WAVES: An Integrated STEM and Music Program for Fifth Grade Students

RTP STRAND 2: Engineering Across the K-12 Curriculum

Jay Brockman (jbb@nd.edu), Doug Hall, Sean Martin, and Arielle Phillips
University of Notre Dame

Abstract
This paper describes the development, implementation, and analysis of a program for fifth grade students that tightly integrates STEM concepts with musical performance by an acclaimed percussion ensemble. The WAVES program was offered as a half-day event during the spring of 2014 attended by over 350 fifth graders from 3 local schools and comprised three main activities: (1) hands-on, museum-style exhibits and demonstrations in the engineering building, (2) small group sessions facilitated by undergraduates with discussion and hands-on activities, (3) a concert where all 350 fifth graders accompanied the artists-in-residence on custom instruments designed and built by undergraduates for the performance of a classical music work composed by the artists specifically for this educational event.

Introduction

Fifth grade academic standards for music in Indiana call for an understanding of the "relationships between music, the other arts, and disciplines outside the arts," specifically citing examples in mathematics. Neither the standards for mathematics nor science (the state does not have fifth grade engineering standards), however, require making connections between these disciplines and the arts. The WAVES project (Wonder, Arts, Vibration, Engineering, Science) at the University of Notre Dame, seeks to promote a better appreciation and understand of both the STEM disciplines and the Arts through their integration. Specifically, through an event centered upon a musical performance by an acclaimed percussion ensemble Third Coast Percussion that is artist-in-residence at the university, WAVES demonstrates how experimentation and analysis—typically associated with the sciences—and creative design—typically associated with the arts—figure strongly in both domains.

The WAVES program was offered as a half-day event, shown in Figure 1, during the spring of 2014 attended by over 350 fifth graders from 3 local schools and comprised three main activities: (1) hands-on, museum-style exhibits and demonstrations in the engineering building, (2) small group sessions facilitated by undergraduates with discussion and hand-on activities, (3) a concert where all 350 fifth graders accompanied Third Coast Percussion on custom instruments designed and built by undergraduates for the performance of a classical music work composed by Third Coast specifically for this educational event.

Figure 1: WAVES performance with over 300 local fifth graders.

Two undergraduate classes, offered during the semester prior to the WAVES event, were critical to its design and implementation. A one-credit, pass/fail course with approximately 40 students from a wide variety of majors focused on the design and construction of the musical instruments. Students in this class were also required to develop lesson plans for the small group sessions. Students in a senior-level Electrical Engineering audio technology course developed, together with the faculty member, a series of demonstrations for the museum-like portion of the event.

There is currently a growing interest in K-12 programs that integrate STEM education with the Arts, commonly known by the acronym STEAM.[1, 2, 6, 9, 10] Even as the nation advocates for advances in K-12 STEM education to spur greater employment and economic development, research has demonstrated a strong correlation between experience and learning in the arts and STEM academic proficiency, as well as innovation.[4] In particular, from a study performed at Michigan State University, 93% of the graduates of their STEM honors college had had musical training at some point in their lives, as compared to 34% of the general American population.[4]

Educational Objectives for Fifth Grade Students

The engineering and science topics addressed by this work, as well as the logistics of the WAVES program, grew from approximately six months of regular discussion with the fifth grade teachers at three local schools. In particular, the teachers wanted to have the students gain more exposure in a meaningful and engaging way to science and engineering in action. Most importantly, the partner schools were in a part of the city of South Bend, Indiana that experiences significant poverty, and while the university is a landmark in the region, very few of the students had ever visited the campus, let alone met an engineering or science undergraduate at the university. Even more so than the specific STEM objectives, this personal connection with local K-12 students was of primary importance.

Undergraduate Courses

Over the course of the past few years, the university as a whole and the College of Engineering in particular has shifted from viewing community based projects as *service* from the university to the community, to viewing them as *engagements* of mutual benefit.

As such, a key objective of the WAVES project was to develop a program that would advance student learning for both K-12 students and university undergraduates. To this end, students from two undergraduate classes played critical roles in developing materials for WAVES, as well as working directly with the fifth graders on the day of the event. Details on these two courses are provided below.

Special Topics Course: Integrating Science, Technology, Engineering, Arts, and Mathematics

An interdisciplinary 200-level special topics course through the Engineering, Science, Technology, and Society series entitled, "Integrating Science, Technology, Engineering, Arts, and Mathematics (STEAM)," was offered during the fall semester of 2013 with the express purpose of developing materials and preparing undergraduates to work with the fifth graders during the WAVES event. The stated objectives in the course description were:

- Students would learn to design and fabricate basic musical instruments, using CAD tools and equipment in the College of Engineering "maker" facility (called the Design Deck), including use of the laser cutter and 3D printing.
- Students would learn about the basic science of sound through using an oscilloscope and spectrum analyzer to analyze the sounds produced by musical instruments.
- Students would learn to communicate STEM concepts to a lay audience by translating their knowledge about how musical instruments work and basic properties of acoustic waves into language that a fifth grader could understand.

