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Music Technology as a Vehicle to STEM/STEAM for High School Students

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Introduction

Trends in the number of students being trained in Science, Technology, Engineering, and Math (STEM) fields in the world today shows the US failing to keep pace with rest of the developed world[1]. The US currently ranks 27th in the proportion of college students obtaining undergraduate degrees in science and engineering[2]. Having fewer students entering these fields will eventually have a major effect on the innovation and competitiveness of the country at the international level. To combat this trend, many programs are being implemented to try encourage interest in the STEM fields at the high school level. Since the scope and methodology of these programs differ in order to address different populations of students, collaboration and the sharing of available resources between the programs may lead to the development of useful activities which may be more effective at encouraging interest[3]. This paper discusses a collaborative attempt between two programs currently being implemented at Drexel University, and an evaluation of the portability of activities from one program to the other.

Additionally, this study focuses on the importance of integrating the arts in STEM education. One longitudinal study found that at-risk K-12 students who participate in an arts-rich curriculum outperform those with little or no arts exposure in terms of overall GPA, reading and math test scores, graduation rates, college enrollment rates, higher education completion rates, and college performance, among other metrics[4]. Toward this end, we've developed several hands-on STEAM activities specifically to illustrate the interconnectedness of the arts and the sciences through music technology.

Summer Music Technology Program

The Summer Music Technology Program (SMT) offers a unique educational experience for rising high school sophomores and juniors[*]. The week-long program, initiated in 2006 as part of an NSF CAREER award, aims to introduce its participants to the concepts underlying modern music technology through inquiry-based projects and activities, drawing upon common music listening and playing experiences[5]. The vast majority of young people today encounter music technology in their daily lives, yet the misconception persists that the arts and engineering are disparate fields requiring entirely separate skill sets. Also, the INFINITY project has shown that music technology has the potential to motivate students into STEM fields[6]. For this reason, the program places heavy emphasis on the mutually reinforcing relationship between engineering and music, with new technology opening up new creative possibilities and newly discovered limitations demanding yet more technical solutions. By presenting the basics of these technologies accessibly in this context, we hope to catalyze curiosity and motivate further investigation which may steer students onto a career path in STEAM.

In most of the SMT activities, we have, in the past, used Macbook laptops and PureData[†], a real-time graphical audio programming environment, where the user manipulates blocks and makes virtual connections between different components to accomplish basis audio synthesis and analysis. In 2012, we debuted a new set of custom-designed education apps for iOS, thus moving from laptops to iPads. The apps are designed to be simple and intuitive for users with little knowledge of DSP, abstracting away more complex details and introducing concepts in an accessible manner.

National Science Foundation GK-12 Program

The NSF GK-12 Fellowship is another program that encourages pre-college students to pursue a career in STEM, but in the context of the fourteen National Academy of Engineering (NAE) Grand Challenges, a set of foreseeable problems to be overcome in the twenty-first century[‡]. This NSF-funded program pairs graduate students in STEM fields (GK-12 Fellows) with K-12 teachers to develop application-driven, project-based lessons that reinforce concepts and motivate further study of aspects of the science and math curriculum throughout the school year. These projects attempt to connect seemingly abstract ideas and concepts with practical application, in the process demystifying some of the technologies students take for granted by illustrating how the concepts they learn in science and math can be applied to the betterment of humanity.

This paper is an investigation into the efficacy of a subset of the SMT modules in a modified form outside of the SMT environment, namely deployment as GK-12 projects. The two programs share the common goals of early introduction to STEM/STEAM and engaging the underserved and underrepresented in these fields, as well as common methods in their emphasis of project and application-based pedagogy and their reliance upon the contributions of graduate students. The most notable difference between the programs is the prior experience of the participants. SMT participants are generally self-selected, so the program tends to attract interest from the musically-inclined, whereas GK-12 participants represent a more general cross-section of pre-college students. Slight modification of the SMT modules is necessary to adapt to the audience, access to technology, instructor to student ratio, and session length.

Several SMT activities were also previously deployed in 2011 as part of the summer section of the Franklin Institute's STEM Scholars Program[§], which serves a similar purpose of increasing matriculation into STEM fields and preparing underserved high school students for college. This yielded positive results, with non-musically inclined students reacting similarly to the SMT participants[6]. Our investigation into efficacy of deployment in a high-school setting seeks to determine if the modules can effectively be adapted to the much more constrained high-school classroom environment as well as a more general population of students. In doing so, we hope to make these modified activities publicly available and deployable by any GK-12 participant or high school science teacher.

