STEAM Education through Music Technology (Evaluation)

Dr. Brandon G. Morton, Drexel University

Brandon Morton received his Ph.D. in Electrical Engineering from Drexel University with a focus on Music Information Retrieval. His work focused on the prediction and detection of influence between musicians. Additionally, as a post-doctoral researcher, he is currently interested in the relationship between mobile technology and education. His background in education includes a NSF GAANN Fellowship and a NSF GK-12 Fellowship.

Mr. Jeff Gregorio, Drexel University

Jeff Gregorio is currently pursuing a PhD in Electrical and Computer Engineering at Drexel University. He received his BSEE from Temple University in 2011, and MSEE from Drexel in 2013. In 2012, he received the NSF-funded GK-12 Fellowship, for which he designed activities for Philadelphia high school students illustrating the connection between the arts and the sciences, to catalyze interest in STEM/STEAM. Jeff currently studies under Dr. Youngmoo Kim in Drexel's Music Entertainment Technology lab, pursuing research in novel musical interfaces and machine learning applications in music information retrieval.

Mr. David S. Rosen, Drexel University

David Rosen is a doctoral student in Drexel University’s Applied Cognitive and Brain Sciences program. He has an M.S degree in Teaching and Instruction and several years of experience as a public school educator. Working in the Music and Entertainment Technology (MET-Lab) and Creativity Research Lab, his interdisciplinary research explores the underlying cognitive mechanisms and factors of creativity, expression, insight, and flow, specifically within the domain of music performance and improvisation. He has also worked on several research projects which attempt to infuse, design, and evaluate various pedagogical methodologies to enhance creativity and creative problem solving in the classroom.

Richard Vallett, Drexel University

Richard Vallett received a B.S. degree and M.S. degree in mechanical engineering from Drexel University in 2012. He is currently pursuing a Ph.D. in Mechanical Engineering from Drexel University. His research includes robotics, control systems, and functional fabrics.

Prof. Youngmoo Kim, Drexel University, ExCITe Center

Youngmoo Kim is director of the Expressive and Creative Interaction Technologies (ExCITe) Center and an associate professor of electrical and computer engineering at Drexel University. He also serves as Resident Technologist for Opera Philadelphia. He received his Ph.D. in media arts and sciences from MIT in 2003 and also holds master’s degrees in electrical engineering and music (vocal performance practice) from Stanford University as well as a B.S. in engineering and a B.A. in music from Swarthmore College. His research group, the Music & Entertainment Technology Laboratory (MET-lab), focuses on the machine understanding of audio, particularly for music information retrieval. Honored as a member of the Apple Distinguished Educator class of 2013 and the recipient of Drexel’s 2012 Christian R. and Mary F. Lindback Award for Distinguished Teaching, Youngmoo also has extensive experience in music performance, including eight years as a member of the Boston Symphony Orchestra’s Tanglewood Festival Chorus.
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Introduction

For the past 10 years, the Music Entertainment Technology Lab (MET-Lab) at Drexel University has hosted the Summer Music Technology Program (SMT) for rising high school freshman and sophomores with the goal of increasing interest in STEM-related fields through the use of music technology. By using music, a medium many students have a high degree of familiarity with, we are able to explain engineering concepts in a way that is engaging and also has a tangible impact on students’ lives. This is the integrated approach of STEAM (STEM + Arts & Design): by learning how, for example, the instruments they play produce and create sound and how the music services they listen to on a daily basis recommend music and relating those topics back to the content they learn in their math and science classes in school, we are able to motivate and catalyze interest in engineering.

Using music and its accompanying technology as a tool for increasing interest in the sciences has been explored before by a number of researchers. Jeanne Bamberger’s work showed that students are able to better learn basic and intermediate math skills when they are also studying coherent musical structure [1]. Scott Douglas developed a high school curriculum incorporating digital music and audio synthesis as a tool to increase student interest in mathematics and science [2]. Douglas was motivated by the belief that everyone in modern society needs to be technically literate and that introducing primary- and secondary-level students to engineering design principles is the best way to accomplish this goal. In more recent work, Mahadevan et. al, developed EarSketch, a web interface for helping its users, primarily high school students, learn about computer programing by creating digital music within a web-based programming environment [3]. By engaging the students with culturally relevant topics (music and its creation), the creators of EarSketch have been able to teach over 10,000 high school students basic programming skills. All of these educational endeavors made use of students familiarity with music to increase students technical literacy and interest in STEM fields. Encouraged by the scope and impact of these and other STEAM related projects, our program has continued to iterate and improve upon our own novel efforts and distinctive approaches to using music technology to motivate interest in STEM fields, particularly engineering.

SMT is a week-long, non-residential program where students are guided through several activities throughout the week, all centered around audio and music technology [4-7]. Additionally, SMT seeks to maximize student interaction with the material they are exploring. Therefore, lecturing is minimized (most activities are limited to a 5 minute brief introduction to a topic before the students begin hands-on activity). Every student is loaned an iPad for use during the week, and most modules integrate our custom-developed app, AudioWorks (which we also make available for free via the App Store). This app, explained in detail in the next section, acts as a tool to help students visually and aurally explore audio. At the end of the first day of the program, students are also presented with four project categories they can explore through a week-long individual project. The four categories are predetermined and allow students the opportunity to explore a particular topic they are introduced to over the week in greater depth. These projects are where the engineering focus on our summer program is heavily emphasized,
and at the end of the week students present their projects, which are also integrated within one of three musical performances.

