ANALOG SYNYTHESIZERS IN THE CLASSROOM:

How creative play, musical composition, and project-based learning can

enhance STEM standard literacy and self-efficacy.

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ANALOG SYNYTHESIZERS IN THE CLASSROOM:

How creative play, musical composition, and project-based learning can

enhance STEM standard literacy and self-efficacy.

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SUMMARY

The state of STEM education in America's high schools is currently in flux, with billions annually being poured into the NSF to increase national STEM literacy. Hands-on project-based learning interventions in the STEM classroom are ubiquitous but tend to focus on robotics or competition based curriculums. These curricula do not address musical creativity or cultural relevancy to reach under-represented or disinterested groups. By utilizing an analog synthesizer for STEM learning standards this research aims to engage students that may otherwise lack confidence in the field. By incorporating the Maker Movement, a STEAM architecture, and culturally relevant musical examples, this study's goal to build both self-efficacy and literacy in STEM within under-represented groups through hands-on exercises with a Moog analog synthesizer, specifically the Moog Werkstatt.

A quasi-experimental one-group pre-test/post-test design was crafted to determine study validity, and has been implemented in three separate studies. Several age demographics were selected across a variety of classroom models and teaching style. The purpose of this wide net was to explore where a tool like the Werkstatt and its accompanying curriculum would have the biggest impact. Results show that this curriculum and technique are largely ineffective in an inverted Music elective classroom. However, in the STEM classroom, literacy and confidence were built across genders, with females showing greater increases in engineering confidence and music technology interest than their male counterparts.

Chapter 1. Introduction

The purpose of this research to discover the roles a modular analog synthesizer, specifically the Moog Werkstatt, can take in K-12 classroom learning opportunities. This research will have a special focus on a musically creative deployment of practical STEM skills (discrete electronics, bread-board prototyping, microprocessors, and computing). The objective is to create, deploy, and evaluate a series of lesson plans that meet an assortment of STEM (Science, Technology, Engineering, and Mathematics) national standards. These lessons utilize an analog synthesizer as its main learning tool, with additional materials including entry-level microcontrollers and discrete electronic components. All lessons are centered around a hands-on project-based learning model, and meet either Common Core or Next Generation Science Standards (Common Core State Standards Initiative & others, 2012).

It is this study's goal to deploy these lesson-plans across a wide student skill set and age demographic. Considering the limited use of analog synthesizers in the formal education K-12 domain, several learning styles and core subjects are explored. By utilizing an analog synthesizer for STEM learning standards this research aims to engage students that may otherwise lack confidence in the field. Through an incorporation of the Maker Movement, a STEAM architecture, and culturally relevant musical examples, it is this study's goal to build both self-efficacy and literacy in STEM within under-represented groups through hands-on exercises with a Moog analog synthesizer, specifically the Moog Werkstatt.

This research aims to align STEM education, Maker Movement culture, music history, and electronic sound synthesis into an exciting learning experience. This research falls into the popular STEAM (Science, Technology, Engineering, Arts Mathematics) model, utilizing a novel creative tool for a STEM educational opportunity, the modular analog synthesizer. A quasi-experimental one-group pre-test/post-test design was crafted to determine study effectiveness, and has been tested in three separate studies. These studies are formally introduced and analyzed in later chapters.

1.1 Motivation

There is a growing concern at the federal level that the American education system is falling behind the rest of the world, particularly in STEM fields (Bybee, 2010). This is exemplified in the 24th and 28th rankings of American 15 year-olds in math and science literacy, respectively (Kuenzi, 2008). This national concern with STEM education motivated the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act of 2007, or America COMPETES Act. The America COMPETES Act was resigned in 2010 by President Obama, and provided the National Science Foundation (NSF) with large annual funding, most recently 8.3 billion dollars for fiscal year 2013 for increasing STEM literacy (Sen Rockefeller, 2010).

Quaye and Harper argue that engagement is directly connected to persistence and success when it comes to STEM education (Quaye & Harper, 2014). This lack of academic engagement is a primary cause of low STEM confidence and success rates (Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2011). Males on average are more likely to have high STEM confidence, perform well on STEM tests, and be active participants in the STEM

classroom (Eddy, Brownell, & Wenderoth, 2014; Martinez & Guzman, 2013). Major

hurdles facing STEM literacy in under-represented groups include interest in STEM

careers, cultural relevant pedagogy, early STEM exposure, and self-efficacy in STEM

fields (Museus, Palmer, Davis, & Maramba, 2011).

The PBL (Project-based Learning) model has gained popularity to encourage STEM

confidence and literacy (Evans, Lopez, Maddox, Drape, & Duke, 2014). PBL encourages

constant group project engagement and a mastering of standards through hands-on

exercises versus a lecture-based student teacher dynamic. This has proven successful in

areas where a lecture based education model may be underappreciated in favor of a more

perceived and immediate practical skill set (Berry). By addressing the students with

culturally relevant learning materials, under-represented groups are more likely to excel

in STEM courses (Museus et al., 2011). A common creative PBL architecture to

encourage STEM appreciation and literacy is robotics (Mataric, Koenig, & Feil-Seifer,

2007). However, for students not interested in robotics, or intimidated in a competition-

based classroom, these interventions can damage self-efficacy in STEM (Milto, Rogers,

& Portsmore, 2002). It is this study's goal to explore the effectiveness of a musically

creative engagement of STEM skills through the analog synthesizer, in the hopes of

avoiding certain caveats to current STEM PBL methods.

By integrating a musical aspect into the STEM classroom curriculum, a STEAM

(Science, Technology, Engineering, Arts, and Mathematics) educational model is

achieved. STEAM is a movement in STEM education sparked by the Rhode Island

School of Art and Design (RISD) (Roach, 2012; Yakman, 2010). RISD's *STEM to*

STEAM initiative is concerned with highlighting the importance of creativity in ingenuity across all disciplines, with a special focus on the sciences.   This creativity has recently tended to take the form of experiments with robots or STEM invention competitions (Khanlari, 2013).   However, under-represented groups tend to perform poorer in these competitive STEM atmospheres (Milto et al., 2002). This study's goal is to use creative musical expression through the analog synthesizer in place of the competitive paradigm of the robotics classroom to increase female STEM confidence and literacy.

Females, an under-represented group in many STEM fields, predominate their male counterparts in music (Green, 1997). However, this does not necessarily translate to literacy in the music technology classroom (Comber, Hargreaves, & Colley, 1993).   It is my objective to build upon a PBL classroom model while using a modular analog synthesizer for creative exercises that engage underrepresented groups in practical STEM skills.   The STEM skills presented will expose students to the fundamentals of electronics and computing, as well as engineering basics like breadboard prototyping and microprocessors. This intervention will aim to increase both STEM efficacy and literacy through music, all while being presented through a culturally relevant musical lens. This research meets STEM National standards (Common Core or Next Generation Science Standards), and simultaneously integrates a level of musical creativity allowing students to create music, study popular music history, and understand the fundamentals of sound synthesis.

Electronic sound synthesis has permeated all forms of music with a special foothold in the popular music domain. Historical popular musical examples are presented, ranging from The Beatles to Kanye West, and students are tasked with emulating the sounds and timbres presented in these songs. Engagement of student bodies that may value popular culture and music over traditional school subjects can be achieved by relating recognizable musical material (Morrell, 2002). Museus et al. have presented evidence that by including culturally relevant material in the STEM classroom, under-represented groups tend to perform better (Museus et al., 2011). It is this study's aim to build upon these popular sounds, allowing the student to follow a musically engaging path while learning and applying practical skills in circuits, computing, mathematics, and the physical sciences.

Chapter 2. Literature Review

This chapter begins by rooting this research in music technology history. This brief review leads to pedagogical history and modern relevant examples, which will serve a similar purpose in positioning this research in the learning sciences. Contemporaneous examples of popular research in the STEM and STEAM education domain will then be presented. A final section expresses the novel contribution the use of an analog synthesizer has in the classroom within the STEAM education model.

2.1 Music Technology and History

It is this study's aim to use the ubiquity of electronic sound synthesis in popular music to uniquely engage students in the aforementioned STEM standards (Common Core, NGSS). This integration of STEM skill building and musical creativity falls under the STEAM educational model, encouraging project-based learning deployment in the classroom. The use of a Moog synthesizer allows for a special focus on the history of electronic music and the use of specific references to popular artists in music history.

Robert Moog's analog synthesizer holds a special place in the history of music technology. His early modular designs of the 1960's were physically towering, and were difficult for a novice to operate. Users were tasked with patching between specific modules to create a signal path for electronic control voltages in hopes of creating a final synthesized sound. A background in electronics was helpful to properly operate these early modular synthesizers. Moog's design had its roots in the electronic tape studios of

the early 1950's spearheaded by the likes of Ussachevsky and Luening in the United States and by Schaeffer and Stockhausen in Europe (PINCH, Trocco, & Pinch, 2009). Synthesizers existed well before Bob Moog, however these early incarnations occupied an entire room. Early examples include Olsen's RCA Mark II (Mathews, 1985) at the Columbia-Princeton Electronic Music Center. Olsen's synthesis method required a great deal of technical knowledge as well as physical space to house the system. In this era institutions or research labs owned synthesizers like the RCA Mark II due to the background required to operate them effectively as well as their overall cost and size. Don Buchla's contemporaneous work embodied the west coast school of synthesizers, with a focus on wave shaping and eccentric modes of control. As unique as these synthesizers were, their modes of interaction and overall design limited the acceptance of them into the mainstream.

It was not until the democratization of this technology through Bob Moog's Minimoog that the practice of electronic sound synthesis began to be practiced outside of the conservatory (Moog, 1964, 1977). The Minimoog took all of the important sound modules from Moog's early models (voltage-controller oscillators, filters, and amplifiers) and packaged them into a portable and familiar keyboard housing. With the dimension downsize came a cost decrease, which made the Minimoog one of the first analog synthesizers created for mass production. This dissemination brought the sound of electronic music synthesis into the mainstream, being featured heavily on albums by the likes of Stevie Wonder, The Beatles, and Kraftwerk.

In the modern musical era, electronic sound synthesis is commonplace. The likes of Kanye West, Lady GaGa, Daft Punk, Radiohead, and Coldplay, and other famous artists use the current Moog synthesizer of choice, the Voyager. These popular and diverse musical acts allow for instructors to make meaningful connections between the circuits, sound synthesis parameters, and final musical product, when engaging students.

2.2 Pedagogy and Learning Sciences

This research is inspired by Seymour Papert as an extension of Jean Piaget's *Constructivism* educational philosophy (S. Papert & Harel, 1991). Papert's theory, conveniently called *Constructionist Learning*, is most simply understood as an extension of Constructivism into a classroom setting (S. Papert, 1994; S. A. Papert, 1993). Piaget's Constructivism states that the learner creates internalized mental situations to fully understand the world with which they are presented (Piaget & Cook, 1952). Papert's theory builds upon that by stating that learning happens most effectively when the learner creates a tangible artifact. It is this creative problem-solving act that aligns Papert's theory with experiential learning, which provide the building blocks for the project-based learning model.

Kao's work in engaging students in cooperative and active learning within technology education presents motivating data (Kao, Lin, & Sun, 2008). Becker et al. make the case for project-based learning in technology (Becker, Hodge, & Sepelyak, 2010). The research of Stephanie Bell and project-based learning for the 21st century is in the same domain as Becker's (Bell, 2010). Additionally, using interest driven learning in the

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STEM classroom has been analyzed previously, sans the analog synthesizer, by Evans et al. (Evans et al., 2014).

Christensen and Knezek present the necessity of a new way to assess technological readiness in the 21st century utilizing hands-on and project-based learning techniques (Christensen & Knezek, 2014). Ricks shows the importance a hands-on constructivist approach has in elementary school mathematics education (Ricks, 2012). Khanlari presents the impact project-based learning in the STEM classroom, with a special focus on robotics, can have on students' science and mathematics attitudes (Khanlari, 2013). Barron et al. expose the difficulties associated with a full project-based learning educational overhaul in the American education system (Barron et al., 1998).

Internationally, Helle, Tynjälä, and Olkinuora have explored how project-based learning has been deployed across the Nordic countries (Helle, Tynjälä, & Olkinuora, 2006). Additionally, Lou et al. present the shift in attitudes towards STEM fields under a project-based learning methodology in Taiwan (Lou, Shih, Diez, & Tseng, 2010). The international popularity of project-based learning, learning by design, and many other Constructionist branches is clearly palpable.

Mitchel Resnick is currently one of the leading figures in Constructionist Learning. Resnick is the Director of the Lifelong Kindergarten group at the MIT Media Lab. This lab's research encourages the direct manipulation of tools through hands-on exercises for elementary school children to learn abstract concepts (Resnick, 1998). Resnick has

continued the expansion of the theory of constructionism into the digital age, focusing on computing opportunities in knowledge building (Resnick, 1996).

2.3 STEM/STEAM Education

Resnick explored the principles of design in educational tool building in STEM learning (Resnick et al., 2005; Resnick & Rosenbaum, 2013). The MIT Lifelong Kindergarten group has gained a great deal of notoriety in this field by spearheading the LEGO Mindstorm series of educational toys as well as the introductory programming language Scratch (Resnick, 2004; Resnick, Martin, Sargent, & Silverman, 1996). Other members of this group have also made contributions that are specifically related to this research. Zuckerman's research revolves around bringing tangible low-tech edutainment technologies into a variety of learning situations (Zuckerman, Arida, & Resnick, 2005).

Leah Buechley is a MIT Media Lab Research group director, exploring the integration of technology in non-traditional education scenarios. Her work includes curriculum development for e-textiles in schools to engage under-represented group in STEM education (Buechley, Eisenberg, & Elumeze, 2007). Buechley has also presented papers on the creativity to be found in electronics and circuit design, aligning her work with other STEAM education researchers (Mellis, Jacoby, Buechley, Perner-Wilson, & Qi, 2013).

The computing community in particular has a great deal to offer in the realm of STEAM curricula with a particular focus on musical creativity. Samuel Aaron's exploration of

live-coding for sound synthesis on the Raspberry Pi presents a STEAM based curriculum using a novel platform (Aaron & Blackwell, 2013) (Aaron, Orchard, & Blackwell, 2014). The miniAudicle project allows for ChucK programming on a touch device for musical computing in the classroom (Spencer & Salazar, 2014). Kobayashi et al. present a reconfigurable I/O module and API for musical instrument creation for novices in an educational setting (Kobayashi, Endo, Harada, & Oishi, 2006). Ruthmann et al. have appropriated Resnicks' Scratch program to explore introductory computing education through musical live coding (Ruthmann, Heines, Greher, Laidler, & Saulters, 2010).