Recruiting for the course was done in conjunction with a Third Coast Percussion concert at the start of the semester. Interested students were offered free tickets to the concert and a meeting with the artists following the concert to introduce the project. Advertisements for the session also announced that students from the course would be able to apply for a funded summer internship that would continue the work. Nearly 80 undergraduates attended the information session and 43 ultimately enrolled in the course. Breakdowns of grade level and major are listed below:

Grade Level		
First Year	20	(47%)
Sophomore	14	(33%)
Junior	6	(14%)
Senior	3	(7%)

College		
Engineering	26	(60%)
Science	4	(9%)
Arts and Letters	5	(12%)
Business	2	(5%)
Undecided	6	(14%)

Class meetings consisted of evening sessions in the Design Deck, where students would learn the use of the tools, offered at a variety of times for convenience. Supplementing this, a course website offered an extensive set of online videos developed by the instructor and Third Coast Percussion on the use of the CAD tools, as well as on elements of music, including a basic approach to composing classical percussion music and illustrations of the roles that different instruments can play in the composition. Freeware or shareware was made available for all course software. SketchUp[8] was adopted for 3D design for 3D printing, and Inkscape[3] was used for 2D design for laser cutting. Free oscilloscope and spectrum analyser apps were also made available, running on the Windows, Mac OSX, iOS, and Android platforms.

All course work was to be submitted through the university's electronic portfolio (ePortfolio) system. Course requirements, which were due by the end of the semester, were as follows:

Lesson Plan: A personal plan for how each student would organize a small group session with approximately 5 fifth graders.

Instrument Design and Fabrication: Students were required to design and fabricate two different instruments using two different Design Deck technologies, shown in Figure 2:

- a 3D printed mouthpiece for a penny whistle, that could be attached to a section of PVC tubing with holes for fingering notes in a traditional D major scale, and
- a log drum fabricated on a laser cutter, consisting of a box with an H-shaped slit in the top surface, such that striking either of the tongues of the H plays a different note.

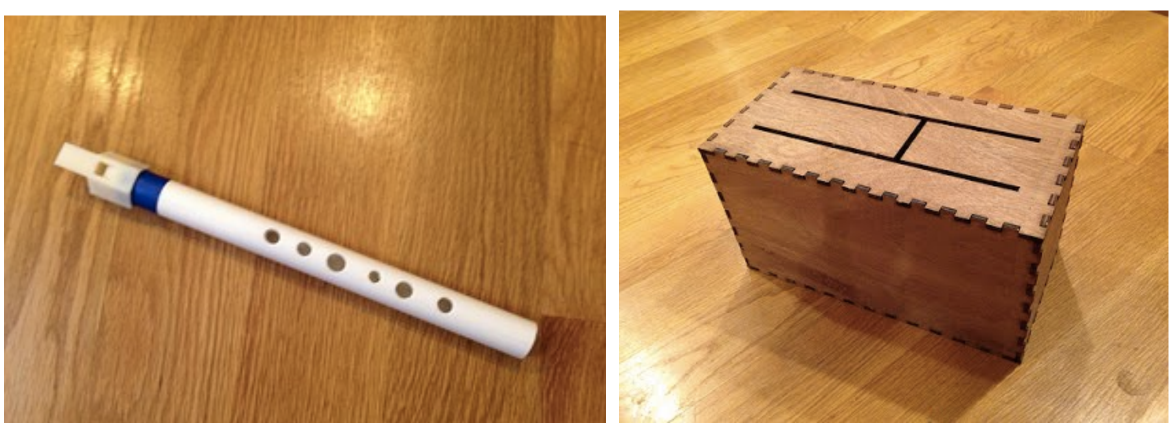

Figure 2: Penny whistle and log drum

Instrument Analysis: a very brief analysis of an instrument of choice. This could be any instrument, ranging from the common band and orchestra instruments, as well as bagpipes, sitar, erhu, etc. For the purposes of the course, different MIDI synthesized instruments or electric guitars with different effects (e.g. distortion, chorus) we considered to be separate instruments. Analyses should be written in simple layman's terms that would be understandable (maybe with some help) by a fifth grader. Analyses must include:

- A picture of the instrument
- A colorful description of 100-300 words, optionally with pictures, of what the instrument sounds like.
- A visualization of the instrument sound using an oscilloscope and spectrum analyzer, shown in Figure 3. These could be still pictures, but in many cases, a

short video with sound, such as recorded on a cell phone, may be much more descriptive.