Students are introduced to various mathematical and scientific concepts in each of the activities and projects, and STEM components are reinforced throughout the week through all activities. SMT has been revised each year to incorporate the very latest technologies, making sure that students have access to and are instructed using tools and methods they could potentially encounter in later STEM studies and careers. Also, during each activity, and with special emphasis in the week-long projects, we encourage students to complete their projects using the framework of the engineering design process (EDP). It has been shown that using the EDP as a guide for students during their projects is an effective tool in K-12 environments [3]. In particular, we stress the importance of iterating and improving their initial prototypes based on results from testing their designs.

AudioWorks: Custom-Developed iPad App for SMT

*AudioWorks* is a custom application designed—specifically for the Summer Music Technology program—to help students develop a strong visual intuition for the physical parameters of sound production and modification [8]. The app affords the essential functionality of a basic oscilloscope (time domain plot) and spectrum analyzer (frequency domain plot) in three modal contexts: audio analysis, synthesis, and effects. All three modes afford intuitive gestures, such as pinch zooming and panning on the two main views, with the time domain plot capable of displaying waveforms at scales ranging continuously from tens of milliseconds up to three seconds, and the frequency domain plot showing an averaged spectrum over the currently visible portion of the time domain plot.

![AudioWorks Screenshots](image)

*Figure 1:* Screenshots of *AudioWorks* app. Right screenshot is of *Effects* mode, center is of *Synthesis* mode, and the left is of *Analysis* mode.

*Analysis* mode is used primarily for exploring time and frequency domain visuals of recorded sound, to illustrate how sounds can be distinguished by their temporal characteristics as well as frequency content. Students can zoom into time-domain segments of a recorded sound and pan...
through to see how the frequency content of the visible segment changes over the duration of, say, a single note recorded from a piano or a spoken word.

*Synthesis* mode puts the visual emphasis on sinusoidal additive synthesis, offering control over fundamental frequency and ten harmonics, plus white noise. The interface for controlling harmonics is intended to reinforce their underlying nature as whole number multiples of the fundamental. Each harmonic control appears as a controllable dot in the frequency domain plot, overlaid at the associated spectral peak. Touching down on the control overlays a view that moves with the control, showing the frequency and amplitude of the harmonic. Increasing the fundamental frequency expands the spacing between the harmonics, with some of the upper harmonics going beyond the bounds of the plot. Custom drawing also affords students the ability to draw single periods of arbitrary waveforms and re-synthesize them at different pitches, as well as draw arbitrary amplitude envelopes.

*Effects* mode is used to offer the same strong visual link between system parameters and underlying concepts in the context of sound manipulation. Like *Synthesis* mode, controls are overlaid on the time domain plots in ways that directly relate to how the effect modifies the signal. Delay is manipulated by moving a control point directly in the time domain plot. Adding and manipulating this control temporarily overlays a copy of the currently displayed waveform, time-shifted to start at the control’s horizontal position, visually emphasizing how a system delay creates a copy (echo) of a sound source. Likewise, low-pass and high-pass filters are implemented as a control handle whose horizontal and vertical position controls the cutoff frequency and resonance, respectively, with the actual frequency response curve being updated and displayed in real time. Similarly, the app also includes controls for amplitude modulation and distortion. Input (dry) and output (wet) signals are plotted simultaneously in different colors.

*AudioWorks* was revised in 2016 to included an on-screen keyboard to control the additive synthesizer’s fundamental frequency, useful for a number of activity modules. This revision also introduced handling of MIDI input including note on/off messages, program changes, and continuous control and aftertouch messages that can be mapped to parameters in Effects mode, a feature primarily useful to students opting to design custom MIDI controllers as their week-long project. The app contains an enormous amount of signal processing capability, but each revision has focused on making the user interface as simple and intuitive as possible, to emphasize the connection between signal and system concepts and their prominent role in music and sound processing. We have made the app available as a free download via the App Store, and it is actively used by both educators (as early as third grade) as well as professional musicians.

**Summer Music Technology Activities**

**Waves and Sound**

The Waves and Sound activity is a pre-requisite for many of the lessons throughout the week of SMT. This activity introduces the students to the idea of waves, their properties, and how those properties are related to our perception of sound. The participants are given a brief introduction to the properties of waves (amplitude, frequency, period, and wavelength) and then given a worksheet which guides them through several activities. These activities focus on manipulating these wave properties, using the *AudioWorks* app for sound analysis and synthesis, and determining how they change the perceptual quality of the generated audio. In addition, students
are able to gain an understanding of these wave properties, by examining the visual displays of the waveforms provided by AudioWorks.