Activity Descriptions

Speaker Building

In the Speaker Building activity students are tasked to construct a speaker using widely available materials. Before beginning construction of their speaker, students are given a brief introduction to the principle of electromagnetic induction and the components and construction of speakers. Students are then given instructions on how to wrap their own speaker coil using magnet wire. A paper plate serves as the speaker cone, and is loosely mounted in a cardboard box enclosure. The coil is attached to the plate and an amplified signal from a volunteer's mp3 player is applied to the coil. In the past we've used custom-built 75W mono hi-fi amplifiers, but recently have switched to 75W off-the-shelf home stereo amplifiers. If time allows, a discussion of ohm's law can illustrate how, for a constant voltage, the amplifier will output more current into a lower resistance load, necessitating a minimum number of coil turns (we use > 70) to avoid damaging the amplifier.

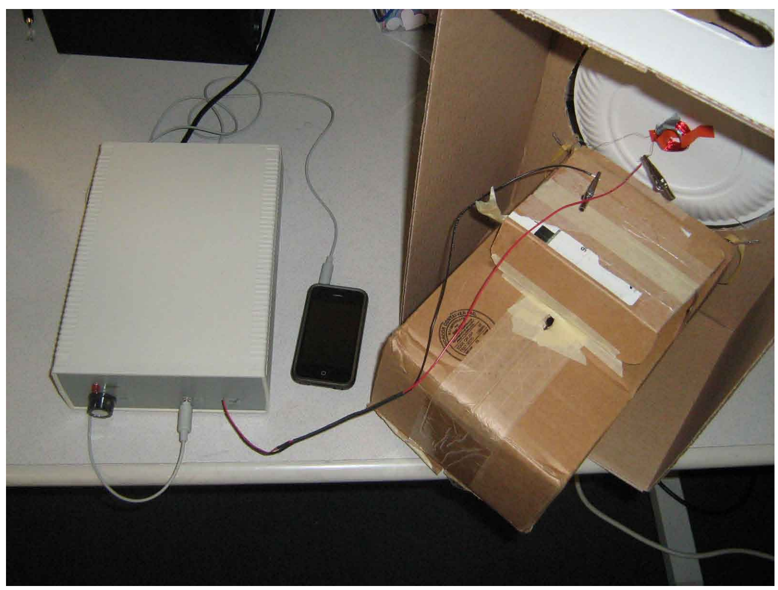

Figure 1: Setup for Speaker Building Activity

Students can then hold strong neodymium magnets near the center of the coil, seeing and feeling directly how interaction between the permanent magnet and electromagnet fields produces vibration of the plate and audible reproduction of their music. Time permitting, the students are allowed to experiment with different numbers of turns in their speaker coils and different types of plates to make qualitative assessments of how these changes affect the fidelity of the sound. Included in the project handout is an equation relating the number of coil turns to the field strength, and a more advanced class warrants a discussion of the trade-off between increasing field strength with more turns and increasing the coil's impedance.

By learning about the principles behind speakers and their construction, students should gain a better understanding of electromagnetism as well as an awareness of how much this technology affects their lives. Experimenting with different materials and coil turns also serves to introduce students to the iterative design process, thus they should gain an appreciation for how different types of components and their design affect the fidelity of a speaker.

