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Introduction to STEAM through Music Technology (Evaluation)

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Abstract

Real-world problem solving across domains in the 21st century requires technical knowledge and skills, as well as creative thinking and problem solving; however, the pedagogy of many STEM education programs only focuses on the technical aspects of their discipline. The point at which students are first introduced to various STEM fields is critical in terms of their interest, motivation, and understanding of potential applications. These early years greatly impact the decision of whether a student pursues a career or major in a STEM field. Thus, teaching methodologies for young STEM students must balance, or better yet, intertwine core concepts and knowledge with student engagement through hands-on, project-based learning and connections to topics of interest, such as music and the arts. Too often, STEM pedagogy paints a picture of a world where problems have convergent solutions, in contrast with a reality where optimal solutions are divergent in nature, requiring creativity, originality, and insight. In order to revitalize and reimagine STEM learning, there must be true integration of the arts and creative thinking in the sciences, debunking the traditional approach of STEM and the arts being dichotomous. Through the Summer Music Technology (SMT) program at Drexel University for rising high school sophomores and juniors, we aim to illustrate the interconnectedness of music with engineering, science, and mathematics through inquiry-based modules and projects involving creative problem solving and self-expression. Our approach not only serves to emphasize creativity amongst the technically inclined, but also, presents STEM in an accessible, engaging way, leveraging students' passion and interest in music as a catalyst for learning. SMT is a unique STEM experience for high-school students who would not otherwise consider supplementing their education with STEM or even pursuing STEM careers.

1 Introduction

The Summer Music Technology (SMT) program 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 performance experiences. Music continues to prove an integral part of students' lives, with the vast majority possessing large personal libraries and utilizing popular streaming services and recommendation systems. Capitalizing on the near-universal interest in music, we hope to bridge gaps and appeal to students on either side of the STEM/arts divide, with the goal of producing more creative, technically literate, well-rounded students.

Over the past nine years, we have developed a series of activities designed to introduce high school students to the engineering, science, and mathematics principles that underly modern music technology [1 2 3]. Each module emphasizes signal processing concepts, tools, and methods through hands-on activities that require minimal background knowledge. Developed by signal processing engineers with musical backgrounds, each activity focuses on an aspect of music technology and has specified objectives that students should understand upon completion. The inquiry-based program strives to maximize time spent engaged in activities, minimizing lectures.

Additionally, the activities are designed to be portable and useful to other instructors, either individually or as a unit, and are available online for any interested parties[4]. Current topics covered in the program include: digital representation of analog signals, digital sound effects and echo modeling, musical instrument acoustics, novel interfaces for music manipulation, music information retrieval, music recording and production, transduction of audio signals using speakers, and a grounding in the fundamental wave-based nature of sound.

The SMT program is heading into its 10th iteration in 2015 and has enrolled over 200 high school students to date. Each year, the curriculum is revised with new material, including significant contributions from graduate and undergraduate engineering students. These revisions are primarily based on student feedback and instructor observations during the activities. Student participants fill out surveys after each activity, providing feedback on how interesting and difficult the activity was, as well as how much the students feel they've learned.

2 Background

There exists a growing body of literature on the benefits of arts education on overall student performance, engagement, and other metrics[5]. 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 indicators[6]. Another longitudinal study found that a sample of honors STEM graduates were far more likely to have a strong arts background than average Americans, and these arts backgrounds strongly correlated with subjects holding patents and starting businesses[7].

In regards to music specifically, Howard Gardener's theory of multiple intelligences suggests that music may be one way that children relate to the world and learn from their experiences[8]. Moreover, Jeanne Bamberger's research has shown that studying coherent musical structure can provide contexts for better learning of basic and intermediate math skills, especially when taught through interactive media[9].

Drawing from this research, the STEAM (Science, Technology, Engineering, Arts, and Mathematics) philosophy realizes that a creative, artistic mindset must be encouraged in approaching problems in all disciplines. Rather than advocating for more compartmentalized arts programs, STEAM embeds elements of the arts in science curricula to avoid the implication that arts exist in isolation from the sciences. Studies of fully arts-integrated programs have thus far been small scale and qualitative, but have produced promising results. At the high school level, a California teacher has implemented a project-based STEAM program that has, in its second year of development, seen its popularity far exceed its capacity and achieved 50% female enrollment, with many students reporting they plan to pursue engineering in college[10]. At the university level, a computer systems technology program has seen improvements in students' application of art and graphic design principles to web interface design[11].