- A brief discussion that relates what is seen on the oscilloscope and spectrum analyzer back to the descriptive paragraph of the instrument's sound.

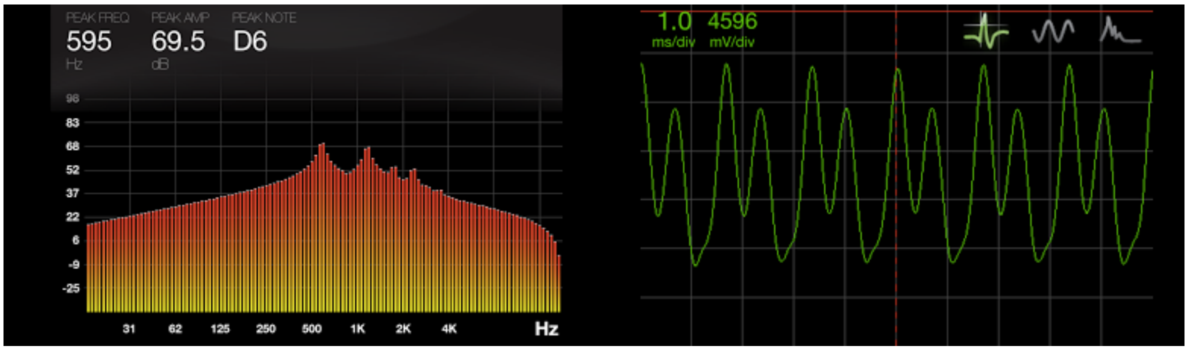

Figure 3: Sample instrument analysis of penny whistle. The whistle is playing a D note. If overblown, it will play the D an octave higher. The sound of the whistle is pleasingly rich, as illustrated by the frequency spectrum and oscilloscope waveform below. Here the whistle is blown hard enough to the point before the octave break. The spectrum shows a main peak at 595 Hz, with a second beak an octave above at 1190 Hz. It also has overtones above that, which contribute to the rich sound. The oscilloscope waveform clearly shows the presence of the fundamental frequency and octave above.

Reflection: How did the session with the fifth graders go? What did the undergraduate student learn? What should be changed?

Audio Electronics Course

EE 40345 - Audio Technology, taught each fall since 2011, aims to examine the scientific and engineering principles at work behind audio technology and sound phenomena. Topics explored include acoustics and psychoacoustics, microphone and speaker characteristics, filters and equalization, Fourier transforms, audio equipment specifications and measurements, digital formats, synthesizers, and recording. The course has been taught in a laboratory setting and incorporates a substantial "hands-on" component with demonstrations, field trips and student projects. The open-ended projects encourage students to further explore their individual interests and require that they research, design, build and test some system involving audio, or perform advanced acoustics or audio measurements, and present their results to their classmates as a final capstone project. Students in the past have built speakers of various types, ribbon microphones, a timbrel synthesizer, an ABX blind testing component signal switch box, solid state and tube amplifiers, and guitar effects boxes, while others have recorded and characterized the timbre and intonation of the historic carillon bells on campus or measured and analyzed the acoustics of the campus' concert hall. In this project, several students were very interested in the opportunity to be involved in a community outreach project aimed towards researching and developing effective and appropriate demonstrations of sound wave phenomena to 5th graders. The entire class was given one research and writing assignment to search for helpful resources related to this effort. When final projects were selected by the twelve enrolled in the course, two senior female electrical engineering students chose to devote their entire capstone project on developing outreach materials and demonstrations, and they became involved in ongoing meetings held by the WAVES project team outside the class, including a meeting with local school teachers.

WAVES Event

Coordination of the WAVES event was a very significant undertaking. In fact, one of the major goals of the first offering of WAVES was simply to develop a logistical system for holding the event, closely observe the flow, and then suggest changes for the future. The event had over 300 fifth grade students, from 3 different schools, arriving in 12 busses. The students first arrived at the university campus at 10:00 AM and departed at 1:30 PM. In order to handle the event flow, and to provide all students with a rich experience, the event was divided into three separate activities:

1. A set of hands-on, children's museum-style exhibits and demonstrations, held in the engineering building
2. Small group discussions with undergraduates, held in the performing arts center
3. A final performance with all fifth graders accompanying Third Coast Percussion in the performance of the WAVES composition in the main hall of the performing arts center.