Musical Instrument Acoustics

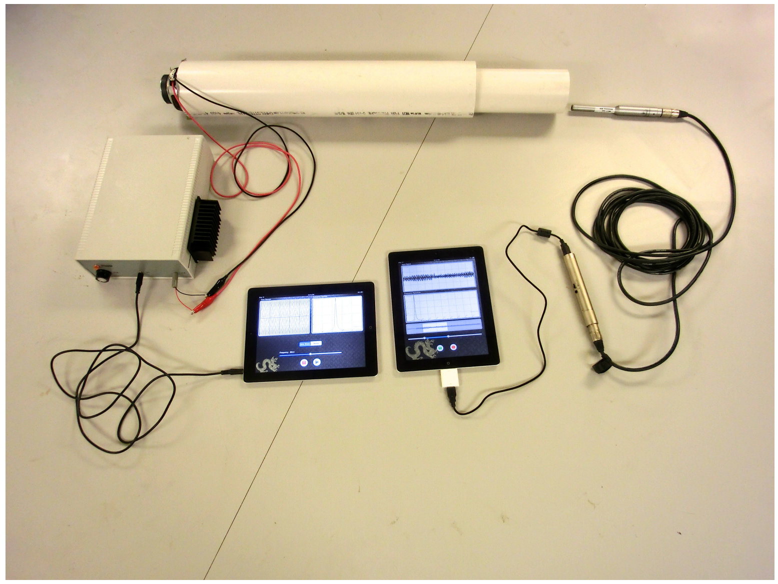
Figure 2: Set up for Musical Instrument Acoustics Activity

The Musical Instrument Acoustics activity introduces students to the concepts of resonant frequencies and filtering using a speaker mounted on one end of a variable-length PVC tube and two custom-designed iPad applications for sound synthesis and analysis. Students are tasked with setting up the equipment, including two iPads, an amplifier, a speaker, a microphone and USB interface, and several cables and adapters. Tones are played through the tube using the synthesis application and students are guided through a series of explorations.

First, students analyze the spectrum of the recorded signal and see how the resonant frequency of the tube changes with the tube's length. They are then given an introduction to the concept of standing waves and how they introduce multiple resonant frequencies. Using a provided equation, students calculate the first three resonant frequencies of their tube for a given length and then can verify these experimentally using the tube. Finally, students again determine resonant frequencies of the tube by driving the speaker with white noise.

This activity makes use of the same amplifiers as the speaker building activity. A variable-length "sound cannon" is accomplished by mounting a speaker on the end of a larger PVC tube, while a smaller tube fits inside of it, easily sliding in and out. All resonant frequencies are calculated assuming a single tube diameter that is the average of the two. We use a test and measurement microphone for its linear frequency response, and a MicMate portable audio interface that connects to an iPad via USB and a camera connection kit.

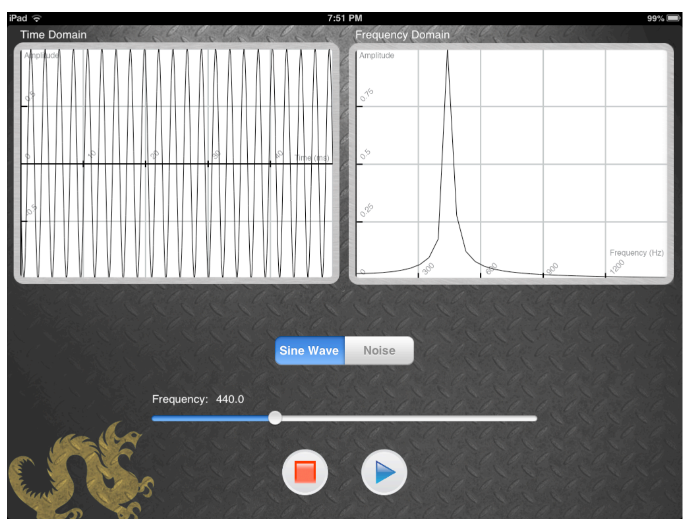

Figure 3: Sound Synthesis app

We use two custom-designed educational apps for iOS for synthesis and analysis. The synthesis app allows the student to generate a pure tone of a single frequency or white noise to amplify and drive the tube's speaker. The analysis app takes a recording from the end of the tube via the test mic and plots the waveform both in the time and frequency domains. Students are tasked with picking out the resonant peaks in the frequency plot due to standing waves in the tube. They can then see whether the frequency of these peaks agrees with their calculations. Both synthesis and analysis are also possible with other audio recording software as well, including free, open source software like Audacity.