After students gain a basic understanding of the properties of the waves, the activity then goes on to explore the effects of combining multiple waves to create more complex waveforms (sawtooth waves and square waves). During this activity, it is stressed to the students that all signals are just combinations of simple sine waves. Students are also introduced to the harmonics of a frequency, which are frequencies that are integer multiples of the fundamental frequency of a wave. This activity concludes with students participating in a group activity, where each student is asked to use their individual iPads to generate a sine wave with a frequency of a harmonic they are assigned (i.e., Student A generates a 100 Hz tone, Student B generates a 200 Hz tone, etc.) in an attempt to prove that their individual contributions contribute to the resulting more complex tone generated from all of their iPads.

**Speaker Building**

Speaker Building is an introductory activity that tasks students with building their own speaker using household materials. During a short introduction, an instructor leads a discussion about the nature of sound, namely that it is being produced by periodic vibration of physical objects, motivating the use of a paper plate as a speaker diaphragm. The discussion then shifts to electricity and magnetism contextualized as a way to produce physical vibration of the diaphragm. Drawing on most students’ familiarity with electromagnets, we review how a direct current traveling through a conductor produces a magnetic field, and introduce the idea that that the field strength and direction is proportional to the amplitude and direction of an alternating current. With the aid of keynote animations, we show an electromagnet with a changing field interacting with a permanent magnet, producing periodic motion.

![Students coiling their wires for the Speaker Building activity](image)
Students are then provided with magnet wire, strong neodymium magnets, index cards, masking tape, scissors, and choose a diaphragm material from several options of disposable plates, bowls, and cups (styrofoam, heavy and light paper, plastic, etc.). Once completed, students test their speakers using a Hi-Fi power amplifier and music from their mobile devices. Time permitting, the students are also encouraged to iteratively re-design their speaker for a range of improvements (better high or low frequency response, reducing rattle, better resting alignment of permanent and electromagnets, etc.), which includes rebuilding the suspension and trying different diaphragm materials. At the end of the activity, students should be familiar with the concept of energy transduction, more specifically understanding the role of electromagnetism in the conversion of electrical energy to acoustic energy.

**Music Information Retrieval**

The Music Information Retrieval activity is a unique effort leveraging our group’s highly specialized research expertise to develop an activity appropriate for high school students to help them understand how modern music services such as Pandora, Apple Music, and Spotify operate. Groups of students are asked to use varying techniques to create a playlist of songs from a pre-determined pool of music. Before the activity, students are given a brief introduction to the motivation behind popular music services. These services typically have music recommendation functionality to help users find new music and develop playlists to group this music together. After this introduction students are split into one of four groups and given 20 pre-determined songs, an initial song that will be the first song in all groups’ playlists, and instructions for how to develop their playlist. A facilitator is assigned to each group to help throughout the activity. The groups and a description of their instructions are listed below.

- **Manual Group** - This group of students are given very little initial instruction when developing their playlist. They are encouraged to discuss their choices and come to a group consensus. This is meant to represent using previous knowledge and experience with music to generate the group playlist. This method simulates gathering music recommendations from friends or, in the past, record shop employees.

- **Tags Group** - Each student in the group is asked to listen to a different subset of the 20 songs and write down three to five simple, descriptive statements about the music (e.g., Danceable, Has guitars, Sounds whimsical, etc.). Students then aggregate this information for all of the songs. They are then asked to look for songs that have similar tags to the previous song in the playlist that are not already included. This simulates sites like Last.fm, which collect user-provided tags and look for similarities between them to suggest music.

- **Small Playlists Group** - Each student is given 10 different subsets of five songs (each subset is different) chosen from the pool of 20 songs. The students are then asked to individually order these songs in a playlist. Once this is finished, students are asked to find all the playlists with the previous song and then list the song that directly follows it. The song that is listed the most times throughout the group is added to the group playlist as the next song. This process is repeated until the playlist is completed. This group is using techniques to simulate collaborative filtering, which is used by services like Apple Music.
• **Features Group** - Each student is given a subset of the 20 songs and asked to rate each song on a scale from 1 to 5 on various musical features (e.g., Hip-Hop Influences, Strong Female Vocals, etc.). The students then put their values onto a spreadsheet, where they are averaged. The most similar song to a previous song is calculated using a simple Euclidean distance metric and then the appropriate song is added to the playlist. This group is simulating sites like Spotify which use a combination of extracted audio features and meta-data to recommend music.

After each group has finished their playlists, they are publicly played and then discussed by the students. At the end of this activity, students should have a better understanding of how music recommendation services work.

**Acoustic Resonance**

The Acoustic Resonance activity introduces several concepts that are fundamental to understanding how sound is produced in musical instruments. In this activity students are asked to take measurements of audio, using the analysis capabilities of the AudioWorks app, produced from acoustic tubes. Students should be able to experimentally determine resonance frequencies using electronic equipment (speaker, function generator).

In this activity, students are provided with a large PVC tube (one tube of a smaller diameter is inserted into a tube with a larger diameter so that the length of the overall tube can be varied) and materials, such as a tape measure and microphone, to measure the tube and the audio it produces. A worksheet guides the students through several exercises where they explore the idea of resonance and how tubes with different properties (lengths, open/closed ends, etc.) can support only certain wavelengths of acoustic pressure waves.