Major research institutions across the United States have explored the ways music can encourage and reinforce computational thinking. Research at Princeton has positioned the Laptop Orchestra as a viable classroom environment (Wang, Trueman, Smallwood, & Cook, 2008). Introductory computing being taught through a musical context has been explored by researchers at Bryn Mawr College (Misra, Blank, & Kumar, 2009). Carnegie Mellon has presented research on computational thinking through novel tangible musical devices (Peng, 2012). The Georgia Institute of Technology has explored similar avenues through the EarSketch project (McCoid et al., 2013).

Obviously, a direct influence on this research is the work of Jason Freeman at Georgia Tech. EarSketch, a computational music-remixing tool, has been brought into the classroom to encourage computing knowledge through interest driven musical composition. Freeman has also engaged low socio-economic and under-represented groups through this project (Freeman et al., 2014).

2.4 Maker Movement

The Maker Movement was sparked over the last decade with the introduction of open source hardware and software and cost efficient microprocessors like the Arduino, and spurred by The Maker Faire, which has had over fifty global events. Flagship events across key cities saw over 280,000 attendees around the world last year (San Francisco, Chicago, Atlanta, Paris, Rome) (Bajarin, 2014). Media outlets like Make Magazine, Wired, Instructables, SparkFun, Adafruit, and Hack-a-Day all helped to push forward DIY culture into the mainstream. Fortune 500 companies are now investing heavily to encourage innovation and exploration (Carmody, 2011).

The incorporation of the Maker Culture into a project-based learning classroom environment is integral to this research. The educational opportunities presented by the flourishing Maker Movement have not gone unnoticed, with PBS posing the question "Can DIY Movement Fix a Crisis in U.S. Science Education?" in a PBS NewsHour focus piece on the subject ("Can DIY Movement Fix a Crisis in U.S. Science Education?"). The United States Government, specifically the Department of Education and the White House, has encouraged this integration through their creation of the White House Maker Faire ("Maker Faire Coming to the White House"). It is important for this research to build upon these cultural and educational movements to encourage students to think creatively while deploying a practical STEM skill in a formal learning environment.

The MIDI Scrapyard Challenge presents a true Maker Movement inspired informal musical learning experience through the hack- a-thon paradigm (Moriwaki, 2007; Moriwaki & Brucker-Cohen, 2006). Similarly, Teen Tech Workshops have absorbed the tradition of circuit bending for musical instrument creation into challenges (Tadhg, 2010).   As an informal component to this research, a hack-a-thon with the Moog Werkstatt was held at Georgia Tech ("Hackathon helps students invent musical instruments").

The integration of the Maker Movement is not limited to informal learning experiences such as hack-a-thons, Maker Faire's, workshops, or challenges; these tactics have been successfully deployed in the classroom. Kylie Peppler, of Indiana University's Learning Sciences Department, has a background in Fine Arts (BFA), and has published on Maker Culture and Constructionist Learning. (Kylie Peppler & Bender, 2013). Peppler's work on STEAM education incorporates novel, cross disciplinary techniques to improve computing learning outcomes (K. Peppler, 2013). By providing a direct correlation between the arts, STEM learning, and the Maker Movement, Peppler's work is of specific importance to this study (K. Peppler & Kafai, 2005).

Shea's work on electronic art and the dissemination of maker culture in education has a direct relation to this study's goal of leveraging interest driven learning (P. Shea, 2013). Tseng explored the role DIY culture, interest driven learning, and play in new educational systems (Tseng & Resnick, 2014). Terrenghi's research on tangible interfaces for design based learning education is insightful in educational module creation

(Terrenghi, Kranz, Holleis, & Schmidt, 2006). The work of Frei and his Curlybot

provides a useful framework for creative STEM focused educational toys (Frei, Su,

Mikhak, & Ishii, 2000). Blikstein covered the maker movement, education, and the

democratization of invention (Blikstein, 2013). LittleBits founder Bdeir has published

content of specific relevance in electronics as educational materials in both the maker

culture and educational settings (Bdeir, 2009).

2.5 Novelty

The novelty of this research lies in the use of a semi-modular analog synthesizer, in

particular, the Moog Werkstatt. Many groups have explored using music as a tool for

STEM learning. However, few have explored the hardware domain, opting to teach

computational thinking through a musical lens. Those who have explored musical

hardware hacking for STEM skill building have been limited to the more informal

hackathon or after school workshop paradigm. The formal deployment of a combined

hardware and software-based curriculum utilizing an authentic Moog semi-modular

synthesizer makes this research unique.

The Werkstatt allows for a level of individual or small group use that would not be

feasible with other Moog synthesizers. Additionally, using a Moog synthesizer allows an

instructor to reference the rich history of electronic music, and Moog's place in that

history, by tying into the broader narrative of electronic sound synthesis and its rise in

popularity. Additionally, the modularity of this device allows for multiple learning

opportunities across several STEM fields including discrete electronics, breadboard prototyping, microprocessors, and computing, all through a musical lens.

Jason Freeman's EarSketch project is of clear influence on this research, however EarSketch currently exists as a digital system focusing on computing over circuit building (McCoid et al., 2013).   Similarly, there are several examples of musical computing listed earlier that do not focus on electronics in lieu of computing-specific curricula.   In this research, by adding an Arduino to certain lessons, not only can the instructor engage the Maker culture with its own tools, but a computing element is added to the standalone electronics learning opportunities inherently present in the Werkstatt.

The MIDI Scrapyard, Tech Teen Workshops, and similar hack-a-thon type challenges that do incorporate an electronics element, take place in an informal learning environment. The curriculum created during this research differs not only in its choice of learning tool, but also in the formality of its deployment. By addressing both Common Core and Next Generation Science Standards specifically, this research reaches out of the challenge paradigm and into the classroom in a practical manner.

LittleBits, a STEAM educational toy company with a Korg synth-kit product, focuses on entry-level circuit building with little computing required. LittleBits does not introduce the student to discrete components or traditional bread boarding fundamentals (Bdeir, 2009).   The proprietary LittleBits snap circuit interface is better suited for a younger age demographic that will not fall prey to the caveats of a non-authentic learning experience

(Lee & Butler, 2003). By referencing the Werkstatt's use by popular artists, this study

aims to reinforce the authenticity of this synthesizer as both a viable musical and

educational tool (*WERKSTATT-01 | P-Thugg*, 2014). Additionally, by including

embedded C/Java lessons and a focus on discrete electronic components, this research

will appeal to an older age demographic with a greater technical skill set.

There are countless studies that present the positive impact playing music has on the

musicians' overall brain structure. Rosenkranz et al. show that playing music has been

shown to increase brain plasticity, or neural effectiveness, in the player (Rosenkranz,

Williamon, & Rothwell, 2007). These brain changes have been observed in the motor,

auditory, and visual-spatial regions (Gaser & Schlaug, 2003). This increase in spatial

engagement provides possible context for why many studies jump to explore

computational thinking through music.

The semi-modular analog synthesizer has intrinsic attributes that make it ideal for

electronics lessons, notably its patchable input/output headers.   By augmenting this

instrument with a microcontroller, computational thinking can also be introduced into the

lessons. The novelty of this research lies in the cross disciplinary nature of the lessons,

allowing the student to explore music, science, electronics, and computing, all while a

level of cultural relevancy is obtained through the storied history of the Moog analog

synthesizer.

Chapter 3. Learning Tools and Curriculum

An integral component to this research is the analog synthesizer. The modular paradigm of the analog synthesizer allows for a wide variety of learning opportunities through hands-on manipulation. Additionally, through the control voltage standard, analog synthesizers have a direct relationship with discrete electronic components (resistors, capacitors, potentiometers). This one to one relationship between pitch, cutoff frequency, and other synthesis parameters to voltage allows for electronics classroom interventions. By augmenting this system with popular Maker Culture tools like the Arduino, which operates on a 5Vpp range, this study can integrate computing lessons directly with the synthesizer, thereby facilitating a more diverse curriculum.

3.1 Early Research

Prior to a relationship with Moog Music being sparked, this research initially was positioned as an Arudino add-on, or shield. The shield was drafted to add a stackable header area to the Arduino to allow for direct audible feedback of discrete component swapping. Figure 1 presents an early prototype model of this system with a removable resistor clearly visible. This intervention would have met both the computing and discrete electronics goals of this study; however, it would have lacked any cultural history.
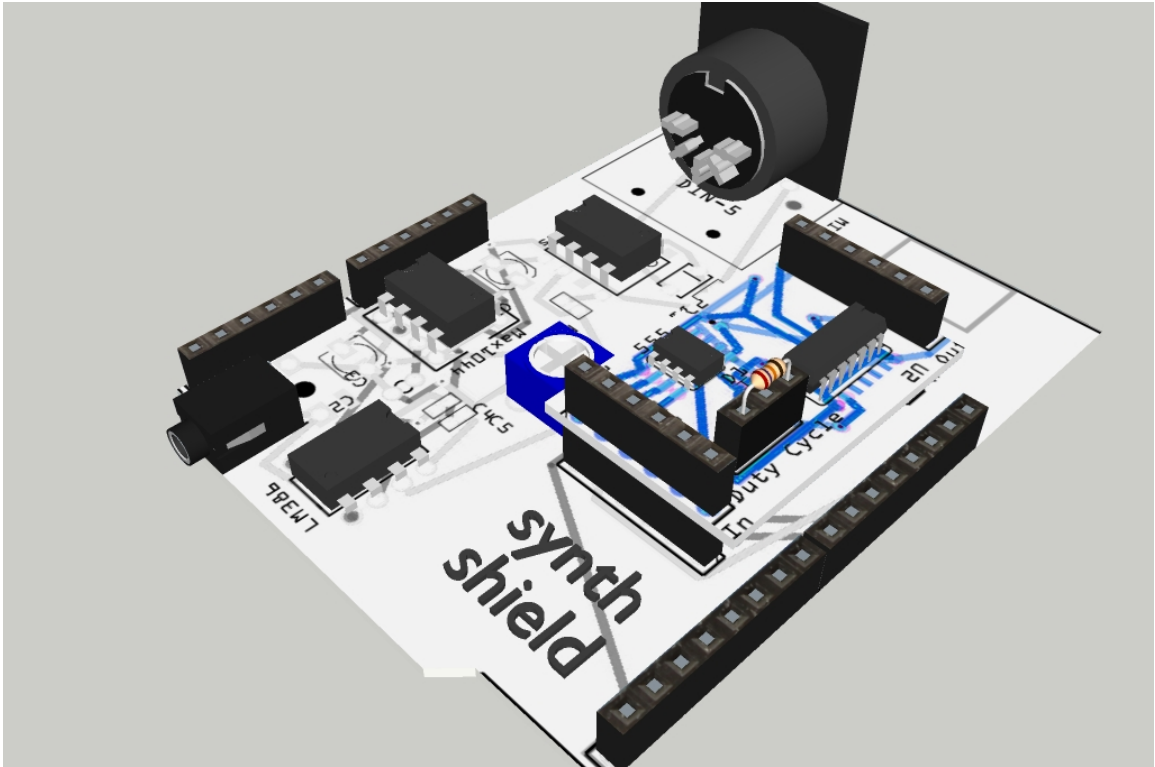
Figure 1. Concept image of Arduino synthesizer shield.

Another concept explored in the early days of this research was that of a stackable magnetic synthesizer. Modules would be housed in small blocks allowing the player to stack them in specific orders to change the signal path. These blocks included removable trays, which allowed for swapping of discrete electronic components for immediate feedback. Figures two and three present concept images of this prototype.
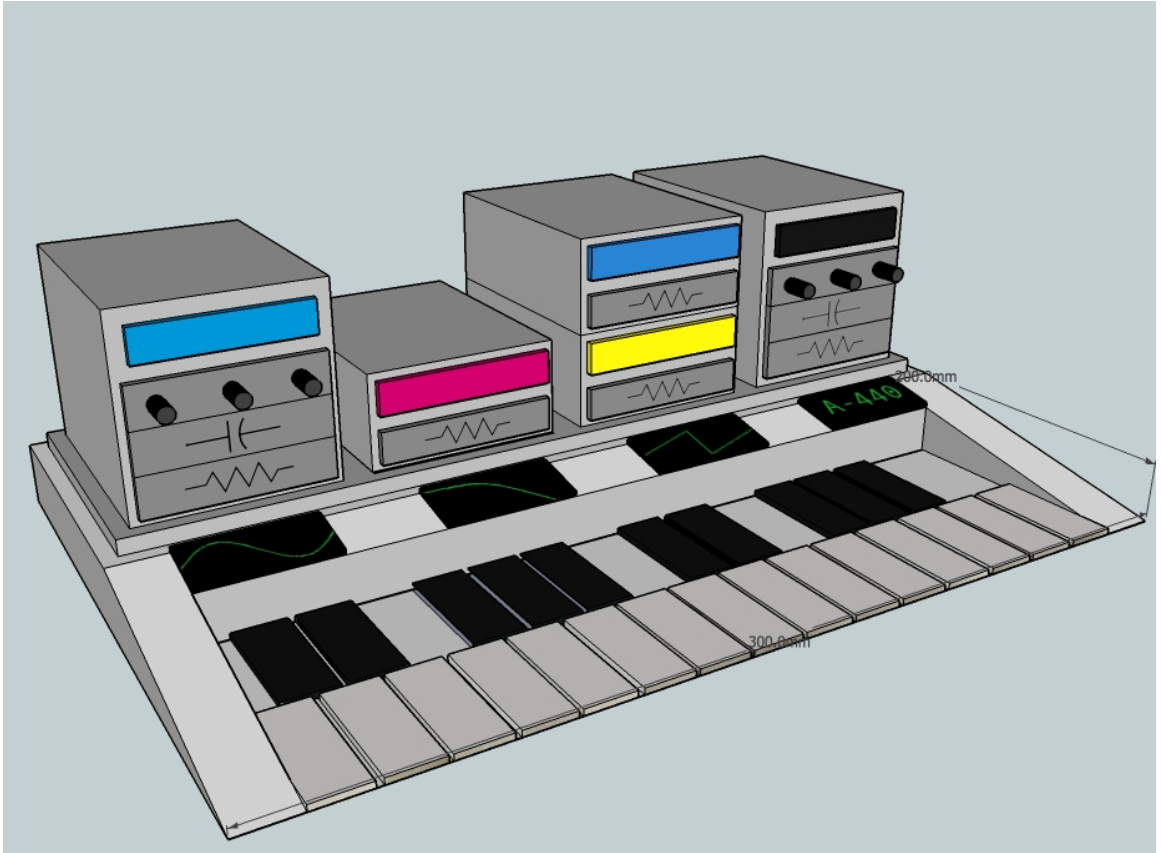
Figure 2. Stackable synthesizer concept prototype.
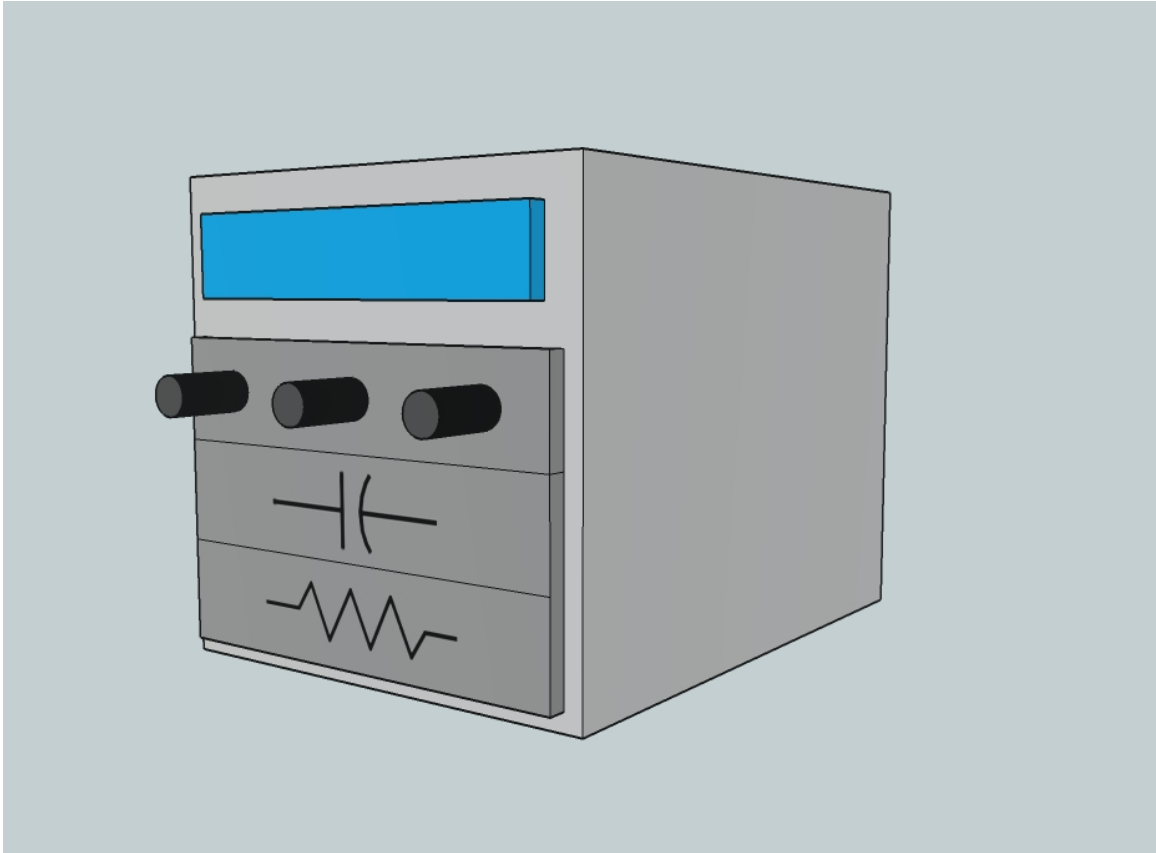
Figure 3. Block module concept with removable capacitors and resistor trays.