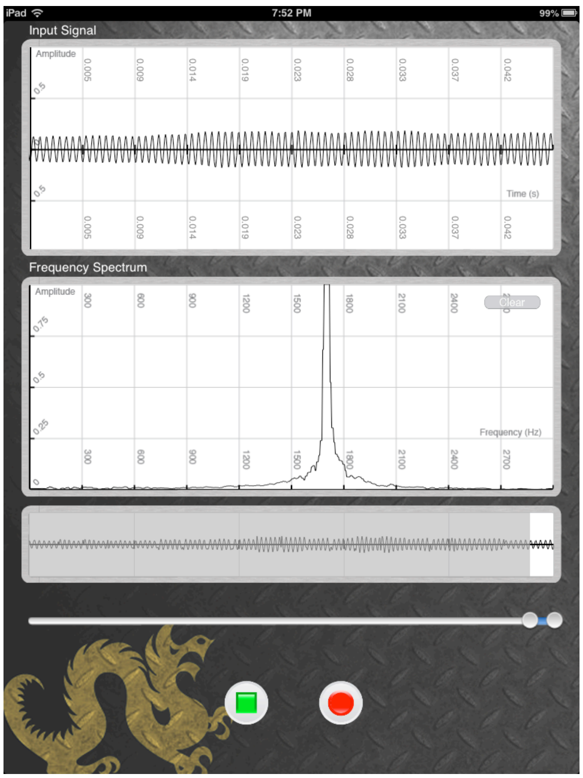

Figure 4: Sound Analysis app

Students require a basic knowledge of waves (frequency, wavelength) and basic algebra to perform this activity successfully. After completing this activity, students should have gained a better understanding of resonance and why different lengths of tubes resonate at certain frequencies. They should also come away with an idea of how one would theoretically and experimentally determine the frequency response of a sound system. Instructors draw parallels between the source-filter model of the experimental setup and commonly encountered phenomena like sound production in wind instruments and the human voice.

Each activity created by the GK-12 program should be related to one or more of the Grand Challenges of Engineering set forth by the NAE. Both the Speaker Building and Musical Instrument Acoustics activity are easily relatable to the grand challenge "engineering the tools of scientific discovery." Emphasis is placed on how the concepts of transduction and spectral analysis are often used in the study of natural phenomena.

Research Methodology

Participants in the SMT program complete surveys after each activity, indicating on a scale from 1-5 their level of interest, difficulty of the activity, and how much the students feel they learned from the activity as well as optional additional comments. The SMT data was collected from two groups of participants over 2011-12 totaling 52 ranging from ages 15-17. Of those 52 students, 49 played at least one musical instrument indicating a level of musical training. The SMT data was compared to student responses collected by two GK-12 fellows in four classrooms (52 students from 11th and 12th grade chemistry and physics classes) at the Philadelphia High School for Girls in 2012, only six of whom play an instrument. Deploying these modules and surveys as GK-12 projects allow us to directly compare student interest in STEM in a musical context between populations with different levels of musical inclination. Using this data, we can determine whether this method of presenting STEM effectively appeals to today's youth's near-universal affinity for music.

Primary Challenges

An effort was made to avoid modifying the activities significantly from their form as deployed in SMT, but several slight changes were ultimately necessary. One significant difference between the SMT and GK-12 programs is that SMT is a week-long sequence of activities designed to be immersive, and certain modules are chosen for the beginning to lay foundational material for later modules. For example, one of the first activities completed by the SMT participants is an introduction to waves in an audio context. In this activity, students use function generators connected to speakers and oscilloscopes to both visually and aurally experience pure tones and more complex waveforms and the effects of varying amplitude and frequency. They are then introduced to the concepts of harmonics, additive synthesis, and Fourier series representation of periodic signals. This activity provides a solid foundation necessary for the spectral analysis performed in the Musical Instrument Acoustics activity. The Introduction To Waves and Sound activity unfortunately could not be deployed without significant modification outside a university electrical engineering laboratory, as it requires access to expensive test equipment not generally available to high schools. Deployed with the greater constraints of a GK-12 module, the instructors were forced to provide only a surface-level introduction to these concepts. Additionally, each SMT module is conducted by one primary instructor, aided by at least four other instructors who can provide individual feedback and assistance at any time. In contrast, GK-12 modules are generally led by just one GK-12 Fellow with the help of the class's teacher. The activities deployed in this paper were done with the help of one additional fellow, but even so, the instructors were often overwhelmed with questions and unable to provide the individual attention needed to maximize understanding and takeaway. Students who did not have their questions answered quickly, became distracted, thus the classroom became more prone to interruptions than the SMT deployments.