At the end of this activity, students should be able to correlate and verify experimentally determined resonance frequencies with theoretical calculations. Ultimately, students should be able to explain what resonance is, what causes it, and how it relates to instruments.

**Modular Synthesis**

While many SMT participants have musical backgrounds that include keyboards and synthesizers, very few are familiar with the building blocks that are used to create, modify, and control sound. The Modular Synthesis activity is built on the littleBits Synth Kit, which is a fully functional modular synthesizer, where connections are made by snapping modules together directly, rather than with patch cables [9].

A short introductory discussion centers on students’ experiences with keyboard and other synthesizer instruments, and touches on the origins of analog synthesizers, and how sample and preset-based synths trade flexibility for ease of use compared to manual control and modularity. The activity then unfolds as a guided experimentation, introducing modules in sequence: sound producing modules (oscillator, noise), followed by sound controlling modules (keyboard, sequencer), and finally sound modifying modules (envelope, filter, delay). Introduction of many modules benefits from projecting real-time time and frequency domain plots of the signal using the AudioWorks app, for example showing how the ‘wah’ sound produced by sweeping the filter is produced by the introduction of upper harmonics as the filter cutoff is increased. Explanations
are kept intentionally brief to allow as much time as possible for reconfiguration and other experimentation.

At the end of this activity, students should know that a synthesizer is a system made of smaller sub-systems, and should know the key differences between producing and modifying sound, and that synthesizer modules communicate with both audio and control signals. Students should also become familiar with the idea of iterating on their initial design based on new knowledge acquired through testing and evaluating their devices, an integral component of the Engineering Design Process.

**Musical Instrument Acoustics**

Musical Instrument Acoustics builds on fundamentals introduced in Waves and Sound, and the idea of resonant frequencies introduced in the first instrument acoustics activity, and introduces the idea of analysis and digital synthesis for approximating the timbre of acoustic instruments. The activity requires a number of instructors familiar with the basic physical principles governing at least one instrument. Students split into groups of 4-5 and rotate to stations for a short discussion and analysis-synthesis activity centered on a single instrument, including guitar, flute, piano, clarinet, violin, etc.

The discussion also explores similarities and differences between families of instruments, focusing on how the instrument is actuated (e.g. plug, bow, reed vibration, etc.), and how the geometry of the instrument dictates its resonant frequencies, producing characteristic overtones.
Using AudioWorks, students are then able to take a short recording of the instrument which shows how the amplitude evolves in the time domain, and what harmonics are produced in the frequency domain. The app also allows the students to synthesize an approximation of the instrument by attempting to match the relative amplitudes of the instrument’s harmonics by adjusting amplitudes of 10 harmonics of the additive synthesizer, and by tracing out an amplitude envelope to match its attack and decay characteristics.

Students should come away from this activity knowing two important factors that contribute our ability to distinguish the sounds of different instruments, namely harmonic content in the frequency domain and amplitude envelope in the time domain, and how these relate to the excitation and resonance of a physical system.

**Sound Effects**

Digital Sound Effects explores in greater depth some of the concepts introduced in Modular Synthesis, namely how sound can be modified, but now in the digital domain. The activity begins with a discussion of echo, drawing upon students’ intuition and common experiences (e.g. “Why does an empty room sound different from a room filled with furniture?”). Students are then led on a short walk around to various rooms with different echoic properties, including high ceilings with hard, reflective floors creating a flutter echo, a long hallway or stairwell that produces reverberations with a gradual decay, and finally an anechoic sound recording booth.

Following the walk, students return to the main classroom and attempt to recreate the different environments they explored using a multi-tap delay effect built into AudioWorks. Three other effects in AudioWorks are also briefly introduced: harmonic distortion, low and high-pass filters, and amplitude modulation. For this activity, students are encouraged to bring their own electric instruments and use the iPad running AudioWorks as an effects processor, which provides a unique opportunity to visually relate the sound of various effects to how they modify an instrument signal in the time and frequency domains. The goal of this activity is to facilitate a deeper understanding of the effect than one can get by turning a knob on a stompbox.

**Analog & Digital**

Analog & Digital is a novel “game show”-style activity where students are introduced to how computers encode analog signals so they can accurately and reliably store and transmit information. The game is “reverse Pictionary” where, rather than trying to guess what is being drawn, teams try to direct what to draw. Students form two competing teams, designating one student per round as the ‘artist,’ who attempts to draw a given waveform on a whiteboard using only verbal instructions from their teammates. Each team attempts to draw the same waveform at the same time, and when time runs out, a judge decides which team drew the more accurate representation of the waveform.

Aside from the waveform that students reference when instructing their partner to draw, the worksheet also has instructions which limit the information that students can give to the artist. For example, in the first round students can use any words to describe the waveform, but they cannot use numbers. In the following rounds, speakers can use words except for a list of keywords that were prohibited which changed for each round. We’ve found this to be a very engaging, competitive, and entertaining activity for the students. The results are often highly
amusing, but emphasize the difficulty in accurately conveying complex information while highlighting effective strategies derived from basic signal processing and information theory.

