cause by the size of the vibrator. This vibration speaker doesn't make much sound, until you hold the vibrator up to a table or wall. What difference can you hear in the sound when the speaker is held up to different surfaces? What is vibrating to cause the sound in each case? http://amzn.com/B00NR1C6ZQ iWerkz 44850 Premium Vibration Bluetooth Speaker
Shoebox loudspeaker: Create a homemade loudspeaker out of a shoebox, a couple of magnets, some wire, and a few other items. What makes the loudspeaker vibrate? How could you make the speaker louder or quieter? http://asa.scitation.org/doi/abs/10.1121/1.3478335[20]
Doppler Rocket Send this sound source "rocketing" down the string by pulling the handles apart at either end. What changes in the sound as the rocket is moving? What real-life sound sources have this feature? https://www.pasco.com/prodCatalog/WA/WA-9826_doppler-rocket/ PASCO Doppler Rocket (WA-9826)

B. TEACHER KITS

The Acoustical Society of America provides an acoustics education kit to K-12 teachers that was similar to what was needed for this conference.[21] We began with the materials and demo ideas from the ASA kit that focus most on music, and expanded the kit with additional materials. For example, a slinky was included to demonstrate the wave nature of sound, a ruler to visualize vibrations, and a kazoo to experiment with creating vibrations with the voice. Combining ASA kit ideas and our own, materials to create three homemade instruments were also included, namely the straw trombone, the cup and string instrument, and the balloon membrane drum. These were packaged together and given to each of the teachers at the conference (see Figure 1). This kit was designed to be made of easily accessible materials that didn't create a large expense for the teachers. Several of the items are already present in an average elementary school classroom, and all of them are available at a local dollar store.

Figure 1: Teacher activity kit provided at the Arts Express conference

3. TEACHER WORKSHOP

The same active-learning approach was taken with the workshop participants as has been implemented in our courses and outreach. We presented the complete lesson plan included in the handout. The teacher participants completed all the activities, taking the materials out of their packets at the appropriate times. We discussed the explorative questions together as a group, and they were given time to experiment on their own to discover what they could learn from the activities. There was a high tendency for crossover between the science and musical aspects of each activity. At one point, all of the teachers spontaneously broke into "The Stars and Stripes" on their kazoos while experimenting with the way that a kazoo produces sound.

Afterward, there was a discussion on how these principles could be applied in the classrooms of the individual teachers, and what could be done to bridge the gap between STEM and arts through acoustics. The discussion was very practical, as nearly all of those in the group were active elementary school teachers. There were many science teachers who commented on the usefulness of the presentation for their classrooms, and there were several music specialists that had a harder time seeing how to apply it to their teaching. This was somewhat expected, as we did focus our presentation on the science core concepts. One music specialist commented that her class was required to build some instruments of their own just as we had been demonstrating.

Following the discussion, a few additional demos were shown without audience participation from the list provided (Table 2). These were chosen to present options to the teachers that are slightly more expensive but also more impressive, such as the hose trumpet shown in Figure 2.

Figure 2: One of the authors demonstrates the "Hose Trumpet" activity from Table 2.

4. DISCUSSION

Both the in-workshop discussion and the feedback we received later from the conference director indicated that our presentation was fixated on the sixth grade science curriculum. Some of the music specialists felt that they were unable to apply what we had presented, and the science teachers teaching grades other than sixth grade also failed to see the applicability of the acoustics concepts. Expanded focus is needed in future workshops to help educators use acoustics in their classrooms.

Even so, educators need to realize the ability of acoustics to clarify concepts and create an integrated environment in many STEM subjects. Using an acoustics demonstration to teach a concept, then creating a musical experience with the same demonstrations can accelerate the movement from STEM to STEAM. Examples include using tuned percussion tubes of different lengths to teach fractions (a tube of half the length of another will sound an octave higher), using the scientific method to figure out what changes the pitch of a blown bottle, or discussing conversion from mechanical to acoustical energy using the membrane of a homemade drum. Opportunities abound to use acoustics in other STEM areas to create STEAM learning experiences.

Our STEAM teacher workshop demonstrated the integration of arts and STEM using acoustics. Though the scope of our presentation was not able to include all STEM disciplines, acoustics is a useful way to explain a broad range of topics with STEAM integration. As STEAM is becoming more common across the United States, we propose a method of implementation. Let us advocate acoustics to put the “A” in STEAM.