Furthermore, research in cognitive science indicates that arts integration not only promotes student motivation, but also may improve long-term content retention[12]. Toward these ends, we've developed a week-long STEAM education program for high-school students with several hands-on STEAM activities and modules, aiming to illustrate the interconnectedness of the arts and sciences through music technology.

3 Curriculum

Each summer, a group of 20-30 students from the Philadelphia area is admitted to the program, consisting of five six-hour days divided into four activity blocks. Throughout the week, eleven blocks are dedicated to structured activities where students get a hands-on lesson in a particular topic. An additional seven blocks are dedicated to individual student projects, which allow the students to explore an area they find interesting in greater depth than the time constraints of the activities allow. This gives students the opportunity to experiment and come up with ideas of their own to implement. Utilizing information, skills, and engineering vocabulary acquired in the activities, each student interactively designs a final project which is presented and demonstrated for their peers, parents, and instructors. A point of emphasis is for students to explicitly discuss key decisions and incremental developments throughout the week with regard to the iterative engineering design process: planning, analysis and design, testing, and evaluation.

Projects fall under one of four main categories, and within each group, students are encouraged to explore a topic they find interesting. *3D Printed Instruments* gives students a chance to explore the forefront of manufacturing technology and the iterative design process by creating musical instrument models or modifying existing ones in CAD software and testing the printed results. *Modular Synthesis* introduces students to the individual components used in both digital and analog synthesizers. Using the littleBits Synth Kits[13], we group components by function, showing which modules generate sound, which modify sound, and which control sound production. Finally, students can come up with their own configuration and work together to create a group performance. *Mechanical Music* provides a creative outlet for those students particularly interested in programming. Using an Arduino microcontroller with various instruments and household materials, students can write sketches to control motors and other actuators that play instruments algorithmically. Finally, *Interfaces* utilizes the MaKeyMaKey platform, which allows students to create custom musical controllers out of everyday objects such as fruit, toy cars, or even other students.

Activity Overviews

In 2012, the program underwent a major revision. In the past, most of the activities had relied heavily on the open source Pure Data graphical audio processing environment. Providing each student with a laptop proved increasingly problematic, so we have since re-designed each activity to utilize tablet computers and two custom applications in conjunction with several third-party

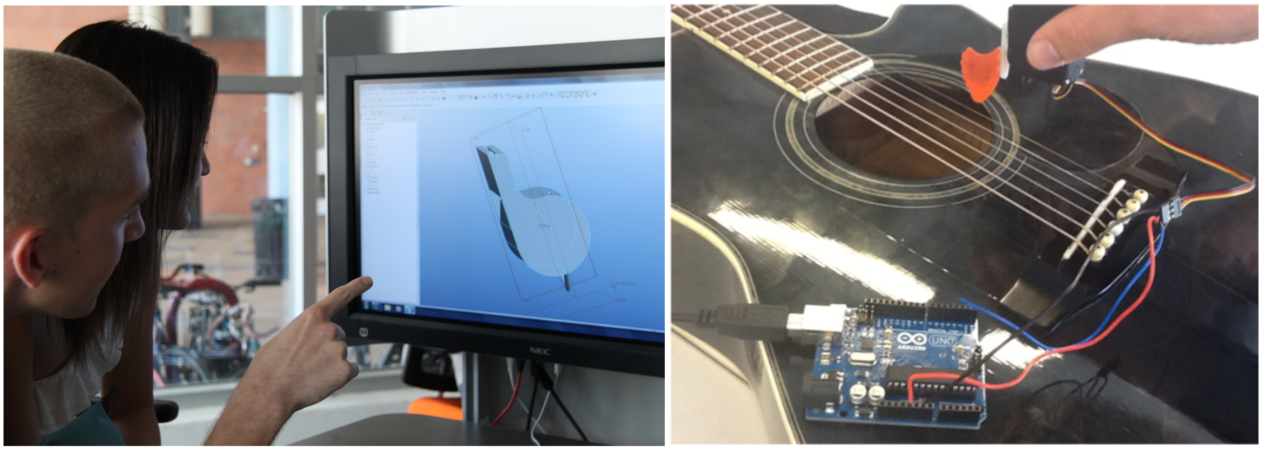

Figure 1: **Left**: An undergraduate instructor explains a CAD model of a whistle for the *3D Printed Instruments* project. **Right**: Students use servo motors controlled by an Arduino microcontroller to play a guitar in the *Mechanical Music* project.