**Week-Long Projects**

**Hardware Hacking**

Hardware Hacking allows students with an interest in sound effects and synthesizers to explore at a lower level how they can be implemented using electronic components, and how these circuits can be prototyped on a solderless breadboard. The project is based on several circuits detailed in *Handmade Electronic Music: the Art of Hardware Hacking* by Nicholas Collins [10]. The project is introduced on Monday and spans the remainder of the week. Project time on Tuesday and Wednesday are spent introducing two basic building-blocks: a simple square wave oscillator using a CD40106 CMOS inverter, followed by a preamplifier circuit based on the CD4049 inverter.

In lieu of an abstract introduction on definitions of a resistor, capacitor, Ohm’s law, etc., these concepts are contextualized using the problem of building a self-oscillating circuit using an inverter gate (one of six on the CD40106), with the capacitor serving as a reservoir of charge that is periodically filled and discharged at a rate controlled by a resistor. The solderless breadboard is introduced as the students are provided with their components and encouraged to experiment with different capacitors and fixed resistances. Variable resistance is also introduced and contextualized as a means of controlling the oscillator’s frequency dynamically, and students are provided with potentiometers and resistive sensors for experimentation, including photoresistors, thermistors, flex sensors, and force sensors.

The CD4049 preamplifier circuit shows how sound can not only be produced, but modified, in this case by increasing the amplitude and distorting. Though feedback in electronic circuits is a difficult concept to grasp without any formal background, students are still able to observe that they can affect the gain of this particular amplifier using a feedback resistor, and affect the frequency response using a feedback capacitor. The idea of a multi-stage preamplifier is also introduced, where students learn that a single stage with high gain will distort more harshly than
multiple stages with lower gain, and that changing the frequency response in an earlier stage can have a larger effect than changing it in a later stage.

Following the introduction of the two basic building-blocks, students are presented with several simple, yet practical sound effects they can make that utilize one or both blocks. Students can opt to make a multi-stage distortion effect, a tremolo, stereo panner, ring modulator, or an octave generator. Each effect has an associated handout that shows multiple versions of the effect, each version adding a feature and increasing in complexity. The remainder of the week’s project time is then devoted to building and debugging these effects on a breadboard. Any students building the tremolo or panner circuits are also guided through the construction of a lo-fi optocoupler using an LED and photoresistor coupled together using heat-shrink. Any students building the octave generator are introduced to the CD4040 Binary Counter.

This project serves as a crash-course in basic circuit concepts and components, breadboard prototyping, and reading circuit diagrams. At the end of the week, students give short presentations detailing how their effects work. They’re encouraged to communicate this by tying concepts back to basics learned in the week’s activities, and most importantly by keeping the discussion high-level and concise. Toward this end, students are shown how their project schematics can be subdivided into blocks that perform a high-level function like producing a square wave or multiplying signals.
Mechanical Music

Mechanical Music is a project of SMT that involves high school students designing and constructing automated instruments using Arduino-based microcontrollers and actuators. Instruments may range from simple percussive instruments (drums, tambourines) to actuating a full-sized electronic keyboard or building their own instruments entirely. The learning outcomes for the project are a basic understanding of mechanisms, simple circuits, and programming logic. The educational backgrounds and experiences of students varies greatly; students sometimes enter the program with a working knowledge of Arduino programming or experience with building circuits or using K’NEX but sometimes have no experience in any relevant area.

On the first day of the program, the project leads show students examples of previous student work or demonstrations that give students an idea of what they can or are expected to accomplish within the five-day period. Students are asked about their musical interests, what instruments they play, or what songs they would like to have an instrument play. The instructors use this time to gauge the skill level of the student and help them develop a clear understanding of their project. Instructors then engage the students with the first steps of the Engineering Design Process. The students know that they will be responsible for building a device which can participate in a musical performance at the end of the week. Throughout the week, they are given more information about the problem, such as which notes, or what musical role (mimicking a bass guitar, developing a drum pattern, etc.) they will be expected to play. Students are then encouraged to sketch out ideas for their actuated instruments or verbally explain how they intend
for their instruments to perform. The instructors then fill in the technical gaps pertaining to how their designs would physically work or what designs would be feasible to create.

Iteration of the design and testing phases are largely left up to the students. If an instructor notices that a student is stuck on a particular facet of a design, then he or she will offer advice. The students are encouraged to quickly prototype ideas to see what will or will not work. The reasoning is to have them perform “sanity-checks” on their concepts and experiment with as many ideas as possible to observe which designs work best.

Students use simple actuators like hobby servos or low-power solenoids to actuate their instruments. Students primarily use K’NEX to create the structure around their instruments, though other building materials are available. To interface the K’NEX with servos or solenoids, K’NEX-like adapters are 3D printed to allow students to easily connect the actuators to their designs. Breakout boards for the servos and solenoids are provided to the students to allow them to easily connect the devices to power and to break out the control connections to the microcontroller.