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APPENDIX A: TEACHER HANDOUT

SOUNDS TO ASTOUND

BYU ACOUSTICS ◆ SOUNDS.BYU.EDU

Follow us on Twitter! **@SoundsToAstound**

Lesson Outcomes:

(See the Utah 6th grade science core standards 6.3a-c at http://www.uen.org/core/core.do?courseNum=3060)
Students will be able to:

- explain that sound is a wave
- describe and demonstrate how vibrating objects create sound
- describe how the pitch of an instrument can be varied by changing its length
- explain how vibrations can cause other objects to vibrate and amplify sound
- relate the volume of a sound to the amount of energy used to create the vibration

Demo Materials:

String and cup with paper clip, straws, Kazoo, Slinky, ruler, balloon

Learning Activities:

1. Sound is a Wave (Slinky)

http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html
https://phet.colorado.edu/en/simulation/sound
https://phet.colorado.edu/en/simulation/wave-on-a-string

- Take your slinky and stretch it out in front of you. Now move one end of the slinky up and then down again rapidly. What moved down the slinky? (A transverse wave)
- Stretch your slinky out in front of you again, but this time move your hand quickly to one side and then back. Now what moved down the slinky? (a longitudinal wave)
- Sound causes air to vibrate. When the air vibrates it pushes the air molecules back and forth in the same direction as the wave is moving. What kind of wave on the slinky is this most like?

2. Vibrating Objects Create Sound (Voices, Slinkies, Rulers)

- Vibrating objects cause the air around them to vibrate, which creates sound. Put your hand on your throat and make a vowel sound. What do you feel? What is vibrating to create the sound?
- Sound is a much quicker vibration than the waves we saw on the slinky, but we can see a vibration that causes sound. Take out your ruler and hang it off the edge of your desk. Now, while holding it tightly down with one hand, use the other hand to pluck the ruler. *(You may have to adjust the length that is hanging off the table in order to produce a nice sound.)* What do you see?

3. Changing Length of the Vibrator Changes the Pitch of the Sound (Rulers, Straws)

https://www.exploratorium.edu/snacks/straw-oboe

- Now change the length of ruler that is hanging off your desk and see if you can make a different sound. What has changed? (the pitch) Why? What is the lowest pitch you can get from your ruler?
- Create a straw instrument according to the instructions in the link above. *(See Utah 6th Grade Science Core standard 6.3d)* This is similar to the vibration of a clarinet or an oboe. What is vibrating in the instrument?
- Once you can get it to make noise, slide the second straw over it. What happens when you change the length? How can you get the lowest pitch?

4. Loudness depends on how much energy you put into making the sound (Cup and balloon)

- Take your balloon and cut off the neck. Stretch your balloon over your cup to create a drum. Strike the drum with your ruler. What is vibrating to create the sound? How can you make the sound louder or quieter?

5. Vibrating Objects can cause other nearby objects to vibrate (Kazoo)

- When objects vibrate loud enough, they can cause other objects that are nearby to vibrate as well. We are going to vibrate another object using our voices. Bring out your kazoo and hum, first with your voice alone, and then into it. What is vibrating along with your voice? How does that change the sound?

6. Vibrating other objects can amplify the sound (string and cup)

http://exploresound.org/explore-sound-home/acoustics-for-k-12/acoustics-activities/home-activities/cup-string-instruments/

- We are going to see another example of this sympathetic vibration. Pull out your string and tie it to your desk or chair. Stretch it tight and pluck it. What do you hear?
- Now we will use that string to vibrate something else. Take your cup and attach it to the string as explained in the above link. *(See Utah 6th Grade Science Core standard 6.3d)* Now pull it tight and pluck the string again. What difference does the cup make?
- This is similar to a banjo or guitar. The cup is the body, which makes it louder than if the string was on its own.
- How could you change the pitch? (Pinch the string at different lengths)

7. Conclusion

Other Resources:
ASA Explore Sound website:http://www.exploresound.org/
Falstad Physics Animations:http://www.falstad.com/mathphysics.html
PhET Interactive Simulations: https://phet.colorado.edu/en/simulations/category/physics/sound-and-waves

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