applications. Each student receives an iPad at the beginning of the week which they use throughout each activity/module.

The custom applications, written and maintained by graduate and undergraduate engineering students, are designed to provide intuitive interaction and insightful visualizations of audio signal concepts. Currently, the two custom applications perform (respectively) analysis and effects processing, and signal generation. The analysis/effects app, titled *AudioWorks* is currently available in the Apple app store free of charge for the iPad[14]. The synthesis app *SoundSynth* will be released with *AudioWorks* as an app bundle in the near future, pending minor revisions.

Music Production

Music Production introduces students to the basics of sound recording, mixing, and editing in GarageBand for iOS. Students are initially provided with several songs in a multitrack format, including tracks for drums, bass, guitar, vocals, etc. They are encouraged to adjust levels, experiment with panning, and effects. They are also introduced to recording techniques to create their own sound effects (e.g., clapping and shouting), which can be mixed in with the existing tracks. Students are instructed on track editing, including cutting and looping sections of tracks, and are encouraged to make their own, original remix of one of the provided songs.

This activity requires no prerequisite knowledge, which makes it an excellent introduction activity for the week. Upon completion, students should understand basic music mixing concepts and be able to create their own unique song using pre-recorded tracks. Throughout the week, students are also encouraged to work on their remixes if they finish other activities with time to spare, with the option to demonstrate their remixes to the class.