Students are taught how to code in Arduino/C++ using both built-in examples in the IDE and from instructor-written examples that are more specific to the project. Students who have prior programming experience find it easier to adapt existing examples or to write their own code. Students who are new to coding are encouraged to dictate to the instructors how they would like for their project to perform. The instructors then walk the student through writing the code and explain the logic behind the code. Students are taught about logic structures like loops and conditional statements and are able to compose a song within their code.

One new component that was incorporated into the project this past year was the LightBlue Bean. The LightBlue Bean is an Arduino-based Atmel 32U4 Bluetooth-enabled microcontroller that can be programmed from an IDE app on the iPad. The board includes a built-in 3-axis accelerometer and tri-color LED. Students were encouraged to use the accelerometer to add an extra element of interactivity into their projects. For instance, a student’s project used the LightBlue Bean’s accelerometer to detect a shaking motion and activate a solenoid to strike a drum.

**Custom Controllers**

Custom Controllers introduces students to the world of microcontroller programming in the context of building custom MIDI instrument controllers. We use the Teensy 2.0, a USB-based development platform for an 8-bit AVR microcontroller. Though Arduino microcontrollers like the UNO are the more ubiquitous platform for AVR microcontroller development, the line of Teensy development boards can also be programmed using the Arduino IDE and offer a reconfigurable “USB Type” option that simplifies the creation of fully class-compliant MIDI devices over USB. This allows the Teensy to easily control a software synthesizer in a digital audio workstation like Garageband, FL Studio, etc., or synthesis and effects parameters in AudioWorks.

The project begins with a general introduction to MIDI (Musical Instrument Digital Interface), emphasizing the role of MIDI as a control signal for a synthesizer, rather than the resulting audio signal itself. While MIDI provides the context, the project proceeds to cover many aspects of microcontroller programming that have wide applicability to other types of projects. An
overview of physical computing and microcontroller applications provides some scope for the wide-ranging utility of skills that students can learn over the course of the project.

Concepts covered include Ohm’s law, variable resistance and voltage division, analog to digital conversion, serial communication, as well as basic C programming. Students learn how to interface with switches, buttons, and analog output sensors like accelerometers and gyroscopes, light, temperature, and force sensors, rotary potentiometers and joysticks. Student projects have ranged from single note and sample triggers, to simplified chord producing interfaces—setting a root note with one of an array of buttons, and the chord quality (major, minor, dominant, etc.) with the position of a joystick—to multi-step sequencers with rate controls. These projects have a high potential for integration with one of the musical performances, and have even allowed students to create interfaces that allow them to easily perform musical parts that would otherwise be difficult to perform on a traditional instrument.

Amazing Apps

This project topic focuses on developing simple applications for the iPad using Swift Playgrounds, an app released (in beta) in June 2016 (just a few weeks prior to the start of SMT 2016, emphasizing how seriously we approach the incorporation of emerging technology). This app allows users to code and interact with applications directly on the iPad which enabled
students to learn about programming with hands-on examples that they could manipulate, and also design their own applications.

Students were first introduced to the environment with a simple piece of code that had them create buttons which changed color when pressed. This simple application allowed students to learn some basics of programming, namely creating variables and arrays (a structure for storing data) as well as some more advanced topics such as the concept of object-oriented programming and developing meaningful graphical user interfaces. Next, students were asked to use their newly acquired skills to create a simple sound board, an app where four buttons triggered four different drum samples.

After students went through these introduction activities, they were then allowed to develop their own applications. Some of the students continued to work on their samples and adapt them for use in their performance in the musical performance they were assigned. One student developed a game that helped players learn the difference between major and minor chords and another student went on to develop an audio sequencer, or an app that periodically triggered a series of audio samples.

**Presentation Showcase and Technology-Infused Musical Performances**

In 2015, SMT introduced technology-infused student-performed musical numbers, which are interspersed during the project showcase for parents, family, and friends on the final day of the program. In addition to giving a 5-minute presentation and demonstration of their individual projects, each student, regardless of their musical training, participates in one of three song groups. Ultimately, this is achieved by allowing students to take on various roles. While some students contribute in more traditional musical roles (i.e., instruments and vocals), other students participate in non-traditional roles, adapting and modifying their projects for a specific musical purpose.

The decision to include music performances in the program was made for a variety of reasons. First, the majority of students who attend SMT are enthusiastic and eager to learn about music; however, a significant portion do not have formal music training and have never had the opportunity to play music in a group setting. Furthermore, several student surveys from previous years indicated that they thought there would be more music during SMT. Therefore, we view the inclusion of technology-infused music performances as a creative and fun outlet which seamlessly merges STEM with the arts in the form of a group concert. Additionally, a fundamental aspect of our STEAM teaching philosophy is that all students can be creative and musically expressive with a minimal amount of experience, yet this creativity may unfold in disparate forms depending on the student. Although this concept is reiterated throughout the week in the activities and projects, we decided that live musical performances would best exemplify this idea, and that highlighting the music in Summer Music Technology would significantly enhance the SMT experience.