Upon first arriving on campus, all students met in the main hall of the performing arts center for an opening session, where introductions were made and the professor who taught the audio technology course showed a set of demonstrations. Following the introductory session, half of the students participated in demonstrations in the engineering building for approximately one hour, while the other half was in the small groups with undergraduates in the performing arts center, and then swapped. Students then ate lunch before coming together in the main hall of the performing arts center for the joint performance, and then departed. Descriptions of each of these sessions are described below.

Introductory Session

An introductory presentation on the basic science of sound waves utilized a familiar keyboard instrument while live oscilloscope and spectrum analyzer plots were displayed. A pure sine wave voice enabled students to experience low vs. high pitch notes as long vs. short waves; wave amplitude was explained with soft and loud notes. Playing notes left to right across the keyboard, the resulting spectrum plot was compared to the different colors in white light as dispersed in a rainbow or by a prism. Students were engaged listening to and looking at the more complex waveforms and spectra of the "same note" played in a variety of synthesized instrument voices (piano, flute, trumpet, tuba, violin, organ, harmonica, automobile, helicopter, etc.) while being invited to identify them.

Hands-On, Museum-Style Exhibits and Demonstrations

A series of exhibit stations was set up throughout a campus engineering building for the fifth grade students to tour with their class. These exhibits are described below.

Design Deck: Fifth graders toured the College of Engineering maker space, called the Design Deck, where they had the opportunity to observe the laser cutter and 3D printers in action.

Audio Technology Demonstrations: In the senior Electrical Engineering elective course on Audio Technology, students developed two demonstrations for the WAVES program's visiting 5th graders. Both utilized speakers built by the undergraduate students, the first to explain the science of sound waves and how audio speakers work to create them, and the second utilizing a large video projection screen to visualize both pure single-frequency sine waves and the complex waveforms present in actual music. Both demonstrations are described further below.

In the first, a simple student-built single full-range driver ported box speaker containing an openly exposed 5" speaker cone was slowed down to oscillate at ≤1 cycle per second, or 1 Hz, where to the students it appeared to be slowly "breathing" in and out, shown in Figure 4. By using a Tektronix AFG 3022 signal generator set to output a 10 volt peak-to-peak AC sine wave, an easily visible speaker cone displacement of ~ +/- 1 cm was achievable even at 0.1-1 Hz. The students were asked why they could see the speaker moving but not hear any sound. The idea of frequency was introduced, and then the frequency was increased to 10 Hz where the speaker cone movement could clearly still be seen, only ten times faster. The students were captivated by the observation that the speaker was moving, but they could hear nothing.

At this point, the idea was introduced that when the speaker was "pushing" outward, it was pushing on the invisible gas molecules in the air, squeezing or compressing them closer to each other. This way of increasing the pressure of the air was likened to pumping up the air in their bicycle tire. And when it pulled back, the air molecules were spread further apart, or "rarefied." And as the speaker cone moves in and out many times, waves of high and low pressure are formed in the air, radiating outward. With each cycle of the speaker, another air pressure peak was created, and these peaks and troughs, like a water wave, then flows away from the speaker like water waves moving on a sea. Throughout the demo, in this manner, the science of how sound waves are created and what they are was connected with everyday experiences familiar to the students. Having shown visually how the speaker creates waves, the students were asked to ponder just why they couldn't hear anything.