Later, a line of communication was opened with Cyril Lance, chief engineer at Moog Music. Moog Music was already interested in engaging the educational community, and graciously provided materials and financial support throughout this study. This sponsorship refocused my initial concepts, however the additions of cultural relevancy to the curricula, and an authentic musical instrument as a learning tool were both invaluable to this research.

3.2 Moog Music Werkstatt-01

During the course of this study I was employed as the Creative Learning Developer for Moog Music Inc. This relationship was initially limited to an internship over summer 2014, however this internship was extended to continue this study. Over the last year I have been conducting thesis research on the effectiveness of the curriculum and associated learning materials created while at Moog Music. My responsibilities at Moog Music included curriculum development, educational product design and research, tutorial videos, Fritzing sketch files for breadboard prototyping, 3D printer files for custom enclosures, Arduino library in C/C++, and website design and development. The focus of my thesis research at Georgia Tech is measuring the effectiveness of these materials in a formal classroom setting in both STEM literacy and self-efficacy.

Moog Music provided this study with all necessary resources and associated funding. In addition to being an inventor, Bob Moog also had a long history in education as the creator and director of the Music Technologies undergraduate program at University of North Carolina Asheville. It is this educational legacy that Moog Music is interested in formally addressing through positioning the Moog Werkstatt as a learning tool as well as a powerful analog synthesizer.
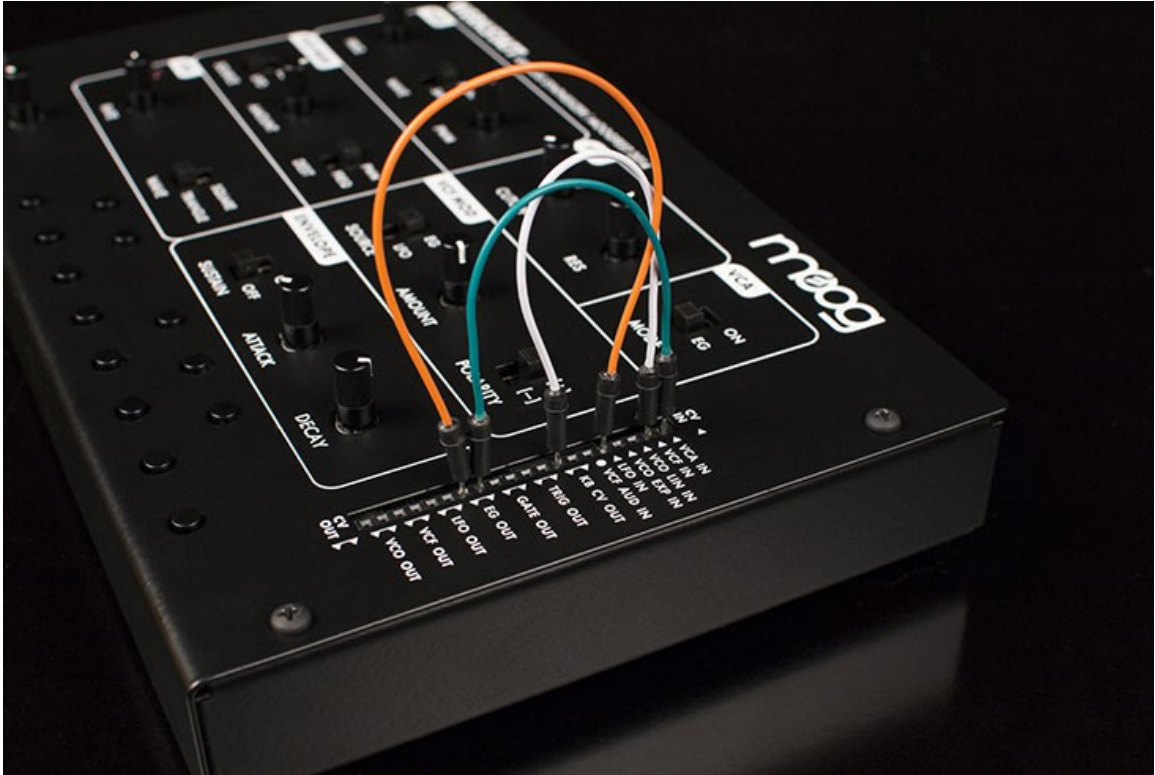
Figure 4. Moog Werkstatt Press Image

The Werkstatt, a compact semi-modular analog synthesizer, features a single oscillator VCO (Voltage Controlled Oscillator) with pulse and sawtooth wave options. Pulse waves can be modulated to create square waves as well as a variety of other duty cycle pulse (rectangular) waves. The Werkstatt also features a LFO (Low Frequency Oscillator) that can modulate other systems of the synthesizer. The VCF (Voltage Controlled Filter) of the Werkstatt is a classic Moog circuit in the four-pole transistor ladder filter (Moog, 1965). An attack/sustain/decay envelope generator is accessible in the VCA (Voltage Controlled Amplifier) for more temporally interesting sonic expression.

The Werkstatt not only presents the students with an educational tool, but a useable synthesizer with a wide variety of timbral possibilities. The Werkstatt's duality as

professional instrument and educational tool has excited teachers who see toy-like

learning tools not being taken seriously in the classroom. Research has shown that the

authenticity of a scientific learning experience relies on the perceived genuineness of the

tools utilized within the classroom (Lee & Butler, 2003). Refer to Figure 5 for a visual

overview of the Werkstatt's front panel in Fritzing, an open source breadboarding

program utilized in the classroom.
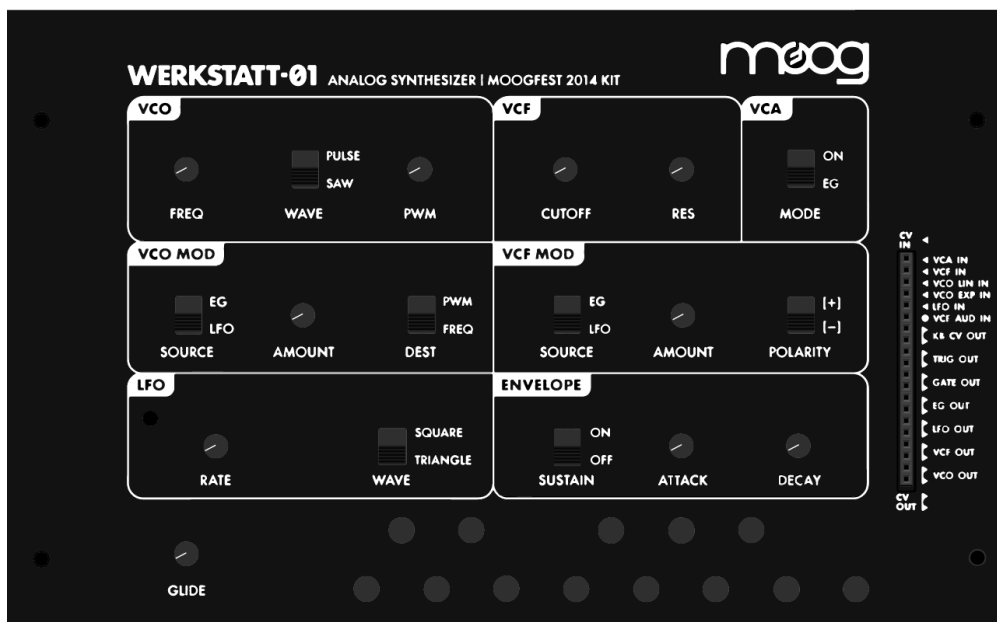
Figure 5. Moog Werkstatt model for electronic prototyping in Fritzing.

The most important aspects of the Moog Werkstatt to this research are its modifiability,

modularity, and capability for integration with a wide variety of maker movement

electronic protocols.   The I/O pin headers featured on the Werkstatt are explained at

greater length in Figures 6 and 7. These images are taken from a simple Javascript applet

that describes the various aspects of the Werkstatt. The I/O pin headers provide breakout

point for breadboarding or Arduino activities with identical .1-inch jumper inputs.

Through the patching process many learning opportunities are found with the Werkstatt,

including introduction to programming, discrete electronic components, and a hands-on

understanding of sound synthesis fundamentals.

CV IN - The Control Voltage (CV) input patchbay allows players to modify the signal path of the Werkstatt.

VCA IN - 0V to 5V+ in VCA EG Mode, +/-2.5V in VCA ON Mode

VCF IN - 5V- to 5V+

VCO LINEAR FM - +/-2.5V - NOTE: this is an inverting control input

VCO EXPONENTIAL FM - 5V- to 5V+, 1V/Octave trimmable

LFO CV - 5V- to 5V+ — NOTE: Negative CV slows LFO more than the panel
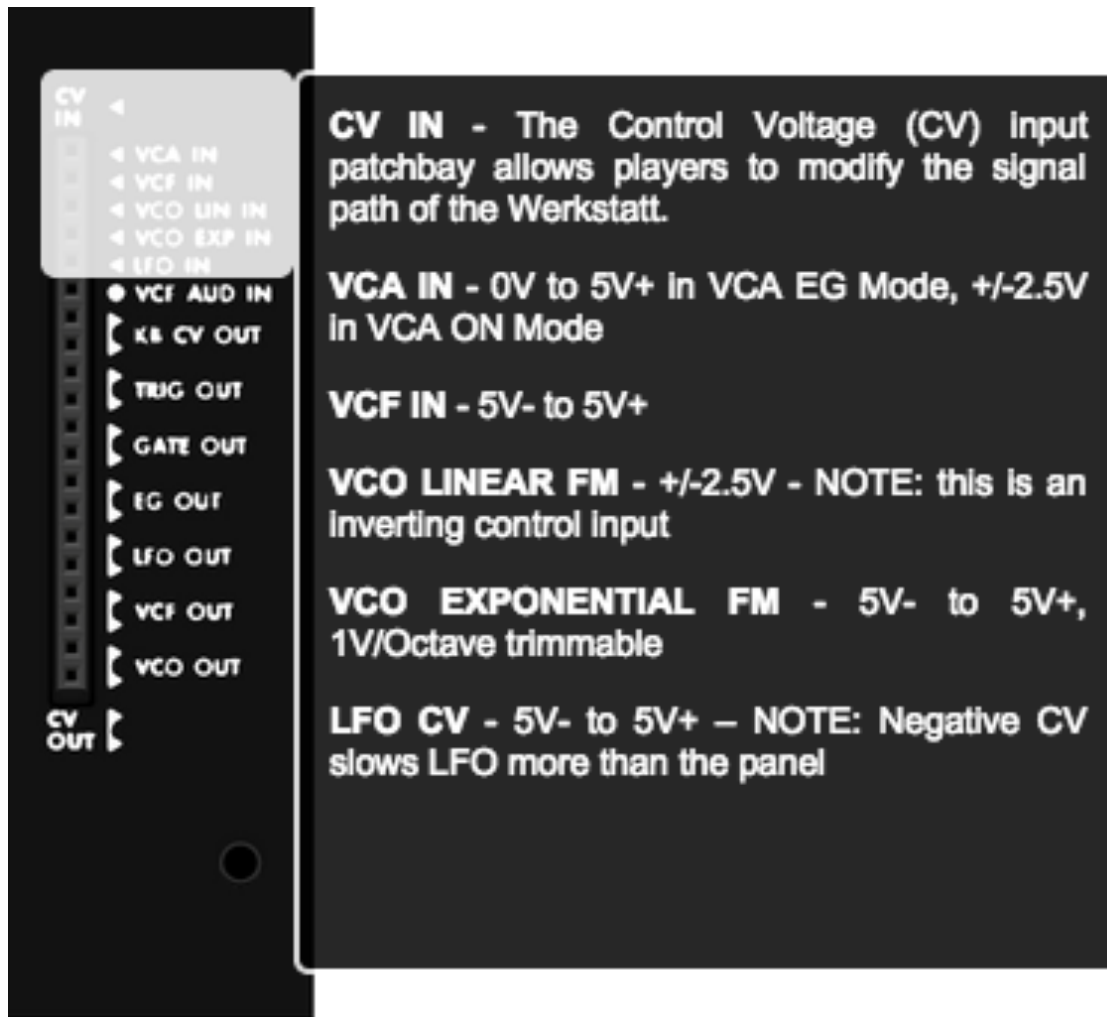
Figure 6. Werkstatt CV (Control Voltage) input headers with electrical characteristics.