Another goal of the musical performances is to incorporate as many student projects as possible into each song. This gives students the opportunity to discover novel and useful music applications for their projects, further reinforcing STEAM concepts, specifically that music can come in many different forms when merged with technology, engineering, math and science. Since each student creates a different project within one of four different project categories, we
are able to form unique student ensembles consisting of familiar musical instruments and technology-infused project instruments. In some cases, students complete their initial project and then apply the knowledge and skills they’ve learned to make a second project that works within the arrangement of their song. For other students, their song assignment at the beginning of the week served as inspiration for the design of their week-long project. These projects tended to be more elaborate musical interfaces, controllers (i.e., Custom Controllers), or self-playing percussion instruments (i.e., Mechanical Music) and were at the forefront of their music

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<tr>
<th>Song</th>
<th>Traditional Instruments</th>
<th>Student Projects (Project Group)</th>
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</table>
| "Everything is Awesome"  
  Tegan & Sara (The Lego Movie) | Electric Guitar, Bass Guitar, Xylophone, Electric Piano, Vocals | Sampler for Hi-Hats (Amazing Apps)  
  Sampler for kick/snare drum (Amazing Apps) |
| "What Makes You Beautiful"  
  One Direction | Electric Piano, Electric Guitar, Bass Guitar, Flute, Drums, Vocals | Self-playing Chords (Mechanical Music)  
  Drum Samplers (Amazing Apps)  
  Synthesizer Notes (Custom Controllers) |
| "Twist and Shout"  
  The Beatles | Tambourine, Acoustic Guitar, Piano, Ukulele, Violin, Drums, Vocals | Robot Tambourine (Mechanical Music) |

Table 1: Songs performed for SMT 2016 along with the traditional instruments and the week-long projects used.
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Waves &amp; Sounds</td>
<td>4.09 ± 0.89</td>
<td>3.73 ± 0.98</td>
<td><strong>4.24 ± 0.88</strong></td>
<td>4.23 ± 0.87</td>
<td>2.90 ± 1.08</td>
<td>3.09 ± 0.68</td>
</tr>
<tr>
<td>Speaker Building</td>
<td>4.25 ± 0.94</td>
<td>4.74 ± 0.56</td>
<td>4.13 ± 0.96</td>
<td><strong>4.47 ± 0.70</strong></td>
<td>3.50 ± 1.01</td>
<td>3.21 ± 1.13</td>
</tr>
<tr>
<td>Music Information Retrieval</td>
<td>4.07 ± 0.91</td>
<td>4.13 ± 0.81</td>
<td>4.16 ± 0.88</td>
<td>4.39 ± 0.82</td>
<td>2.92 ± 1.10</td>
<td>2.09 ± 0.94</td>
</tr>
<tr>
<td>Acoustic Resonance</td>
<td>3.37 ± 1.02</td>
<td>3.78 ± 1.11</td>
<td>3.74 ± 1.06</td>
<td>3.94 ± 0.87</td>
<td>3.27 ± 1.07</td>
<td>3.56 ± 1.04</td>
</tr>
<tr>
<td>Modular Synthesis</td>
<td>N/A</td>
<td><strong>4.94 ± 0.24</strong></td>
<td>N/A</td>
<td>4.33 ± 0.77</td>
<td>N/A</td>
<td>2.11 ± 0.96</td>
</tr>
<tr>
<td>Real Instrument Acoustics</td>
<td>3.74 ± 1.00</td>
<td>4.05 ± 0.73</td>
<td>4.14 ± 0.95</td>
<td>3.90 ± 0.91</td>
<td>2.88 ± 1.02</td>
<td>1.86 ± 1.15</td>
</tr>
<tr>
<td>Sound Effects</td>
<td>3.44 ± 0.99</td>
<td>3.72 ± 1.27</td>
<td>3.53 ± 1.02</td>
<td>3.94 ± 0.87</td>
<td><strong>3.78 ± 1.35</strong></td>
<td>2.61 ± 1.33</td>
</tr>
<tr>
<td>Analog &amp; Digital</td>
<td><strong>4.30 ± 0.94</strong></td>
<td>4.84 ± 0.37</td>
<td>3.83 ± 0.95</td>
<td>3.74 ± 1.19</td>
<td>3.49 ± 1.07</td>
<td><strong>3.74 ± 1.05</strong></td>
</tr>
</tbody>
</table>

**Table 2:** Results (mean ± std. dev) of the surveys, using a 5-pt Likert scale, given after each activity for SMT 2015 and 2016. Highest ratings for 2016 are shown in bold.