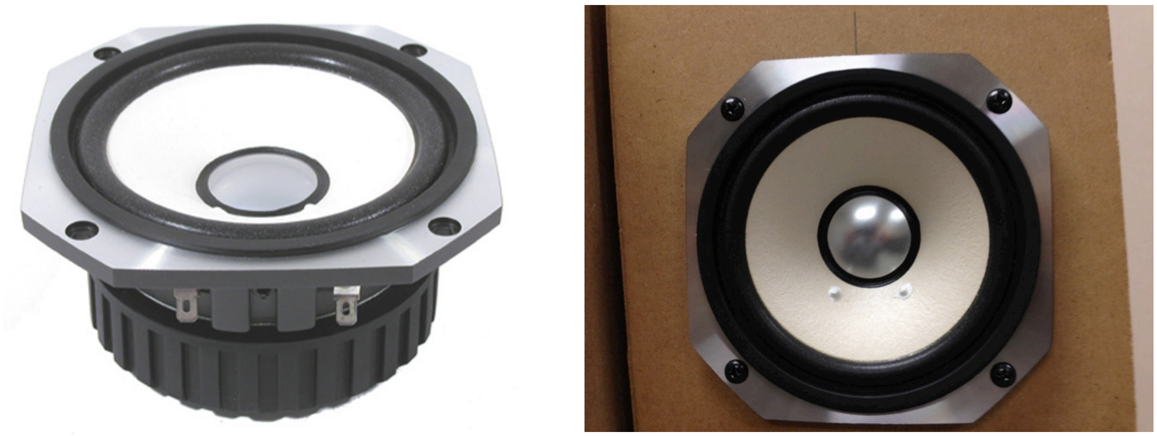

Figure 4: "Breathing" speakers

The speaker oscillation frequency was then increased upward until the students indicated they could hear it produce an audible, low frequency bass sound, and the frequency of the signal generator was then read to them. While humans can typically hear tones as low as ~20 Hz, the relatively small size of this driver made it inadequate for producing an audible bass response until a frequency of around 60 Hz. The demonstrators became aware here of an artifact of the speaker causing it to produce a stronger, audible 60 Hz harmonic when driven at 30 Hz, and carefully bypassed this region to avoid confusion by more advanced concepts. This harmonic is dependent on the box speaker dimensions, and was prevented in later demos by using a larger dimension speaker box. At this point, students observed that while they could now *hear* the sound, they could no longer clearly *see* the speaker moving at all. Here the analogy of a hummingbird was invoked to emphasize that often objects, like a hummingbird's wings or a vibrating string on a guitar, move faster than our eyes can see, but at a frequency that may produce an audible sound. When the speaker was audible, but not visible, the 5th graders were each invited up to feel that the speaker was indeed producing air pressure variations. Although they could not see it moving, a substantial air pressure wave, sensed on their hand as a continuously blowing "wind," could be felt as they held their hands in close proximity to either the speaker cone or the ~1.5" air port incorporated into the ported box speaker design. Although the students were asked not to touch the speaker, this instruction proved too tempting for many of them. Fortunately the KENAF paper fiber composite construction of the diaphragm cone made it sufficiently immune to the gentle touching of young, curious hands.

Finally, the frequency was increased somewhat further to perhaps 1 KHz so that students could observe that as the "frequency knob" was continually turned towards "higher" frequencies, the pitch they heard would continue to go higher and higher. If more time were available, this system could readily be used to roughly demonstrate to the students that the human hearing range extends upwards towards about 20,000 Hz, and students can be asked to keep their hand raised while they can still hear the speaker tone, performing an entertaining "group hearing test". We note that it was necessary at frequencies above ~100 Hz to decrease the signal generator voltage downward to ~1 V as the speaker, with reduced impedance, requires much less drive voltage.

In summary, this moving speaker cone demonstration enabled the students to directly observe -- through the real-time adjustment of frequency through the transition from visible-not-audible to audible-not-visible vibrations -- that sounds they hear are the result of air pressure waves created by too-fast-to-see vibrations of moving objects. For students interested in how technology works, a clearer understanding of how speakers create sound could be grasped. For each class group cycling through, this demo required no more than about 5 minutes to touch upon each of the points and descriptions noted above. Throughout the presentations, a subset of strongly-curious students were observed to exhibit additional interest and asked further questions as time allowed; it would seem that the simple demo was effective at stimulating thinking and helping them to formulate new mental models that may stick with the students and help them recall important concepts of the science and technology of sound whenever they listen to music or other entertainment programming over loudspeakers in the future.

In a second demo developed by Audio Technology class students, the main attraction was the simultaneous playback of a high-fidelity stereo recording of the piece "Fractalia" by Third Coast Percussion and projection on a large screen of live oscilloscope and frequency spectrum analyzer windows similar to those used elsewhere throughout the day. The lights in the room were dimmed to enhance the ambience and mood to that of an Arts performance, which it was (albeit prerecorded). Here, a set of very high-fidelity, premium sound quality stereo speakers were a special focal point, as they were also built by the engineering students themselves, following the popular Pluto™ design developed by former Hewlett-Packard RF Engineer Siegfried Linkwitz. Linkwitz is the founder of Linkwitz Labs and a true a legend to do-it-yourself audiophiles and speaker enthusiasts, and these speakers and other Linkwitz designs have been built by literally thousands of audio enthusiasts around the world. His speaker designs are widely respected for their ability to produce an extraordinarily realistic, life-like stereo sound image. The simple, freestanding Pluto™ stereo speakers were built at relatively low cost using a PVC pipe housing and wood base, following the design plans and circuit boards purchased from Linkwitz Labs, and have a particularly unique, do-it-yourself appearance that forms a particular impression of being down to earth and accessible to anyone with a home workshop. Without intending this to be an advertisement, it must be stated that they are simply a joy to listen to, and the 5th graders showed widespread agreement with this fact. The oscilloscope and frequency spectrum analyzer windows were first briefly used to yet again visually reinforce the relationships between short vs. long wavelengths and high vs. low pitch sine wave tones. Then the dramatically moving recorded Third Coast Percussion performance was played at an impressively loud yet safe volume while the students observed the live dance of waveforms and soundwave spectra on the screen and each filed past the speakers to again feel with their hands that the speakers producing all this musical sound were also producing substantial air pressure waves just as they had seen in the earlier breathing speaker demo, and after a few minutes of enjoying this interaction of science, technology, engineering, and math with the musical arts. This demo formed a meaningful bridge between the earlier science of sound and technology of speakers demo, and their full potential for highly aesthetically pleasing music reproduction, while also tying to the performing arts component to be experience at the end-of-day live concert performance with the percussion ensemble.