CV IN ◄
◄ VCA IN
◄ VCF IN
◄ VCO LIN IN
◄ VCO EXP IN
◄ LFO IN
● VCF AUD IN

KB CV OUT
TRIG OUT
GATE OUT
EG OUT
LFO OUT
VCF OUT
VCO OUT

CV OUT

CV OUT - The Control Voltage (CV) output patchbay users players to modify the signal path of the Werkstatt.

KB CV - 3V+/semitone from 1 keyboard - NOTE: Attenuate for 1V+/Octave

TRIG - 5 millisecond pulse, 0 to 5V+ signal generated from low-note priority

GATE - 0 to 5V+ signal generated from low-note priority

EG - 0 to 5V+ signal, Simple ASD or AD type Envelope Generator

LFO - 2.5V- to 2.5V+ Triangle or Square wave, selected via LFO Switch

VCF - 2V- to 2V+ signal for audio or CV uses

VCO - 0V to 5V+ VCO signal, wave selected by VCO Wave Switch

Figure 7. Werkstatt CV (Control Voltage) output headers with electrical characteristics.

The open source circuit and breadboarding program Fritzing is adopted as the standard

tool for prototyping. This drag-and-drop visual tool is easy to use, free to download, and

integrates into each associated lesson in the curriculum. See Figure 8 for an example

Fritzing sketch showing the circuit for the arpeggiator lesson.
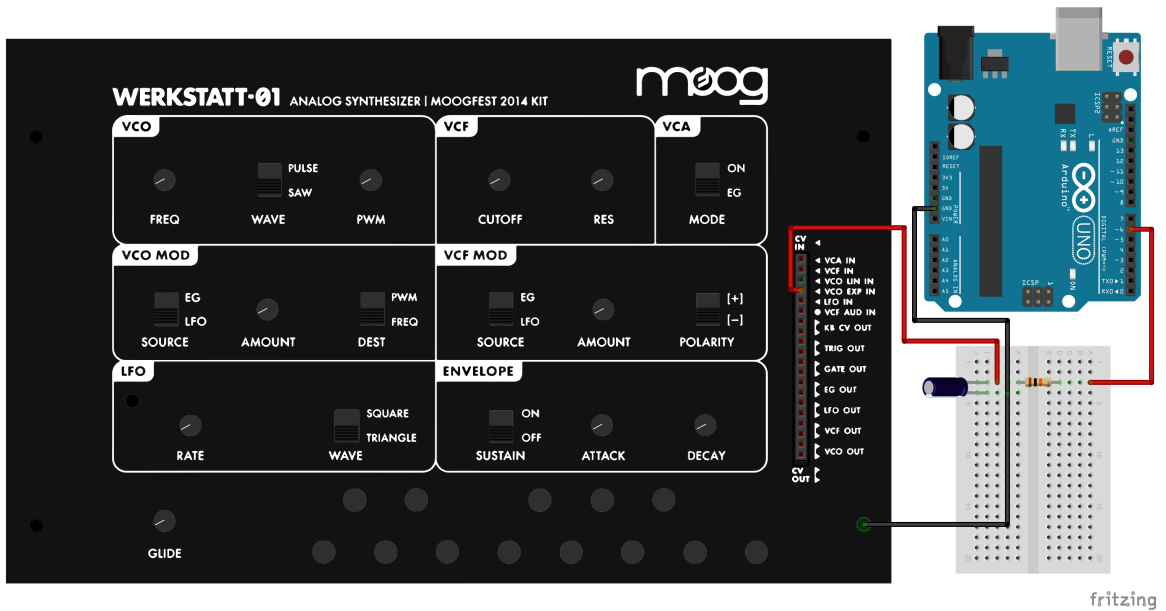
Figure 8. Werkstatt Apeggiator Lesson Fritzing Sktech.

As a way to introduce the principles of design and additive manufacturing, 3D printer

files have been included in many of the lessons. In the preliminary months of research,

similar lessons were requested by many of the schools to expose their students to new

and novel ways to use additive manufacturing technologies.   Refer to Figures 9 through

11 for examples of included printer models for certain modifications included in the

lesson plans.   These enclosures were specifically designed to hold the included mini

breadboard modifications carried out in each lesson.
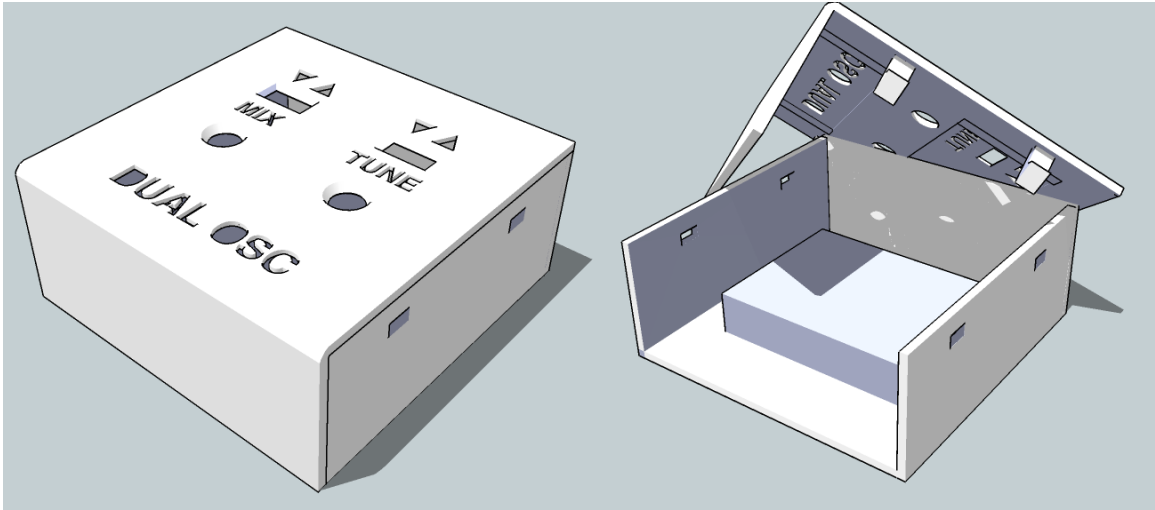
Figure 9. Dual oscillator modification 3D printer tray.
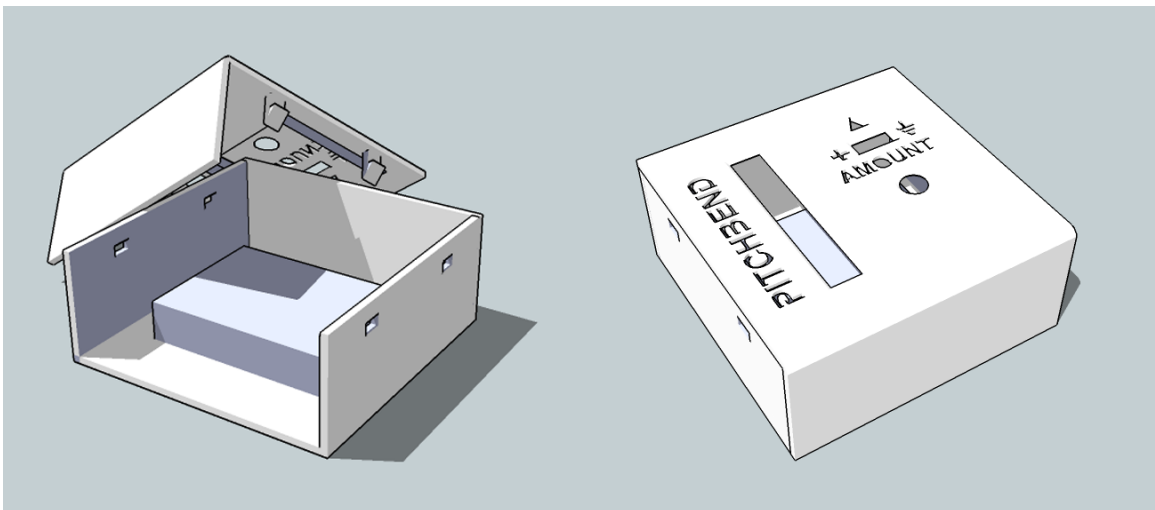
Figure 10. Softpot pitchbend modification 3D printer tray.

Tutorial videos were also created at Moog headquarters in Asheville, NC. Not all modifications currently have associated videos. However, lessons with more difficult builds, or that may be of special interest to the research and curriculum, have associated tutorial videos ranging in length from 2-10 minutes. See Figure 11 and 12 for still images from several tutorial videos.

Figure 11. Dual Oscillator mod housing featured in its tutorial video.

Figure 12. Tuning the VCO for use with the Adruino in the arpeggiator tutorial video.

The website WerkstattWorkshop.com serves as an interactive creative learning portal containing project ideas, mod tutorials, parts lists, educational lesson plans, 3D printer files, and everything else involved with learning and modifying the Werkstatt. Emmy Parker, Moog Music's Director of Marketing, said about the project:

> Analog synthesizers have long had their own maker culture born of curious engineers, physicists and hobbyists who have created and crafted their sounds through electronic experimentation. It is our goal to share our love for learning, music, and electronics by encouraging everyone to create the world they want to hear, one mod at a time.
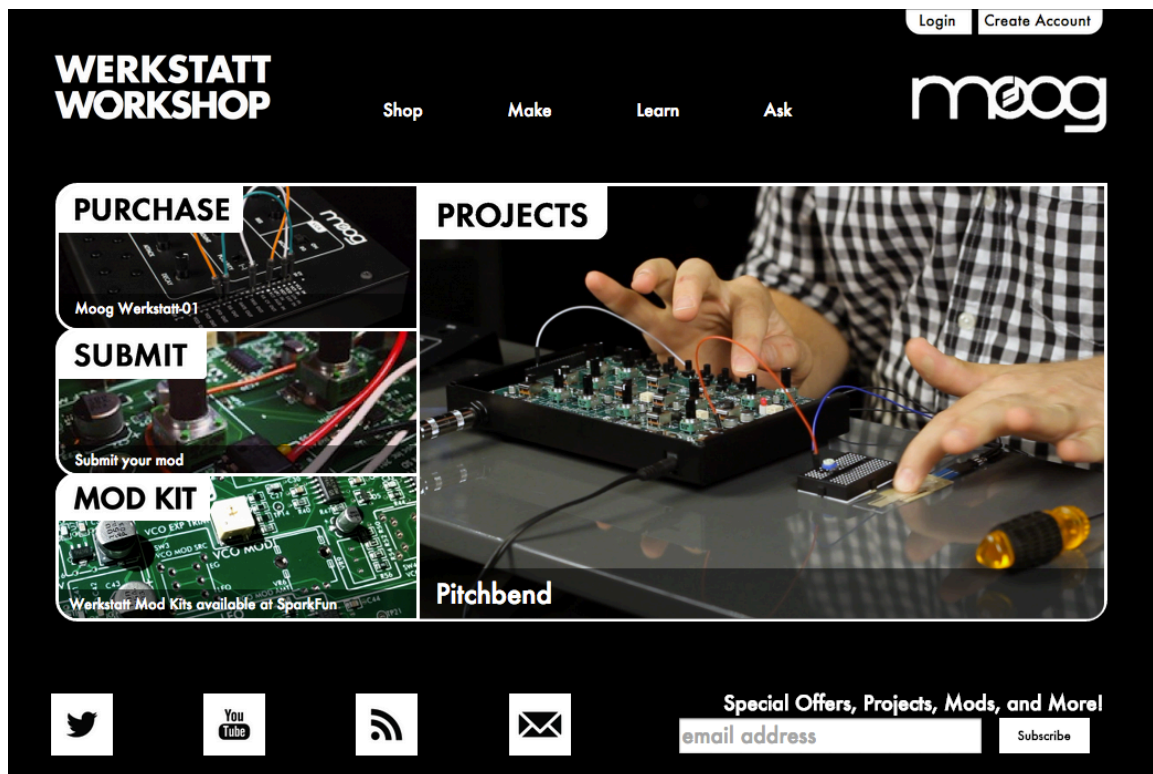
Figure 13. WerkstattWorkshop.com website screen capture

3.3 Curriculum Development

This research includes development of a STEAM curriculum revolving around a Moog synthesizer, specifically the Moog Werkstatt. This curriculum aims to meet the standards presented by either Common Core or Next Generation Science Standards. These standards were selected to ensure compatibility across state school systems within the United States and an easier integration into pilot study school's previously planned lessons (Common Core State Standards Initiative & others, 2012; National Science Teachers Association, 2012).

The Werkstatt is a single-oscillator monophonic analog synthesizer created for the Moogfest 2014 Engineering Workshops. This compact synthesizer features many of Moog's patented circuits, as well as an extensive input/output control voltage pin header for experimentation and modification. This I/O interface is exploited in most educational lessons. Each module of the Werkstatt (VCO, VCF, VCA, EG, LFO) has been delineated into separate learning target objective units. Within each unit four core learning subjects are defined; Science, Mathematics, Music History/Theory, and Engineering/Technology. Each lesson includes vocabulary, an exercise with step-by-step tutorial and images, and practice questions. Target objectives may include Fritzing sketches, 3D printer files (MakerBot, SketchUp), Processing code, and references to an Arduino library. Lessons will also feature a related standard and standard taxonomy link. Refer to target objective VCO.MTH.4 listed in the Appendix under A1 for a detailed lesson example.