![Figure 7](image-url)  
**Figure 7:** Changes between the pre- and post- surveys of the agreement scores of the three main questions investigated (N=12)
In 2016, we continued this performance and selected three songs: *Twist and Shout* by the Beatles, *Everything is Awesome* by Tegan and Sara (from the Lego Movie) and *What Makes You Beautiful* by One Direction. We sought songs with fairly simple chord progressions and melodies. As students joined their project groups on Day 2, SMT instructors went around to each project group, noting the various project ideas to see how they could fit in to the arrangement of the songs that the students had selected. After arranging and organizing the musical performances, we were able to create a rehearsal schedule and anticipate certain issues leading up to the actual concert, which had included projects not working properly, synchronization, volume of inputs for digital instruments, etc. At this time, we also collected information about the instruments students would be interested in playing during the music performances. During days 3 – 5, each student music ensemble had between 30 -45 minutes to practice with an SMT instructor, a MET-Lab graduate student with professional music experience. The SMT 2016 student music ensembles are listed below in Table 1. A few of the projects we would like to highlight include drum samplers for the beat in *Everything is Awesome*, a custom MIDI controller connected to an Ableton Live synthesizer which contained the 8 notes of a diatonic scale and could be set to all 12 major and 12 natural minor scales (used for *What Makes You Beautiful*), and a self-playing tambourine during *Twist and Shout*.

**Evaluation of Efficacy**

**Surveys**

During SMT, we collected information, in the form of surveys, from the students at the beginning and end of the week and also at the end of each activity. These surveys were created to gauge the effectiveness of our program in its ability to impact students’ feelings toward STEM
fields as well as give us an idea about the students opinions of the activities which will inform us about which activities need to be modified in the future.

The surveys also collected demographic information from the students as well as information about prior experience in math, science, and music. This year SMT consisted of 6 female and 15 male students. Of those students, 18 students had taken algebra, 12 had taken geometry, and 1 had taken pre-calculus.

The results for the surveys given after the activities for SMT 2015 and SMT 2016 can be seen in Table 2. Overall, in terms of how interested the students were in the topic, there was an increase from 2015 to 2016 in every activity except for the Waves & Sound activity. For the question regarding how much students learned during the activities, there was an increase in the ratings between 2015 and 2016 for majority of the activities with the exceptions being Waves & Sound, Real Instrument Acoustics, and the Analog & Digital activities. The change in ratings for how challenging the activities were are generally decreasing between 2015 and 2016. Additionally, we can see that the highest rated activities changed in 2016, with the new activity Modular Synthesis receiving the highest rating in regards to interest.

The results to the three questions investigating students beliefs towards future careers in STEM fields are shown in Figure 7. This figure shows the percentage of students who had a positive change in their agreement with the provided statements along with students who had a negative change in their agreement for those same statements. Some student responses were not captured, so here we are only presenting the data from 12 students.

It seems that SMT had a positive impact on students feelings toward future careers in math and engineering, while having a negative effect on students in relation to science.

**Presentation Rubrics**

At the end of the week, students were asked to give a short, five minute presentation on their week-long project along with a functioning prototype of their project idea. These presentations were evaluated with a rubric by several people with expertise in the education field. Table 3 shows the mean scores (graded on a 4 point Likert scale) from those experts on the rubric categories. The categories are defined as follows:

- **Design** - Does the student show evidence of planning the project thoughtfully?
- **Knowledge** - Does the student demonstrate the understanding of ideas?
- **Application** - Does the student use a variety of skills to apply knowledge to the project?
- **Presentation** - Does the student effectively communicate the central ideas of the project?
- **Process** - Does student take the necessary steps to fully realize the project goals?
- **Novel** - Does the student develop a novel project?

The evaluators deemed the presentations from the Hardware Hacking activities (score of 20 out of 24) to be of higher quality than those from the other project categories. These presentations provided evidence suggesting that students in this group had a better grasp of their project and its
applications based on the high knowledge and application scores. The Custom Controllers presentations had the highest novelty rating. Amazing Apps presentations had the lowest scores in most categories.

Conclusions and Future Steps

The evaluations that were given to students seem to indicate that our program is having a positive impact on participants ideas about future careers in STEM fields. Specifically, we have evidence to suggest that SMT encourages interest in math and engineering. The program still has some improvements to make in terms of garnering interest for science-related careers. This discrepancy may be explained by the fact that many of the activities involved math and additionally the week-long projects have an emphasis on engineering design principles. There was little direct mention of the science, as we made the assumption that students would understand the connection between the program and the sciences. This is something that will be addressed in future SMT programs. We plan on explicitly making the connection between science and the week’s activities to students.

The presentations of the week-long projects offer an important view of what the students were able to grasp throughout SMT. The expert evaluations of the projects show that with the exception of the Amazing Apps project, students are producing high quality presentations that are capable of understanding their work to the point where they can effectively communicate their ideas and thought processes to others. The Amazing Apps project is new and indicates that we need to continue improving the tools given to the students who chose this topic. There were issues arising from using beta versions of the software and also the methodology used to teach students the necessary programming concepts in such a short amount of time. Apple has since released the finished version of Swift Playgrounds which addressed many of the bugs that were present in the beta version. Additionally, we are working to develop a shortened curriculum for teaching the necessary programming techniques to students which we hope to implement next year.

Over 10 years, the Summer Music Technology program has seen a myriad of improvements and updates that seem to be effective in the original goals SMT set out to achieve. This program succeeds in developing students interest in STEM careers and, at the same time, allows students to develop their appreciation for art and explore its connections to STEM fields.

Bibliography