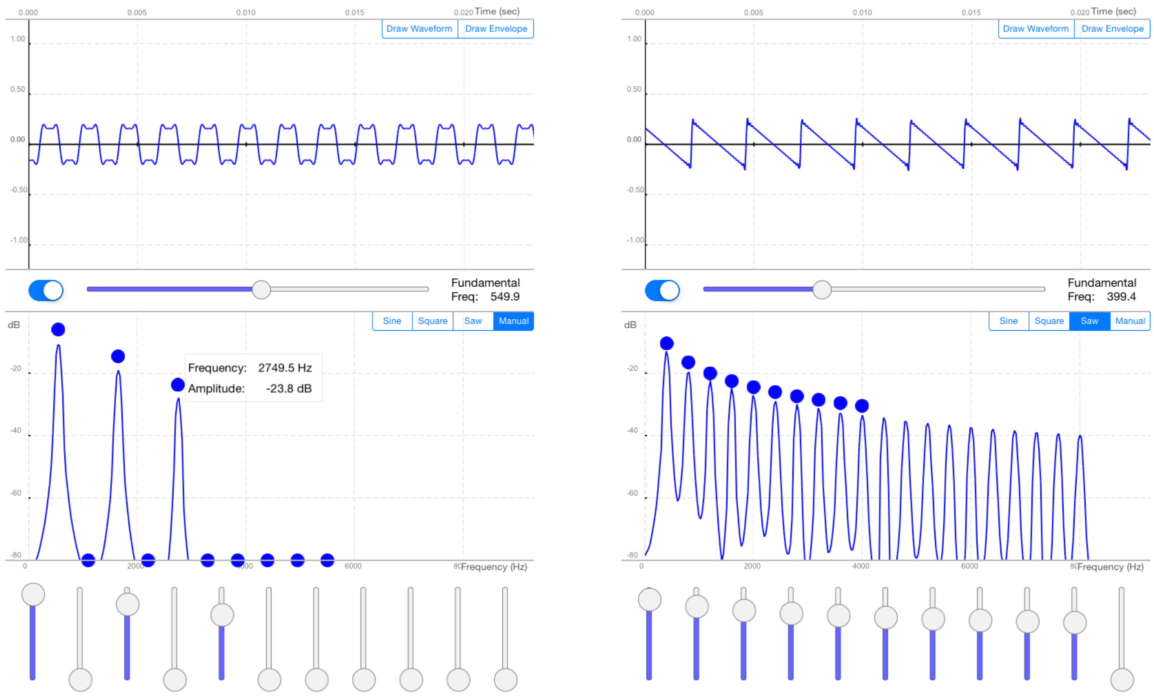

Figure 2: Synthesis app *SoundSynth* used in *Waves and Sounds*. Students begin to explore the sound and shape of periodic waveforms in the time and frequency domains by controlling harmonics individually (left) or using harmonic presets (right).

Waves and Sounds

Waves and Sounds allows students to explore the nature of sound. A short introduction teaches students the basic principles of sound using real-world examples. Afterwards, they learn how basic periodic signals can be created and visualized using *SoundSynth*, which functions as a variable frequency and waveform function generator, oscilloscope, and frequency analyzer. Students are also exposed to the frequency limits of human hearing and the concept of harmonics (overtones).

After this activity, students should understand the basic premise of Fourier's Theorem, that any periodic signal can be broken down into a sum of individual sinusoids. They should have an understanding of the basic parameters of a sinusoid (period, frequency, amplitude, etc.) and be able to explain the concept of a harmonic series.

Speaker Building

In *Speaker Building*, students learn the physical principles behind speaker operation by building a speaker from household materials. They are introduced to the concept of energy transduction, which in the case of speakers draws upon the familiar physical science principle of electromagnetism. Most students know that a direct current through a coil of wire creates a magnetic field. Building upon this, we demonstrate that an alternating current through the same coil creates a field that changes with the amplitude of the signal and constantly reverses its polarity, and by placing a permanent magnet inside this coil, we can create physical motion that is transformed into sound pressure via a diaphragm made from paper plates, cups, or bowls.

Students are given the materials to build their own speaker and test them by playing music from their mobile devices. Time permitting, they're also encouraged to iteratively re-design their speakers to obtain better results (e.g., better low-frequency response, sonic clarity). At the end of this activity, students should understand how electromagnetism is utilized in the translation of electrical signals to acoustic signals.

Musical Interfaces

Musical Interfaces is divided into two separate activities that allow students to explore the use of nontraditional, modern interfaces and computer-based instruments in music.

Part 1 requires laptops with the Pure Data (Pd) graphical audio programming environment with a custom synthesis patch designed to accept incoming Open Sound Control (OSC) messages for control. This part utilizes different hardware interfaces including a Nintendo Wii remote, a pressure-sensitive track pad, and others. Students are divided into groups, each group receiving one type of controller. Students learn how to connect these controllers (some wired, some wirelessly) to synthesizer parameters in a Pd patch (e.g., volume, pitch, carrier frequency, modulation frequency, etc.).

Part 1 tasks students with experimentally determining which parameter each control is modifying by listening to the changes in the sound. Each group then presents their findings to the class and demonstrates the use of their device. In the second half of the activity, students are allowed to customize their own interface by manipulating mappings from controls to synthesizer parameters. Before moving on to Part 2, students should have learned how to experiment with unknown items in a structured manner and convey their findings to others. They should also become familiar with the differences between discrete and continuous controls (e.g., buttons vs. sliders), and know how many degrees of freedom their controller allows.

In Part 2, students design their own custom interfaces with a third-party iPad application called TC-11 and decide what method of control makes intuitive sense for each synth parameter[15]. Students can access touch positions on a Cartesian or radial grid, accelerometer, compass, and gyroscope to control sound sources, filters, envelopes, LFOs, sequencers, and effects. At the end, students can demonstrate their synth patches and describe what modes of control they chose and why.