Cosmic Waves: The Cosmic Waves activity initiates children to the idea that sound waves are behind the formation of all structure in the universe. A professor in the physics department who is also the community engagement chair for her department and has an extensive background in dance and the arts presented this part of the program. Early in the universe, these sound waves gave rise to perturbations that are frozen into the distribution of matter. Slightly over-dense regions collapse to form the clusters and filaments of galaxies we find in the universe today. This activity breaks down this rather complex concept into a series of experiences that the children can tackle. First, we discover that sound waves can affect the shape of materials. It starts by watching movies of non-Newtonian fluids reacting to music. This serves to grab the group's attention and gives them time to settle down. The children are asked to describe what they see and to pick their favorite section of the movie. Past descriptions have included "dancing yogurt", "sand bouncing around", and "this video is tight". Sand on a drum surface that is driven at a certain resonant frequencies confirms this idea of material moved and shaped by sound. Second the children get a tactile experience of waves using two dozen Slinky's (Figure 5) of various circumferences and lengths (including one that takes up the entire length of the workshop space). They are guided to create compression waves, transverse waves, and standing waves. Finally, after a brief recap of the patterns they have seen and created using waves, with the non-Newtonian fluid video paused to feature a clear pattern, the children watch the Wilkinson Microwave Anisotropy Probe (WMAP) animation of fluctuations caused by sounds waves collapsing into the stars and galaxies we see in the sky today. The movie ends with a fly through of the observed universe.

Figure 5: Using Slinkys to create and observe compression waves.

Small Group Discussions with Undergraduates

Because of the logistics of moving groups of students during the event from place to place, the small group session were held with larger groups than originally planned, with 1 or 2 undergraduate students working with a class of 25-30 fifth graders, shown in

Figure 6. The fifth graders classroom teachers helped provide order while the undergraduates focused on the content of the session.

The session content was based on the lesson plans that the undergraduates developed as part of the 1-credit STEAM course. During the sessions, the undergraduates projected oscilloscope software, such that the fifth graders could observe the waves associated with different kinds of sounds, as illustrated in Figure 6.

Figure 6: Undergraduate student leads small group session.

Fifth graders were given a short 4 page workbook, in which they were asked to draw what they thought waves would look like for soft and loud sounds, high and low sounds, and smooth (whistling) and noisy (clapping) sounds.

WAVES Performance

In the final session of the day, all 300+ students assembled in the main hall of the campus performing arts center to accompany Third Coast Percussion in the performance of a musical work that was composed by Third Coast Percussion especially for this event. Also called "WAVES," this work consisted of simple rhythmic patterns and textures, built around the four notes of an Amaj7 chord (A, G#, C#, E). The music was written for 4 different instruments: log drum, 2-note whistle, pipe chimes, and shakers. The log drums were based on the design from the undergraduate STEAM class and fabricated on a laser cutter. The whistle were originally planned to be 3D printed, but cost and fabrication time was prohibitive. Instead, the whistles were made from cut and drilled inexpensive slide whistles with the slide discarded. Two different whistles types were made, each with one hole, that could play either A/C# or E/G#. The pipe chimes, pictured in Figure 7, were fabricated from 0.5" steel conduit cut to length in the same note parings as the whistles. The chimes were set in custom-designed plywood base, also cut on a laser cutter. The shakers were simply made from two paper cups taped together with rice inside, also shown in Figure 7. All students were given a shaker to play along with one of the other 3 instruments. The instruments were assembled by undergraduates in the STEAM course, along with a number of other recruited helpers, including local high school students.

Figure 7: Students playing tube chimes and shakers during WAVES performance.