Finally, time proved to be one of the more limiting constraints set by the format of a single-period high school class. In both high school classes, the instructors were forced to cut the end section of the Speaker Building activity, where students experiment with different numbers of coil turns and different speaker cone materials. This unfortunately left students without participation in the design process, which is an integral component in catalyzing interest in STEM, as the students not only get to be creative, but are able to make educated guesses about how different materials would influence the sound quality and test them experimentally. Without this component, the activity is reduced to a cookbook-type activity rather than an exploration. Additionally, some GK-12 groups also did not reach the final section of the Musical Instrument Acoustics activity, where they were tasked with driving the speaker with white noise and finding the frequency of the resonant peaks. The students were unable to compare these experimental findings with the theoretically calculated values in a previous section of the model.

Results

Means and standard deviations of survey results are summarized in Tables 1-2. Results indicate similar levels of learning, enjoyment, and interest, with the most notable difference being that the SMT participants felt more strongly that they had learned from the Musical Instrument Acoustics activity. SMT participants also enjoyed and found the activity more interesting, with the opposite being true for the Speaker Building activity (though both groups felt they had learned about the same amount).

	Did you learn from this activity?	Did you enjoy this activity?	Was this activity interesting?
SMT	4.25 ± 0.90	3.98 ± 1.23	4.25 ± 0.98
GK-12	4.08 ± 1.35	4.38 ± 1.01	4.52 ± 0.83

Table 1: Survey results for the Speaker Building activity (scale: 1 = a little, 5 = a lot)

	Did you learn from this activity?	Did you enjoy this activity?	Was this activity interesting?
SMT	4.10 ± 1.04	3.49 ± 1.03	3.76 ± 1.08
GK-12	3.07 ± 1.34	3.16 ± 1.57	3.41 ± 1.39

Table 2: Survey results for the Musical Instrument Acoustics activity (scale: 1 = a little, 5 = a lot)

	Speaker Building	Musical Instrument Acoustics I
Was this activity challenging?	2.83 ± 1.31	3.75 ± 1.28
Did you have the abilities to complete this activity?	4.13 ±1.10	3.84 ± 1.33
How well were you concentrating?	4.21 ± 0.89	3.34 ± 1.49
Was this activity important to you?	2.98 ± 1.20	2.32 ± 1.38
Were you succeeding at what you were doing?	3.69 ± 1.25	3.43 ± 1.28
How creative were you feeling?	3.87 ±1.33	3.16 ± 1.51

Table 3: Results of additional questions for GK-12 deployment (scale: 1 = a little, 5 = a lot)

In order to compare the efficacy of the adapted modules to each other, additional questions were included in the surveys for the GK-12 students (SMT surveys were conducted in the summer of

2012, before this research paper was conceived and so only included the three original questions). Table 3 shows that the students found the Musical Instrument Acoustics activity more challenging than Speaker Building, which scored consistently higher for all other questions including the original three.

Conclusions and Future Work

Overall, our results seem to indicate that music technology is indeed an accessible topic that can potentially catalyze interest in STEM for a more general student body outside the musically-inclined SMT participants. The level of success in this endeavor may depend upon the subject of the activity as well as details of implementation and amount of time spent on background material.
The more positive response to Speaker Building over Musical Instrument Acoustics activity may be attributed to these sources. GK-12 students found the acoustics activity less interesting and important, and found themselves concentrating less, which may indicate that more students commonly encounter speakers than encounter other types of resonant enclosures and wind instruments, thus the activity seemed less applicable to their experience.

GK-12 students also felt they learned less from the acoustics activity, which is inevitably linked with level of prior interest, but they also found the activity much more challenging, and felt less like they had the abilities to complete the activity. This could be attributed to the less thorough introduction to sound waves and spectral analysis as a result of the tighter time constraints of the high school class period. We intend to explore more variations on the musical instrument acoustics activity to increase learning and enjoyment.

Most of the SMT activities have been deployed in SMT six times thus far, and have been slightly updated every year based on student survey results. Future work will focus on modifications to better suit the high-school classroom environment such as the possibility of splitting the activities up into smaller sections, or designing a shorter activity focusing on background material so students are better prepared to analyze the spectrum of a recorded signal.

Future evaluation methods should also be refined. While we ask students to rate how much they have learned from the activity, we know that students self-assessments are inherently limited[8]. Asking students to summarize what they've learned from the activity may ameliorate this problem and allow us to compare actual concepts learned to self-assessment.

Acknowledgements

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