The novelty of using an analog synthesizer in an educational context relies on the

diversity of educational opportunities within a single system. By itself, the Werkstatt

offers lessons in electronics, algebra, and the physical sciences. However, by adding a

microcontroller like the Arduino, or other similar introductory MCU, this research is able

to expand its lessons into entry level computing and the fundamentals of

microprocessors. Refer to Figure 14 for a Fritzing representation of an Arduino board.
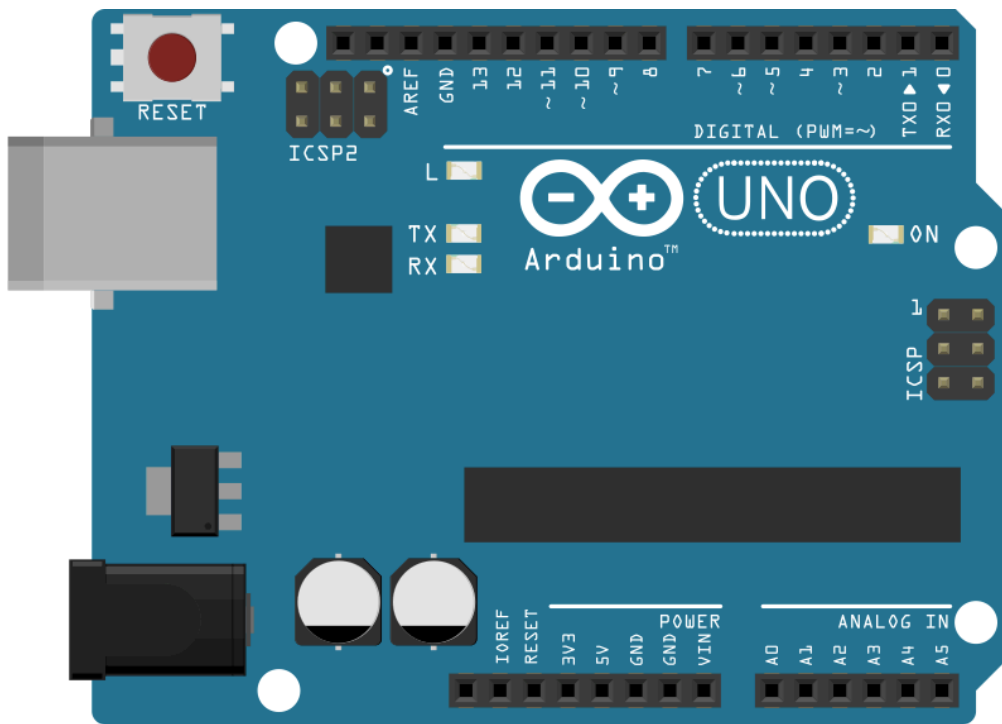
Figure 14. Arduino Microprocessor Board in Fritzing Breadboarding environment.

An example of the novelty presented in Chapter 2 is apparent in target objective

VCF.TECH.3. In this lesson students are tasked with creating an arpeggiator for their

Werkstatt. This extension is created with an Arduino, an open source microcontroller

ubiquitous in technology classrooms, and only two discrete components. By creating a

low-pass RC filter using a resistor and capacitor, students pass digital signals from the Arduino to the analog Werkstatt. Digital signals from the Arduino are formatted as pulse width modulated (PWM) voltages. Once low pass filtered with the included discrete component values, these PWM signals can simulate an analog voltage. Students patch this low-passed signal into the Werkstatt's VCO EXP IN. During this exercise students also tune the Werkstatt's VCO to recognize the musical octave intervals. Once the filter is created and the Werkstatt is tuned, students are then able to program specific interval sequences and note values via changing values in two arrays in the Processing IDE. This lesson exposes the students to concepts in music theory, computing, and electronics, while moving towards a musically interesting and useful end modification to the Werkstatt. For a detailed tutorial of VCF.TECH.4, see Appendix item A2.

Chapter 4. Methodology

4.1 Selected Classrooms

Several age demographics were selected for this study across a variety of classroom models and teaching styles. The purpose of this wide net approach is to explore where a system like the Werkstatt and its accompanying curriculum would have the most significant impact.

The youngest age group studied included sixty 8th graders (22 male, 38 female) engaged in a two-week program in their *Introduction to Computational Media* class. See Figure 12 for a candid shot of this curriculum in action within the 8th Grade classroom. The focus of this unit was entry level programming for microcontrollers and basic wave dynamics. Students used both the Werkstatt and an Arduino microcontroller to achieve these target objectives. A majority of students enrolled in this elective course were novices with little to no previous electronics and computing experience. Curriculum lessons were pulled from the VCO and VCF target objectives, including the lesson VCO.MTH.4, which is presented under A1 in the Appendix.

This classroom follows a project-based learning instructional model taught by Christopher Michaud at the Marist School in Atlanta, GA. Marist is a private school in Cobb County. This school was selected due to the ease of integration of the educational material with teacher Christopher Michaud's current PBL classroom model. Because of

its private school status, curriculum can be greatly dictated at the classroom level without the hierarchal approval of the district. Mr. Michaud has a unique background in that he is a trained concert trumpeter as well as an avid programmer and technologist. This experience made him an ideal candidate for this study.
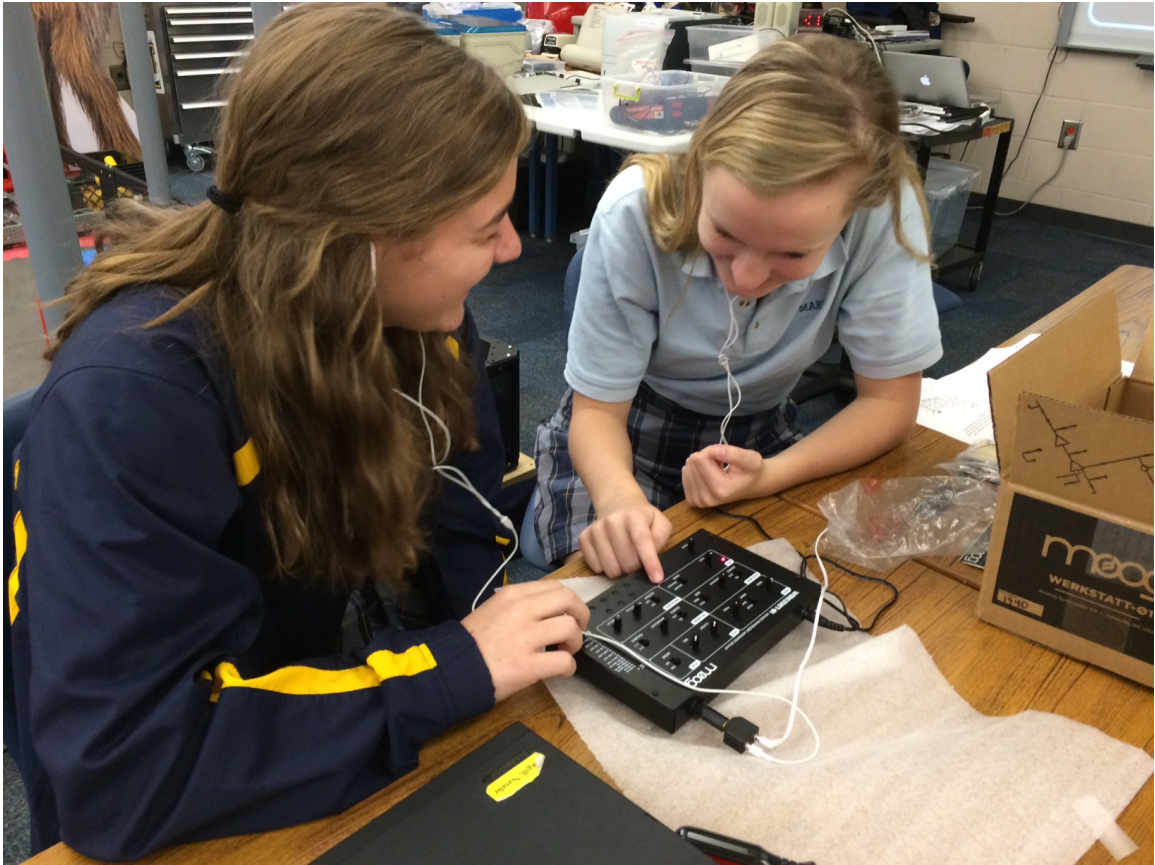
Figure 15. Two students build the Werkstatt on the first day of the 8th grade pilot study.

Additionally at Marist, twelve 10th graders were enrolled in a three-week Electronics course. Focus was on more advanced levels of electronics theory including resistance, capacitance, node analysis, Kirchhoff's Laws, and Ohm's Law. The Werkstatt was the main unit of interest for this course and was used alongside various discrete electronic

components and other basic tools, like the oscilloscope and multimeter. This group

included high performing students in electronics and technology, which added a certain

bias to the results discussed later in this document. This classroom followed a project-

based learning instructional model and was taught by Christopher Michaud.

Marist instructor Christopher Michaud has a long-standing relationship with the Georgia

Tech Center for Music Technology, principally serving as a pilot teacher and initial

developer of the EarSketch system with Jason Freeman. This point of contact allowed

for a direct pathway into his classroom. This ease of curriculum integration and

excitement for new modes of teaching STEM through music led to the final decision of

the Marist School as a pilot study institution.

The second selected institution for this curriculum was the Gwinnett School of

Mathematics, Science and Technology (GSMST). GSMST is a STEM magnet school

featuring class integration, with a heavy focus on Mathematics, Science, and Technology.

In U.S. News & World Report's 2014 Best High Schools in the United States, GSMST

maintained its 3rd place position for the second consecutive year ("Best High Schools in

the US | Top US High Schools | Education - US News"). This very high performing

group was selected to explore the possible opportunities in STEM charter creative

elective courses. Considering the background knowledge of the student body in

advanced science and mathematics, the use of a STEAM-based curriculum in a creative

elective was of special interest to push creative engagement in a rigorous STEM

institution. Twelve 10th -12th graders enrolled in a Music Technology course at GSMST

participated in this section of the study. The course followed an independent learning

model with students given full access to the online portal and encouraged to follow the

lessons on their own (Strayer, 2012). Instructor Michael Appelbaum is the Orchestra

Director and also a skilled recording engineer. Figure 16 shows students experimenting

with the accelerometer modification of the Werkstatt as well as exploring the 3D printed

enclosure projects.
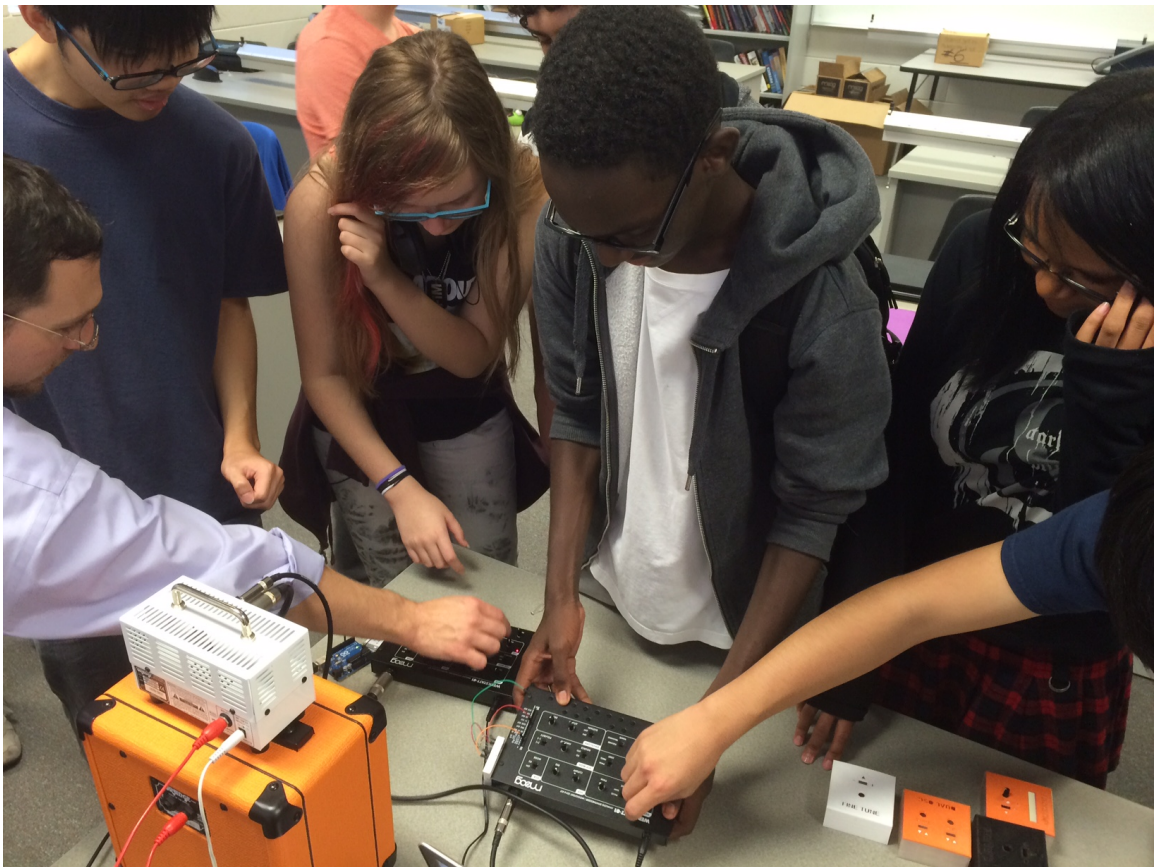
Figure 16. GSMST students utilizing an accelerometer with the Werkstatt.

Throughout the nine-month initial research stage several other schools were consulted

and visited about participating in this study. However, the integration of an authentic

STEAM curriculum proved difficult, given the hierarchical nature of certain school systems. Even though the including lesson plans were tailored for Common Core or Next Generation Science Standards, such an experimental learning model became an obstacle in many potential pilot classrooms. Another issue faced in implementation was limited teacher knowledge and the learning curve of accurately and efficiently deploy such a system. Several schools that self-identified as STEM or STEAM institutions were far along in the acceptance process, only to drop out due to the initial learning curve or to administrative doubts about the experimental model.

The selected institutions present a unique and highly motivated student body that may not be reproducible in all schools. Dozens of traditional high schools were contacted to participate, however the integrated nature of the study proved difficult to move through all necessary levels of bureaucracy. To ensure teacher confidence in the material as well as curriculum fidelity, future exploration in teacher professional training is warranted. Teaching training could take the form of weekend workshops or in-school interventions coordinated before curriculum deployment. Teachers may also be encouraged to enroll in said workshops by including professional development/learning units. However, formal research in this domain was outside of the scope of this study.

4.2 Procedure

Research methodology took the form of a quasi-experimental/one-group pre-test/post-test design. During the course of these pilot studies, selected educators deployed analog synthesizers to fulfill a wide variety of curriculum requirements. This STEAM curriculum was made available for teachers through an online portal, www.werkstattworkshop.com. Educators were encouraged to pick and choose what standards would best fit their use, and no pacing guide was enforced. No specific teacher training was provided outside of the online portal.