Musical Instrument Acoustics

Musical Instrument Acoustics is divided into two activities, the first of which uses variable-length PVC tubes to explore the concept of resonant frequencies and filtering. Speakers are mounted on one end of the PVC tubes, which are driven by amplified signals generated by *SoundSynth*. Students then use *AudioWorks* for analysis by recording the sound at the open end of the tube and observing the time and frequency domain waveforms for comparison with the input waveform. The tubes are driven with sinusoids of varying frequencies as well as white noise to observe

Figure 3: **Left**: Students measure resonant frequencies of a PVC tube in *Musical Instrument Acoustics* Part 1. **Right**: Students use what they've learned to explore the concept of timbre in Part 2.

resonant peaks in the tube's frequency response for different tube lengths. Students then learn to calculate predicted resonant frequencies for different PVC pipe lengths using provided equations.

The second activity extends this concept to actual musical instruments. Students use *AudioWorks* to analyze recordings from provided instruments including guitar, flute, piano, clarinet, violin, etc., or are encouraged to bring their own to analyze. Similarities and differences are explored between families of instruments. Students focus on how the instrument is actuated (e.g., pluck, bow, reed vibration, etc.) and its characteristic overtones. *SoundSynth* app allows students to synthesize a signal by replicating the instrument's harmonic content and drawing arbitrary amplitude envelopes to emulate the instrument's actuation.

This activity builds upon knowledge gained in the *Waves and Sound* activity. After *Instrument Acoustics*, students should have an understanding of the concept of acoustic resonance and frequency response, and should be able to explain the critical factors that make one instrument sound different from another.

Analog and Digital

Analog and Digital is a game-show format activity to teach students how computers store and reproduce continuous audio signals. A brief introduction explains the concept of a digital signal and why a computer cannot store continuous analog signals. Afterwards, students are divided into teams and the game begins. One student is asked to convey information about the shape of a waveform to the other using only discrete coordinates on a grid and various other stages of constrained description. The student's partner needs to draw the described waveform accurately. Pairs of students from each team compete to finish drawing their waveform before the other.

Before this activity, the students should have a basic understanding of waves. After the activity, they should understand the concepts of sampling and quantization, as well as the distortion produced by each. Time permitting, they learn about common sampling frequencies and why they are used in relation to the range of human hearing.

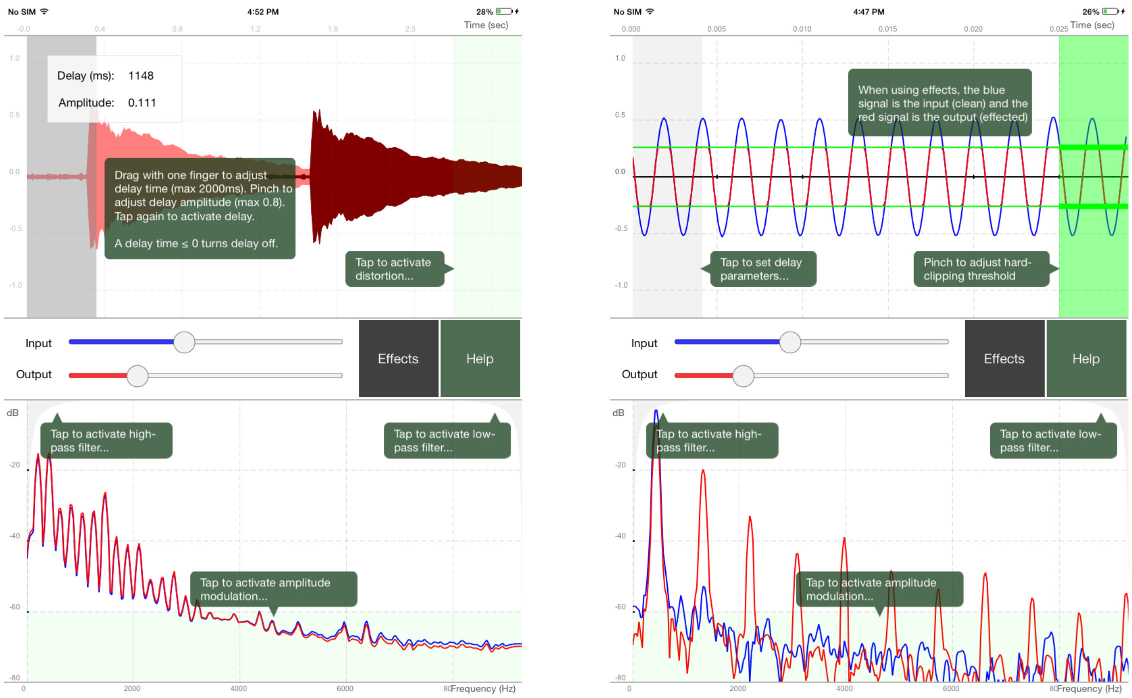

Figure 4: *AudioWorks* app used to apply effects to incoming audio. Showing help menu guiding control of delay (left) and distortion (right) effects.