The WAVES composition was not taught and played using the conventional music notation consisting of notes on a staff. Instead, Third Coast Percussion invented a notation where different musical patterns and textures were represented by a system of simple colored shapes. The series patterns in the piece were included in a deck of PowerPoint slides, as illustrated in Figure 8. One of the Third Coast Percussion performers served as the conductor for the piece, manually stepping through the slides and leading the fifth graders at each transition. The other three members of the ensemble played a counterpoint to the fifth graders parts on marimba, kick drum, and other percussion instruments.

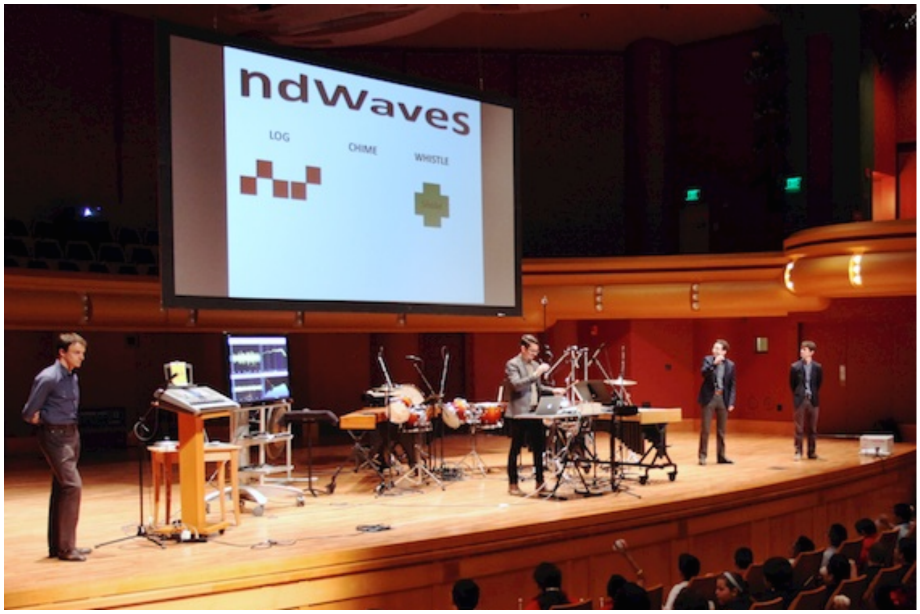

Figure 8: Color and shape notation for WAVES performance score.

Assessment and Future Work

Seven undergraduate students from the STEAM course continued work on the WAVES project as summer research interns, with the goal of assessing the WAVES project and in particular, determining alternative approaches for providing greater access to programs that integrate STEM and the arts for K-12 students. To conduct this study, the interns were trained in an approach to design thinking and innovation, based on the use of a Business Model Canvas, developed at Stanford University[7]. Using the LaunchPad Central[5] software platform to archive their results, the interns interviewed over 50 teachers, parents, administrators, students, and others to gain insights on the WAVES program in particular and possible mechanisms for delivering STEAM education in general. Using the results of these interviews, students determined a “value proposition” for a business plan. A key finding was that because of existing constraints on classroom time, that teachers face, and other pressures, it would be in practice be very difficult to integrate significant STEAM learning into K-12 classroom beyond select prototype activities. Instead, the students chose to pursue a path involving informal learning through either after school, weekend, or summer programs. The students continued to discuss this idea with leaders of existing programs in an effort to make this a reality.