Students were asked to complete a pre/post knowledge test, a retrospective pre/post engagement survey, and possibly participate in a focus group. Focus group participants were elected by the teacher on the basis of a students' overall improvement and engagement with the lessons. Instructors were encouraged to select both students that showed interest and disinterest throughout the intervention to lend diversity to the focus groups. Pilot studies were expected to have a total of 12-14 student contact hours. Instructors documented what target objectives they selected to deploy in their classrooms, and these subjects were reflected in the line of questioning in the pre/post-content knowledge assessments.

The first lesson of each deployment closely followed the Werkstatt Workshop model, including a short Moog history lesson, a build phase, and a sound synthesis overview. All lessons after this introductory session were led by the individual instructor and were tailored to meet the goals of that specific classroom, i.e. a focus on microcontrollers and

programming in *Introduction to Computational Media,* or discrete electronics

components in *Advanced Electronics*.

4.3 Evaluation

Evaluation of test data took the form of quantitative and qualitative analysis.

Quantitative data was retrieved via the pre/post content knowledge assessment (CKA)

and a retrospective pre/post engagement survey. CKA questions were developed

individually during target object formation, accommodating for two-to-three questions

per specific objective. These target object questions were then assembled into a final

CKA based on which lessons were selected by the instructor. A pre/post-content

knowledge exam has been selected for the integral role it plays in a quasi-experimental

one-group pre-test/post-test methodology (Millsap & Maydeu-Olivares, 2009; Panter &

Sterba, 2011). Refer to the Appendix item A2 for an example of one of the Content

Knowledge Assessments. Sections of each CKA focus on wave dynamics, basic

formulas needed for electronics, and the fundamentals of music. Quantitative analysis

techniques utilized on the CKAs include Mean, Standard Deviation, and Percentage of

Change. This study's goals in STEM literacy are to show content knowledge increase

across multiple disciplines through the use of an analog synthesizer, specifically the

Moog Werkstatt, as a learning tool.

This study chose a retrospective pre/post engagement survey in favor of a separate pre

and post-survey to avoid data contamination from negative shift bias (Howard, 1980;

Howard & Dailey, 1979). The survey was broken into several constructs, each containing

at least three questions; each construct will first be analyzed separately, and then discussed together. Presented retrospective pre/post-survey constructs include Confidence in Science and Mathematics, Confidence in Engineering, Interest in Music Technology, Interest in Synthesizers, Confidence in Music, and Intention to Persist. The above constructs were informed by the Computer Attitude Questionnaire presented by Knezek et al. (Knezek & Christensen, 1996). The overall structure also closely mirrored that of the EarSketch study (Freeman et al., 2014). Several consultant meetings with the SageFox Consulting Group enhanced this close procedural relationship to Freeman's work. SageFox specializes in education research, evaluation, and grant support services for both K–12 and higher education, and was the data analysis group that worked on the EarSketch project.

Students were asked to respond to both positive and negative positional questions along the Likert scale. (Albaum, 1997) Refer to item A3 in the Appendix for an example of the retrospective pre/post survey. Quantitative analysis includes limited t-tests of statistical significance due to our lack of a control group. Other measures of quantitative analysis on the retrospective pre/post will include mean, standard deviation, percentage of change, and Pearson's correlation coefficient. This study's goal is to show a positive correlation between increase in STEM confidence and interest in music technology through the use of an analog synthesizer in the classroom. Additionally, the study aims to show an engagement of under-represented groups in STEM education.

Qualitative analysis uses the progressive focusing method of focus group interviewing to ensure a greater whole is taken into consideration and interrelated concepts between groups are observed (Berg & Lune, 2004). Studies that lack a control group are open to significant criticism due to a host of scientific caveats. This project hopes to avoid some of these scientific contaminators by keeping the study short and focusing on material that would not be specifically learned in everyday life (Eckert, 2000). In addition to focus groups including participating students, a write-in questionnaire was requested from the instructor to gauge perceived engagement and success as well as any recommendations. It is the intent of this study that after the deployment of student lessons, we will see higher knowledge exam scores and a correlation between STEM field confidence and Music Technology interest in under-represented groups.

Chapter 5. Results & Discussion

Due to the wide variety of age demographics, core subjects, and classroom models, the results of each pilot study will be presented separately. Brief descriptions, graphs, and discussion of results will be presented independently in each section.

This chapter will also delve deeper into each pilot study's results and attempt to pull out greater narratives from this data. This discussion not only includes related literature references, but qualitative data via focus groups. Focus groups were held for both Marist and Gwinnett School of Science, Mathematics, and Technology to provide a voice to participating students (Berg & Lune, 2004).

5.1 GSMST Music Technology

This section presents the results of the Music Technology pilot at the Gwinnett School of Science Mathematics and Technology. The study at GSMST ran from November 2014 through January 2015. The extended run of this pilot study was due to the inverted classroom model followed by instructor Michael Appelbaum. This teaching style encourages the students to exploit technology to teach themselves and ask questions when needed during class time (Strayer, 2012). The study included nine students – three females and six males. Ethnic demographics were predominantly Asian American followed by African American. Unfortunately, due to the small class size, no one

specific group could be extracted for analysis, so all data analysis will only be conducted on the full sample size.

5.1.1 GSMST Music Technology Results

Table. 1 GSMST Before/After CKA Correct Answers

	Before	**After**
Mean	**21.8**	**22.1**
Standard Deviation	**5.1**	**6.4**

Table 1 shows the mean and standard deviation pre and post-Content Knowledge Assessments. Considering the non-traditional teaching model no single student followed an identical target objective pathway, therefore, all 35 questions were included in the CKA. The majority of students were already high performing before intervention answering 25+ questions correctly, with a mean of 21. A very small increase in the mean is seen after intervention. The high-performing nature of students at GSMST is underscored by the average 5% increase post intervention. The minimal mean increase from 21.8, an already high score out of a 35-question test, to 22.1, suggest that little was gained post-intervention in relation to the CKA.
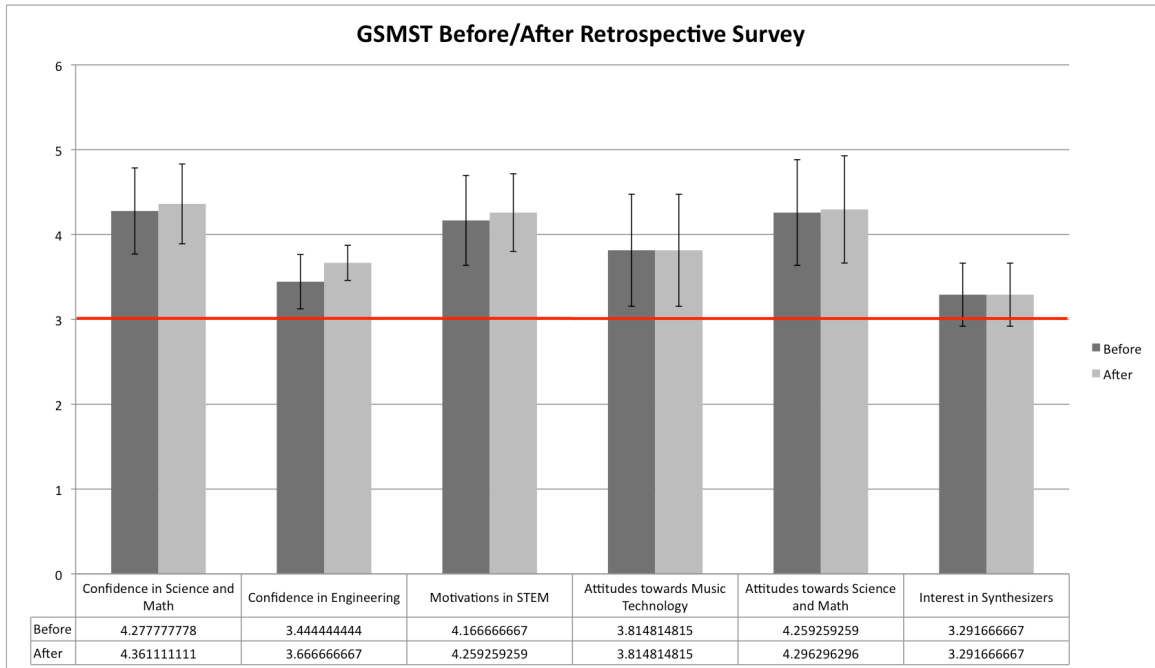
GSMST Before/After Retrospective Survey

	Confidence in Science and Math	Confidence in Engineering	Motivations in STEM	Attitudes towards Music Technology	Attitudes towards Science and Math	Interest in Synthesizers
Before	4.277777778	3.444444444	4.166666667	3.814814815	4.259259259	3.291666667
After	4.361111111	3.666666667	4.259259259	3.814814815	4.296296296	3.291666667

Figure 17. GSMST Retrospective Pre/Post Survey Before/After Average Answers per Construct

Figure 17 shows the average answer across constructs on the retrospective pre/post-survey. The before average per construct is represented as the dark grey, while the after average per construct is in light grey. The red line demarcates the neutral point on the Likert scale. Standard deviation around the mean is shown in black lines on top of each column. As an already high-performing group at GSMST, it is readily obvious that all means are above the neutral line, even before the study. The most interesting data presented belongs to the Confidence in Engineering construct, which presents the highest jump in before/after averages, as well as the narrowest standard deviation, indicating a stronger relationship.   However, with a p-value = 0.1037, the statistical significance of this finding is in question. Usually a p-value of .05 or less is desirable to show true statistical significance. A possible reason for this result would be the very limited sample size presented at GSMST.

44
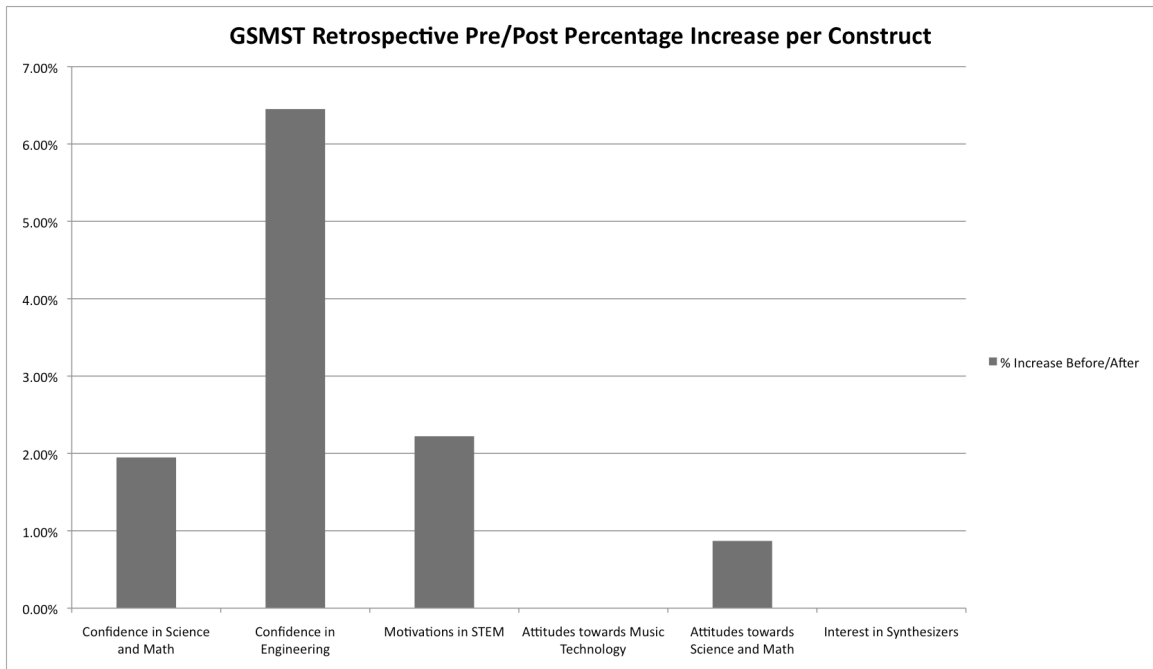
Figure 18. GSMST Retrospective Pre/Post Survey Percentage Increase Per Construct

Figure 18 presents the overall percentage change between constructs on the retrospective pre/post survey. As was visually apparent in the previous figure, the percentage change in the Confidence in Engineering construct is the highest, at 6.45%. However, as discussed earlier the dubious p-value shows a possible lack of statistical significance. Notably, zero increase was seen in both Attitudes toward Music Technology and Interest in Synthesizers. This was a particularly interesting finding considering the class, Music Technology, was specifically a creative one. However, during the focus group with selected students from this pilot study a specific narrative emerged that explains this data.

5.1.2 GSMST Music Technology Discussion

With such a high-performing student body, the increase in content knowledge and overall engagement was negligible. In reference to Table 1, one can see that an increase did occur, but not on a substantial scale. Most students increased their content knowledge by one-to-two correct answers as is evident in Table 1. This can be explained by the already high-performing nature of this student body.

Moving on to the retrospective pre/post-survey, this study observed similar results in Figure 18. This shows the average response on a Likert scale to specific constructs and one can see that all students started above the neutral zone, with already a great deal of confidence and knowledge. The most interesting data from this group lies in Figure 18, where this study observed a large upward increase in Confidence in Engineering , with absolutely no increase in Attitudes Towards Music Technology or Interest in Synthesizers.

This increase in engineering confidence at an already high performing STEM magnet is of special interest. One plausible explanation for this trend is the analog synthesizer's opportunity for hands-on learning experiences. Stohr-Hunt states that hands-on exercises in the science classroom greatly increase retention. (Stohr-Hunt, 1996) Even though GSMST is a STEM magnet, that does not necessarily mean all courses are based on the project-based learning model. By giving the students an opportunity to explore an authentic musical tool hands-on, an increase in this construct is plausible. For more specific insight a focus group was held with selected students. When asked about

continuing hands-on electronics projects relating to music technology a female sophomore stated:

"I find it more interesting, after working with it I want to go deeper into it" – female sophomore, GSMST.

This quote seems to solidify this study's reasoning for an increase in the Confidence in Engineering construct.

The lack of any increase in both the Attitudes Towards Music Technology and Interest in Synthesizers was initially puzzling. Given that these were high performing students who electively took a course in Music Technology, one would assume their interest would be peaked in this domain. It was not until our focus group that this trend started to make more sense. Michael Appelbaum follows an inverted classroom style where little lecturing occurs and students are encouraged to use virtual resources to learn and ask questions when needed (Strayer, 2012). Even though Mr. Appelbaum is a skilled musician and recording engineer, his traditional STEM education skill set is not that of a STEM teacher. An issue faced by many students was lack of teacher knowledge in the subject, therefore when a question was posed no answer was readily available. When this issue was discussed in the focus group, student thoughts such as this were common:

"If it was a group effort…if we paired with physics and computer science teachers this (the study) would have been fine but without the base background it was different." – male senior, GSMST.