Digital Sound Effects

Digital Sound Effects teaches students about several types of audio effects and how they are modeled digitally. The activity begins with a discussion of echoes and draws upon students' intuitions and common experiences (e.g., "Why does an empty room sounds different from the same room filled with furniture?"). We then lead a guided tour of various echoic environments near the main classroom, including areas with hard parallel surfaces creating flutter echoes, long hallways or stairwells producing long-decaying reverberations, and an anechoic sound booth. Returning to the classroom, students attempt to recreate each of these situations using an echo effect built into the *AudioWorks* app.

Following the echo portion, students are also introduced to the concepts of harmonic distortion via wave shaping by modifying a clipping threshold on a waveform display. Students are also able to apply low and high pass filters to incoming audio and modify their cutoff frequencies by pinching and zooming on the frequency domain plot. Finally, students can apply amplitude modulation to create ring modulator and tremolo effects. The *AudioWorks* app is designed so that each effect parameter is controlled in a visually intuitive way, and includes a contextual floating help menu that guides the user in manipulating effect parameters.

Students in this activity are also encouraged to bring their own electric instruments (guitar, bass, keyboard, etc.), which they can plug into the iPad via iRig adapter and use *AudioWorks* as a real-time effects processor.

Music Information Retrieval

In the final activity, Music Information Retrieval, students are introduced to the technology underlying modern music recommendation and playlist generation systems. Students are divided into groups and asked to generate playlists using methods similar to popular systems Pandora, iTunes Genius, and Last.fm. After the activity, students should understand how math and engineering are used to 'listen' to and organize music algorithmically. They should understand the differences in how popular services make recommendations and the advantages and disadvantages of each method.

4 Results

Pre-Survey

Student participants are asked to complete a general survey as the first activity of the program. The survey collects basic demographic information, as well as information regarding levels of interest and prior experience in math, science, and music. In 2012-14, we had a total of 69 students. Participants are selected to favor gender balance and priority is given to the School District of Philadelphia. Among the 69 were

• 25 female and 44 male students • 24 private and 45 public school students • 59 musicians (played at least one instrument), with 51 involved in band, choir, or orchestra.

All had taken algebra, 18 had taken trigonometry, and 10 had taken pre-calculus or calculus.

Post-Survey

Another general survey is issued at the conclusion of the program. This survey is used to gauge the overall perception of SMT and asks questions about which activities were most enjoyable in hindsight. When asked which activity the students enjoyed most, the most popular choice was *Music Production*, followed by *Analog & Digital*. The students were also asked about their opinion of their individual projects. Responses were collected on a five-point Likert scale.

Individual Module Surveys

In addition to the general surveys, students also complete brief surveys at the conclusion of each activity. All surveys in 2012-14 included the questions "Did you learn from this activity?", "Did you enjoy this activity?", and "Did you find this activity interesting?". Surveys from 2013-14 had additional questions "Was this activity challenging?" and "How creative were you feeling?" Results from each activity are summarized in Table 1, shown as means scores $\pm$ standard deviations. Note some activities did not permit enough time to get a significant sample of survey responses.