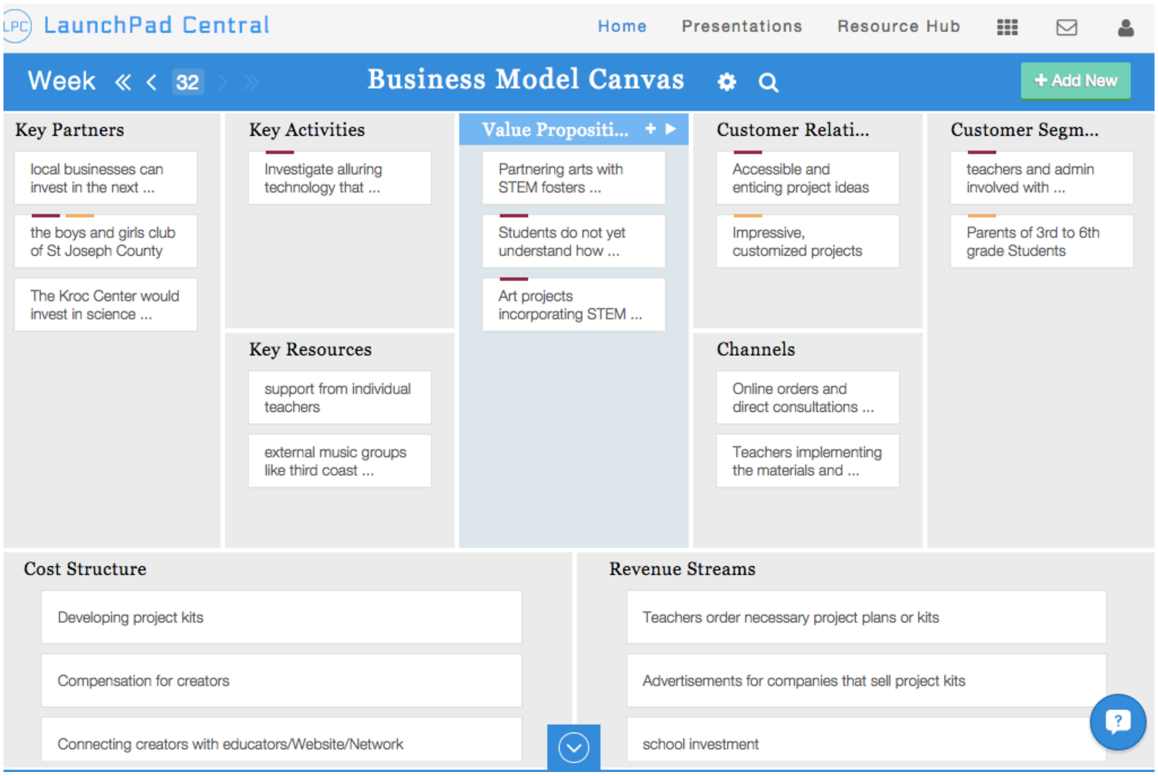

Figure 9: Business model canvas from LaunchPad Central

Interviews with undergraduates who participated in the project brought forth several noteworthy observations on the impact of the project on their own learning. Some samples are provided below:

- "Working on a combined project like we did this summer allowed us to draw some great parallels between the creative processes of music and engineering. Seeing how similar each of these disciplines really is has encouraged me to be more innovative with projects I have worked on this past year."
- "The project also enhanced my own musicianship by making me more receptive to the nuances and colors of instruments to get a desired sound from any particular instrument. I thought working on this project was a great way of combining both my passions for music and engineering, which was a great advantage by making me even more passionate about what I was doing."
- "I think there should be more course opportunities for ways to combine engineering and the arts."

Follow-up discussions with the fifth grade teachers suggested further refinements for future offerings of the WAVES program. While the event was highly *participatory* for the fifth grade students, it was not as *exploratory* as it could have been. In particular, in the future, the teachers would like to see a stronger connection made to the process of scientific discovery: namely, formulating a hypothesis, performing an experiment, making observations, and summarizing findings. We believe that working with musical instruments provides excellent opportunities for doing so, such as by having students speculate on properties of a sound that a particular instrument might make, in a context that many students would find to be highly engaging. Further, the teachers would also like to see greater involvement of the students in the design process itself, giving the students the opportunity to construct their own instruments. Plans for future WAVES activities include not only having students design and build instruments, but also composing their own pieces with these instruments, and even inventing their own musical notation. These activities would likely be undertaken at the schools before or after the WAVES event on campus.

Acknowledgements

This work has been supported by funding from NSF grant DUE1161222, "Finding Your Vocation in STEM," as well as by funding from the Lilly Foundation.

References

1. Eger, J. M. (2011, May 31). National Science Foundation Slowly Turning STEM to STEAM [Web log post]. Retrived from http://www.huffingtonpost.com/john-m-eger/national-science-foundati_b_868449.html .
2. Fountain, Henry. "Putting Art in STEM." *The New York Times*, October 31, 2014. http://www.nytimes.com/2014/11/02/education/edlife/putting-art-in-stem.html.
3. Inkscape. https://inkscape.org
4. LaMore, R., Root-Bernstein, R., Root-Bernstein, M., Schweitzer, J. H., Lawton, J. L., Roraback, E., ... & Fernandez, L. (2013). Arts and crafts: Critical to economic innovation. *Economic Development Quarterly*.
5. Launchpad. http://www.launchpadcentral.com
6. O'Herron, P. (12, April 2013). Yo-Yo Ma urges 'STEAM' to drive nation's workforce. Retrieved from http://www.partnershipmovement.org/news/p/yo-yo-ma-urges-steam-to-drive-the-nations-workforce/
7. Osterwalder, S. et. al. Value proposition design. Wiley, 2014.
8. SketchUp. http://www.sketchup.com
9. Sousa, D. A., & Pilecki, T. (2013). *From STEM to STEAM: Using brain-compatible strategies to integrate the arts*. Corwin Press.
10. STE[+a]M Connnect. http://steamconnect.org