One might interepret his use of the word "different" and inflection in the recording of this quote as a nice way of saying unsuccessful. Lack of teacher experience and content knowledge was always a possible caveat of deploying this curriculum in a Music-specific classroom. By seeking out a high-performing STEM magnet and a Music Technology classroom, this research attempted to ensure success. However, the combination of the inverted classroom and lack of instructor background seems to have played a large role in this success rate of this deployment.

Another factor that had an impact on the data was the nature of this elective, and its culture within GSMST at large. As the 17th most difficult high school in the nation, GSMST brings with it a great deal of student pressure ("National Schools - The Washington Post"). When asked about student resistance to STEM educational lessons in their elective music course a senior led the group in a unanimous discussion stating:

"There was a lot of resistance…we are already under so much pressure… academics are already pushed so hard…we are forced into AP classes… we want to escape" – male senior, GSMST.

These students saw Mr. Appelbaum's Music Technology course as a creative escape from their rigorous educational workload. The attempt to focus on engineering and computing concepts within the music technology domain was not accepted because of its close correlation to their already intense STEM education curriculum.

5.2 Marist – Advanced Electronics

Results and discussions from the 10th grade Advanced Electronics deployment of the Werkstatt curriculum at the Marist School are presented below. Mr. Michaud uses his Advanced Electronics course to cover concepts in resistance, capacitance, and electronics basics as well as circuit analysis techniques of Ohm's Law and Kirchhoff's Law.

5.2.1 Marist Advanced Electronic Results

Table. 2 Marist Advanced Electronics Before/After CKA Correct Answers

	Before	After
Mean	11.3	18.75
Standard Deviation	3.6	4.9

Table 2 shows the mean and standard deviation of correct answers on the Marist 10th grade Advanced Electronics CKA's. Before data is shown in the left column, and presents that most students answered 10-15 questions out of 25 correctly before the intervention with a mean of 11.3. Post-intervention data is presented in the right column and displays a trend of increased content knowledge with a mean of 18.75. This data

shows that many students answered close to 25 questions correctly out of a 25 question CKA after curriculum deployment. The majority of students increased their content knowledge by 25%.
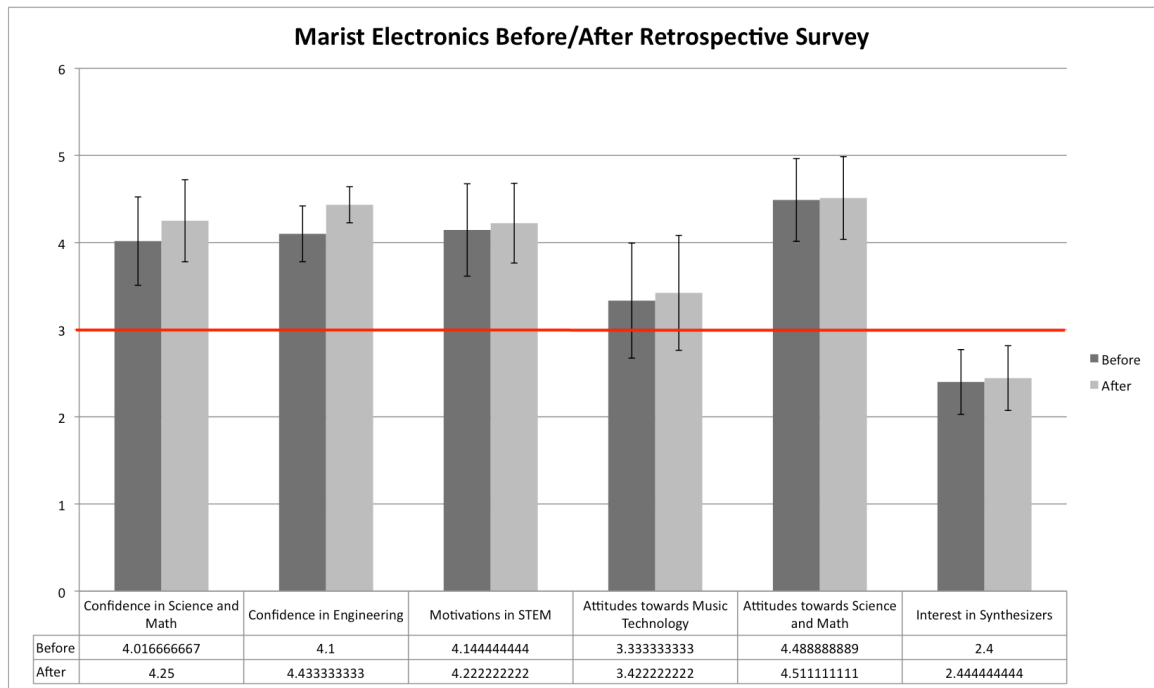

Figure 19. Marist Advanced Electronics Retrospective Pre/Post Survey Before/After Average Answer per Construct

Figure 19 shows the average answer across constructs on the retrospective pre/post survey. The before average per construct is represented as the dark grey while the after average per construct is in light grey. The red line demarcates the neutral point on the Likert scale. Standard deviation around the mean is shown in black lines on top of each column. As an already high-performing group in an Advanced Electronics course, most students were well above the neutral line, even before intervention. However, in contrast

with the GSMST data, we see that this group's interest in synthesizers is below what our music technology students presented with.
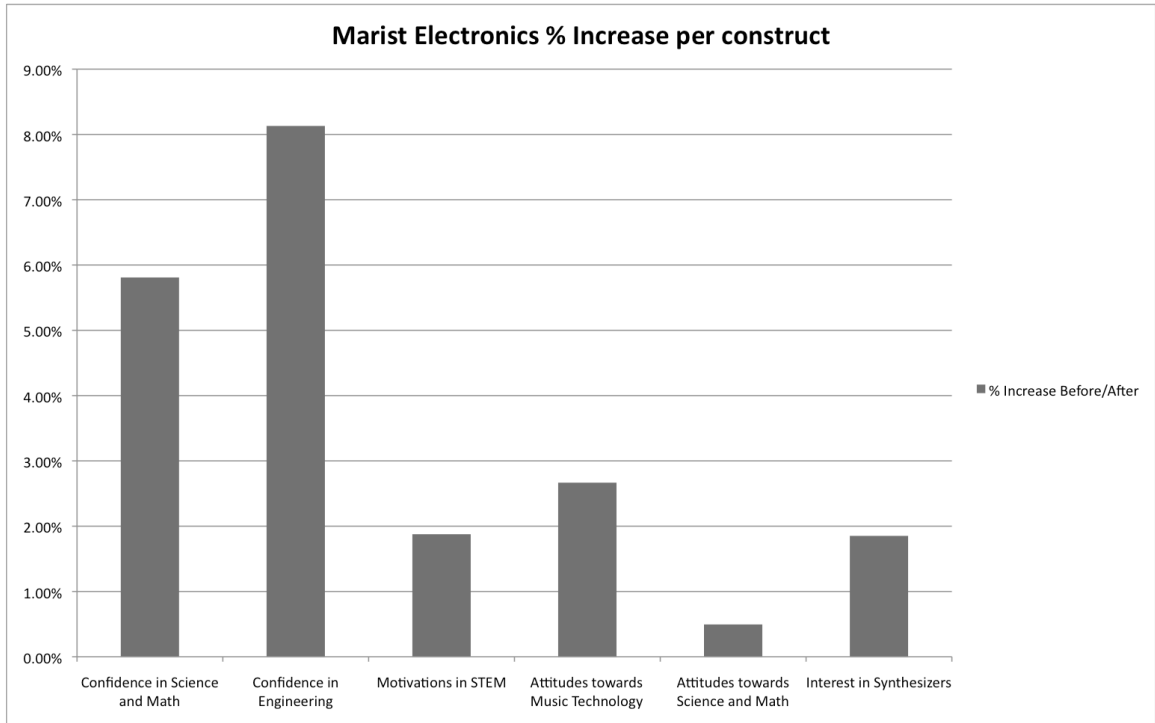

Figure 20. Marist Advanced Electronics Retrospective Pre/Post Survey Before/After Percent Increase per Construct

Figure 20 presents the percentage change between before and after means of each construct within the retrospective pre/post-survey. Confidence in Engineering dominates the chart with an 8.13% increase. After a t-test this data returns a p-value = 0.00067, making this result well within statistical significance and something to note for discussion. Similarly, Confidence in Science and Mathematics are increased by 5.81%, which is still encouraging when one takes into account the already high performing nature of this group. With a p-value = 0.0012, the statistical significance of this construct's increase is also well worth future exploration in Chapter 6. The Attitudes

Towards Music Technology show an increase of 2.67%; however, with only a p-value of

0.15, the significance of this result is in question. Table 3 shows the top three construct

increases with their p-values and percentage increases.

Table 3. Top Three constructs with corresponding p-values for Marist Advanced Electronics

Construct	Confidence in Engineering	Confidence in Science and Mathematics	Attitudes towards Music Technology
% Increase	8.13%	5.81%	2.67%
P-value	.00067	.0012	.15

5.2.2 Marist Advanced Electronics Discussion

Christopher Michaud's Advanced Electronics course at Marist served 10th and 11th

graders interested in electronics as an elective. This group was of an older age

demographic and specifically interested in the content material, and this is apparent in the

data. Table 2 shows the correct answers per student on both before and after content

knowledge assessments. All students were high-performing to begin with, with no

student getting fewer than ten answers correct on the pre-intervention CKA. However, if

one compares and contrasts this data against GSMST, this group came in with a lower

understanding. An upward trend is seen as students' post-intervention performed

markedly better, with the majority of participants answering over twenty-five questions

correctly on the post-CKA. This data becomes underscored by what is presented in

Figure 19, the percentage change between pre and post CKA's. With a peak at 25% and

equivalent data at 50% increase and 5% increase, an upward trend is apparent. A 5%

increase in pre/post-CKA can be explained by a student body that is already high

performing, starting with a high pre-CKA with little room for improvement possible before a perfect score is obtained.

Figure 19 presents the retrospective pre/post survey average, displaying a group of students that already have an interest and confidence in STEM and Music Technology. More interesting data can be found in Figure 20, which presents the percentage change between pre and post-intervention survey answers. This study presents large increases in Confidence in Engineering and Confidence in Science and Mathematics on the order of 8.13% and 5.81% respectively. With p-values well within statistically significant ranges, one can take these results as being indicative of a true increase in overall STEM confidence. When students were asked about building their own instruments, a unanimous decision was that they were more confident in hands-on engineering practices post-intervention. When asked how it made them feel after building the Werkstatt a sophomore said:

"You made it, it's your accomplishment" – male sophomore, Marist.

In Figure 19, this study presents that the Attitudes Towards Music Technology construct is showing an increase at 2.67%, with a p-value = 0.15. Even though this significance is questionable we wanted to have a better understanding of this data point. When asked how they saw music and technology interacting through these lessons with the Werkstatt, a sophomore said:

"(He)…drew new relationship between music and electronics, doing it hands-on gives you a whole new understanding of it." – male sophomore, Marist.

This shift towards hands-on and project-based learning methods is a mirroring of the positive responses described in the GSMST study. This trend towards PBL in the engineering classroom is an extension of the constructionist educational paradigm presented by Mitch Resnick, Leah Buchely, and others at major technical research universities (Buechley et al., 2007; Resnick et al., 2005).

Michaud's instructional style is more project-based. This allows for an interesting opportunity to compare and contrast between the inverted classroom and project-based instructional methods. The data presented possibly shows a better success rate and overall outcome from a more hands-on method. When asked about their instructional method preference during our focus group a freshman said:

"I wouldn't really know the whole frequencies or what a lot of the stuff meant, if it was informal you'd have no clue what you were doing" male freshman, Marist.

Several other students held this opinion; however, one would have preferred an inverted classroom model. From this particular student's described background it appeared that they may have been bored with many of the lessons due to their already above average incoming electronics experience.

Marist instructor Christopher Michaud was asked to complete a post-study questionnaire based on his personal experience with the curriculum, lesson plans, and the Werkstatt itself. Overall comments were positive, with several organizational suggestions for the website and lesson plans that will be discussed in Section 6.5. However, something mentioned that is of particular interest to this research is the most desirable age demographic for deployment. Christopher Michaud stated in his questionnaire that he "…predicts higher success with 9th graders." This perceived younger age demographic success rate is brought to fruition in Section 5.3 and discussed at length.

5.3 Marist – Introduction to Computational Media

This section presents the results of the 8th grade Introduction to Computational Media Marist pilot study are presented. Since the sample size of this group was much larger and more diverse then either previous pilot studies, sixty 8th graders (22 male, 38 female), additional analysis will be presented comparing results across gender. Considering that an aim of this research is to engage under-represented groups, the ability to specifically look at female engagement and success is of special interest. Unfortunately, this study still lacked enough data to perform a majority vs. minority comparison.

5.3.1 Marist Computational Media Data

Table. 4 Marist Computational Media Before/After CKA Correct Answers

	Before	After
Mean	3.2	7.4
Standard Deviation	1.7	2

Table 4 presents the mean and standard deviation of before and after correct answers on the Marist 8th grade Introduction to Computational Media Content Knowledge Assessments. Before data is presented in the left column, and illustrates a mean of 3.2. After data is presented in the right column and displays a trend of increased content knowledge with most students achieving nine or more correctly answered questions providing a mean of 7.4. These numbers are presented out of a CKA with 15 questions in total.