Students felt they learned the most from *Instrument Acoustics 2*, *Music Information Retrieval*, *Speaker Building*, and *Waves and Sounds*. Consistently among the most enjoyable are the game show-style *Analog & Digital* and *Music Production*. The most interesting were *Analog & Digital*

Q	A&D	DSFX	IA1	IA2	MI1
1	3.83 ± 0.95	3.53 ± 1.02	3.74 ± 1.06	4.14 ± 0.95	3.75 ± 1.01
2	4.39 ± 0.90	3.40 ± 1.01	3.16 ± 1.03	3.66 ± 1.00	3.73 ± 0.95
3	4.30 ± 0.94	3.44 ± 0.99	3.37 ± 1.02	3.74 ± 1.00	3.70 ± 0.96
4	3.49 ± 1.07	3.78 ± 1.35	3.27 ± 1.07	2.88 ± 1.02	3.80 ± 1.24
5	3.87 ± 0.97	n/a	3.30 ± 0.99	3.64 ± 0.97	n/a

Q	MI2	MIR	MP	SB	WS
1	3.83 ± 1.07	4.16 ± 0.88	3.56 ± 1.04	4.13 ± 0.96	4.24 ± 0.88
2	4.06 ± 1.07	3.98 ± 1.04	4.20 ± 0.90	3.98 ± 0.99	3.86 ± 0.92
3	4.12 ± 1.07	4.07 ± 0.91	4.05 ± 0.97	4.25 ± 0.94	4.09 ± 0.89
4	4.09 ± 1.30	2.92 ± 1.10	3.04 ± 1.07	3.50 ± 1.01	2.90 ± 1.08
5	n/a	3.96 ± 1.02	4.00 ± 0.99	3.57 ± 1.08	3.73 ± 0.96

Table 1: **Activity Codes**: Analog & Digital, Digital Sound FX, Instrument Acoustics I-II, Musical Interfaces I-II, Music Information Retrieval, Music Production, Speaker Building, Waves & Sounds. **Questions**: 1) Rate how much you learned, 2) Rate how much you enjoyed this activity, 3) Rate how interesting this activity was, 4) Was this activity challenging? 5) How creative were you feeling?

and *Speaker Building*. Students felt the most challenged by the *Speaker Building* activity, and felt the most creative during *Music Production*.

In addition, we also examined the effects of gender, musical experience, and public school vs. private school students.

While activity ratings varied across the male-female as well as public-private school divides, no major trends were observed, though this data collection is ongoing and may show more significant trends in the future. As of now, it appears the SMT activities have a wide appeal across these groups. The data does show non-musicians indicating they learned more on average (across all activities) than musicians, though the musicians found the activities slightly more interesting, likely as a product of prior interest.

Q	Male	Female
1	Instrument Acoustics 2	Music Information Retrieval
2	Instrument Acoustics 2	Analog & Digital
3	Speaker Building	Music Information Retrieval
4	Music Production	Music Production
5	Music Information Retrieval	Music Information Retrieval

Table 2: Highest activity scores by gender.

Q	Musicians	Non-Musicians
1	Speaker Building	Waves & Sounds
2	Analog & Digital	Music Production
3	Speaker Building	Music Production
4	Analog & Digital	Instrument Acoustics 1
5	Music Information Retrieval	Music Production

Table 3: Highest activity scores by musical experience

Q	Public	Private
1	Instrument Acoustics 2	Music Information Retrieval
2	Analog & Digital	Analog & Digital
3	Speaker Building	Analog & Digital
4	Analog & Digital	Analog & Digital
5	Music Production	Music Production

Table 4: Highest activity scores by school type

5 Conclusions

The activities presented in this paper have been used eight times with improvements made on each iteration based on feedback from students and instructor observations. Each activity focuses on a specific set of musical and STEM concepts. Minimal background knowledge is required for the activities and any prerequisite material is covered in lesson overviews. Students have indicated through the surveys that they both learn from and enjoy the activities, and these results remain relatively constant across gender lines and socioeconomic backgrounds. Additionally, presentations and discussions between students and instructors show that they do gain understanding of the concepts and are able to communicate this understanding.

The activities are portable enough to be used as part of another program or high school curriculum. Several modules have been successfully incorporated into the Philadelphia Franklin Institute's STEM Scholars Program [3], as well as several Philadelphia high schools through the NSF GK-12 Program [4], with student feedback in both programs providing comparable results, indicating that general population students demonstrate universal interest in music technology, regardless of prior musical experience and STEM backgrounds.

Future work will continue to improve the activities. In particular, modification of modules and projects to better fit within allotted times. We are also working on porting each of the custom iOS applications, which are in a continual state of development, to a web-based platform to make them available on a wider range of devices.

Acknowledgements

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