Table. 5 Marist Computational Media Before/After CKA Correct Answers, Male

	Before	After
Mean	3.6	7.5
Standard Deviation	1.79	2.08

Table. 6 Marist Computational Media Before/After CKA Correct Answers, Female

	Before	After
Mean	3	7.39
Standard Deviation	1.75	2.06

Tables 5 and 6 separate the mean and standard deviation of the pre/post-CKA correct answers across gender lines. It is observed that males present with a slightly higher mean in both pre and post intervention data, around the order of 0.5. However, both genders increase at almost identical rates, with quite similar standard deviations.
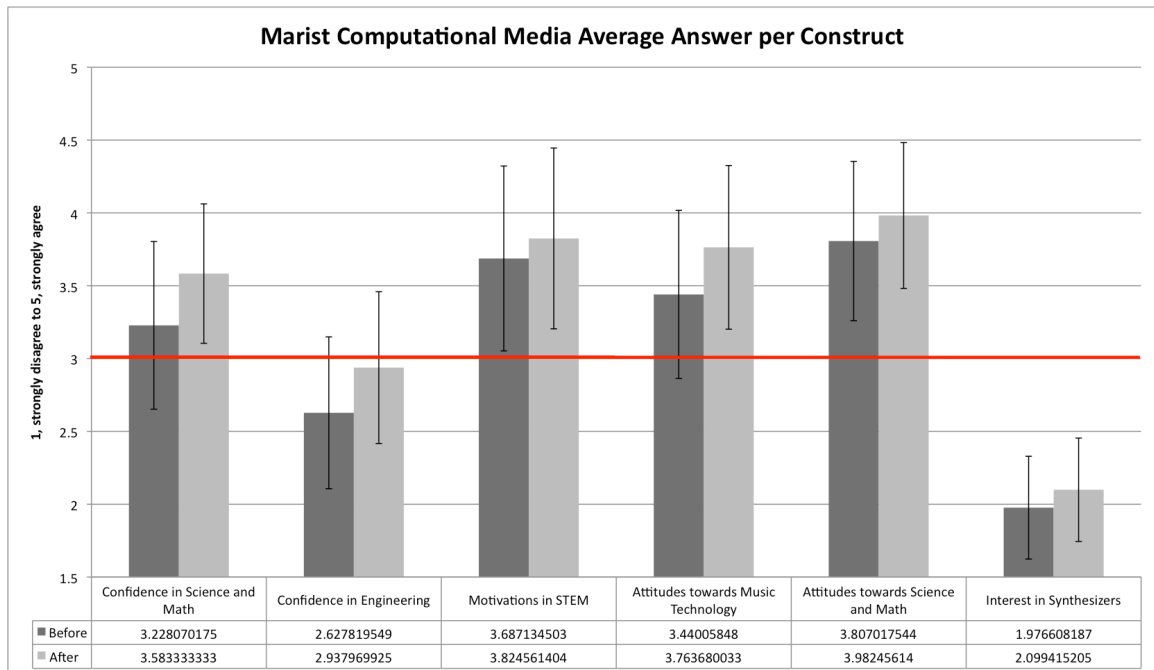

	Confidence in Science and Math	Confidence in Engineering	Motivations in STEM	Attitudes towards Music Technology	Attitudes towards Science and Math	Interest in Synthesizers
Before	3.228070175	2.627819549	3.687134503	3.44005848	3.807017544	1.976608187
After	3.583333333	2.937969925	3.824561404	3.763680033	3.98245614	2.099415205

Figure 21. Marist Introduction to Computational Media Retrospective Pre/Post Survey Before/After Average Answer per Construct

Figure 21 shows the average answer across constructs on the retrospective pre/post survey. The before average per construct is represented as the dark grey while the after average per construct is in light grey. The red line demarcates the neutral point on the Likert scale. Standard deviation around the mean is shown in black lines on top of each column. With a very wide standard deviation, this study observed increases across all constructs, particularly Confidence in Science and Math, Confidence in Engineering, and Attitudes Towards Music Technology.
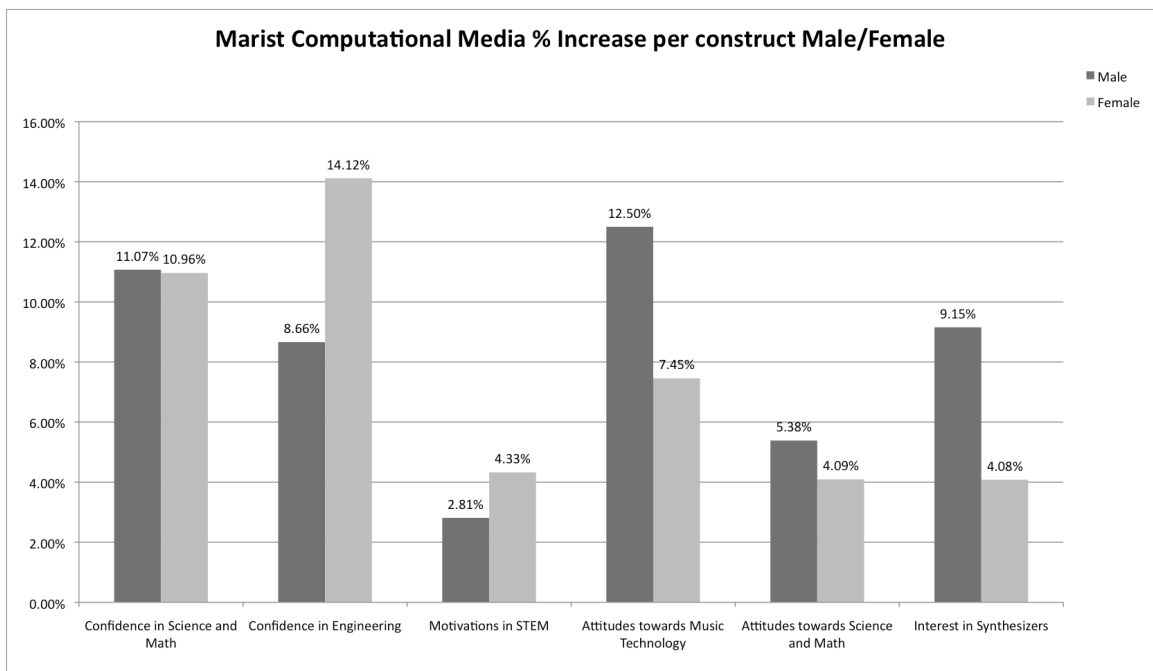
Figure 22. Marist Introduction to Computational Media Retrospective Pre/Post Survey Before/After Percent Increase

Figure 22 shows the percentage change before and after intervention separated between genders. Male percentage change is show in dark grey while female percentage change is in light grey.

For females the greatest increase is seen in Confidence in Engineering at 14.12%, and with a p-value = < .00001; this is clearly a significant result. The second strongest increase for females lies in the Confidence in Science and Math construct at 10.96% and a p-value = < .00001, which is also an incredibly significant p-value. Thirdly, females showed an increase in their Attitudes towards Music Technology of 7.45% with a p-value = 0.000405. Other constructs show an increase of 4% +, which are still considerable, but trumped by the previous three data points.

Table 7. Top Three constructs with corresponding p-values for Marist Introduction to Computational Media, Female.

Construct	Confidence in Engineering	Confidence in Science and Mathematics	Attitudes towards Music Technology
% Increase	14.12%	10.96%	7.45%
P-value	< .00001	< .00001	.0004

For males the greatest increase is seen in Attitudes towards Music Technology at 12.5% with a p-value = 0.0145, suggesting that this increase is statistically significant. Males showed a second increase in Confidence in Science and Mathematics at 11.07% with a p-value < .00001, which is another incredibly statistically significant p-value. Thirdly, males showed an increase in Interest in Synthesizers at a rate of 9.15% with a p-value = 0.057, which is just barely statistically significant.

Table 8. Top three constructs with corresponding p-values for Marist Introduction to Computational Media, Male.

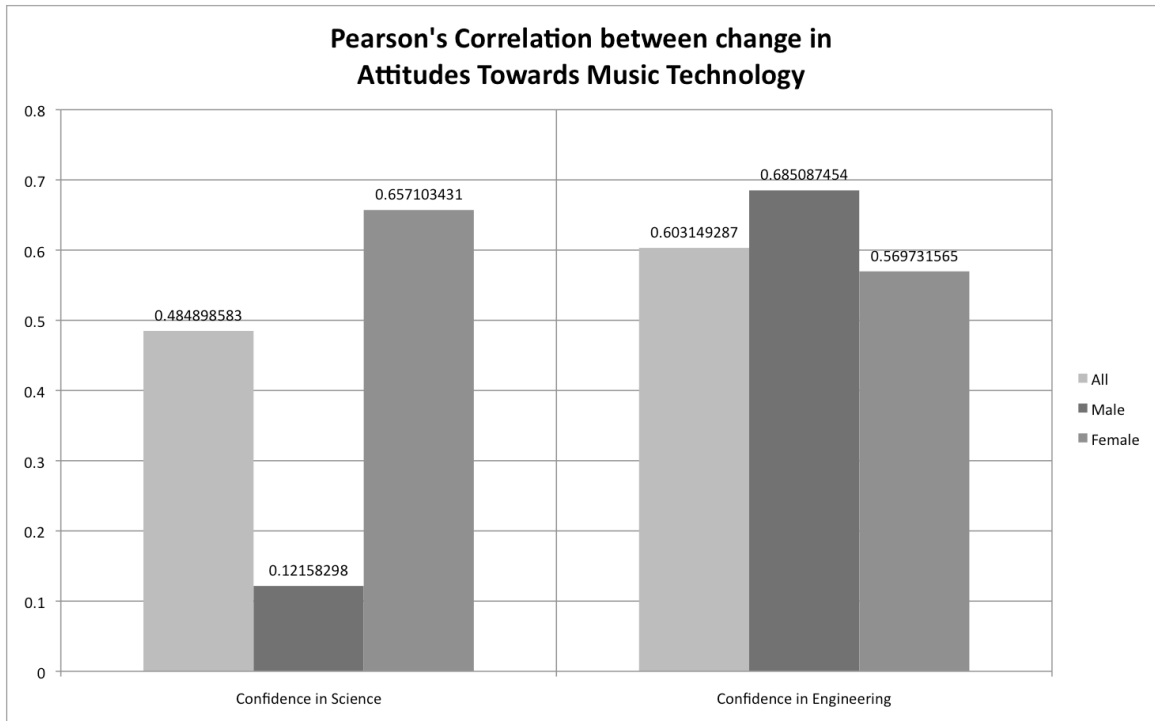| Construct	Attitudes towards Music Technology	Confidence in Science and Mathematics	Interest in Synthesizers
% Increase	12.5%	11.07%	9.15%
P-value	.0145	< .00001	.057

Figure 23. Marist Introduction to Computational Media Retrospective Pre/Post Survey Pearson's Correlation Coefficient between Genders

Figure 23 presents the Pearson's correlation coefficients *r* between several constructs from the retrospective pre/post separated by gender. Lightest grey column presents total correlation; darkest grey presents male-only correlation, and the medium grey presents the female-only correlation. Correlation is calculated between the constructs of

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Confidence in Science and Mathematics or Confidence in Engineering and Attitudes Towards Music Technology.

It is generally accepted that anything above $r = .4$ is considered a strong positive correlation. (Lee Rodgers & Nicewander, 1988) The presented graph shows that this study presents that a strong positive correlation, $r > .4$, exists between all tested constructs, excluding male Confidence in Science and Mathematics and Attitudes Towards Music Technology. Highest correlation is found between female Confidence in Science and Mathematics and Attitudes Towards Music Technology, $r = 0.65$, as well as male Confidence in Engineering and Attitudes Towards Music Technology, $r = 0.68$. As a rule of thumb an $r > 0.7$ indicates the strongest positive correlation; the highest correlation coefficients are close to that ceiling ("Pearson's r Correlation – A Rule of Thumb," n.d.).

5.3.2 Marist Computational Media Discussion

Christopher Michaud's 8th grade Introduction to Computational Media course focuses on introducing a pre-high school age demographic to a wide range of technologies including programming, microprocessors, circuits, professional light and audio, and robotics. This particular pilot features the youngest age demographic studied. Additionally, this study included the largest sample size, sixty 8th graders (22 male, 38 female), allowing for greater confidence values and an analysis of underrepresented groups in STEM education.

Table 4 shows the before/after mean and standard deviation of the pre/post content knowledge assessments. This study observed a clear trend of increasing knowledge with the mean jumping from 3.2 questions answered correctly to 7.4. A majority of students increased their scores to nine questions answered correctly while some excelled to 15 correct answers. Tables 5 and 6 present both male and female increase their correct scores on the post-CKA at almost identical rates. A majority of students showed a 25% increase in pre/post CKA scores. This data point reinforces studies that suggest that when female students are provided with the building blocks they need to succeed in STEM they will do as well if not better than their male counterparts. Milto et. al found that while males did somewhat better on STEM pre-tests than females, females did as well as the males on the post-test following intervention. (Milto et al., 2002) Clearly the study was an effective tool to increase STEM knowledge, particularly with females.

Figure 21 presents the retrospective pre/post survey average results with standard deviations and the neutral response delineated by a red line. This presents the largest increases in the study, as well as the lowest starting point for many constructs. This low data floor is explained by the lower entrance knowledge and younger age demographic of the participants.

Figure 22 presents the retrospective pre/post survey percentage increase per construct along gender lines. For males, the top three increases were seen in Attitudes towards Music Technology at 12.5%, p-value = 0.0145, Confidence in Science and Mathematics at 11.07%, p-value = < .00001, and Interest in Synthesizers at a rate of 9.15%, p-value =

0.057. There seems to be a strong correlation between music technology and confidence throughout this study, and with this larger sample size a correlation coefficient can be calculated. Figure 23 displays this correlation through the calculation of Pearson's correlation coefficient r. The most prominent result for males was Confidence in Engineering and Attitudes Towards Music Technology, $r = 0.68$. These increases in male confidence and interest are not only proven statistically significant, but quantifiably show a positive correlation between STEM education and creative engagement through music.

A group of special interest to this study is the females in the 8th grade Introduction to Computational Media class. Figure 21 presents that this study's largest female increase is seen in the Confidence in Engineering construct at 14.12%, with a p-value = < .00001. This is the largest percentage increase seen in the study, and with such a p-value clearly a statistically viable one. Following female increases are in Confidence in Science and Math at 10.96%, p-value < .00001, and Attitudes towards Music Technology at 7.45% , p-value = 0.000405. These increases show great promise for increasing STEM appreciation and achievement in the under-represented demographic of young girls.

According to the National Center for Women and Information Technology (NCWIT), only 21% of computer science degrees were awarded to women in 2006. Within the past decade, higher education has experienced a rapid decline in the number of women STEM fields. (Kulturel-Konak, D'Allegro, & Dickinson, 2011). Between 2005 and 2006, 60% of degrees in the United States were awarded to women; however, only 11% of computer engineering and 15% of computer science degrees went to females (Nagel). A gender

study of computer science majors at Carnegie-Mellon University found that male students came prepared with a higher computer skill set than their female counterparts. (Milgram, 2011) Clearly, there is a deficit of girls and women in STEM fields and this study has shown positive impacts within this group.

A popular argument for this gender discrepancy is the gendered nature of young girls at play in early childhood. At large, girls play games that underscore relationships (playing house, dolls) and creativity (painting, drawing, color books). This is in contrast to boys who play games that focus on problem solving (video games) and spatial relationships/hands-on skills (blocks, LEGO®) (Ross, 2012). Many studies have shown a strong correlation between spatial skills, or spatial visualization, and advancement in STEM (Lubinski, Benbow, Shea, Eftekhari-Sanjani, & Halvorson, 2001; D. L. Shea, Lubinski, & Benbow, 2001). Music has been shown to increase brain plasticity and neural effectiveness in the region that controls spatial skills (Gaser & Schlaug, 2003; Rosenkranz et al., 2007). A possible reason for this female increase in STEM confidence and literacy is through musical engagement and encouragement of these spatial skills.

Figure 23 presents a correlation between STEM constructs and creative constructs of the retrospective pre/post survey. Female correlation is observed in Confidence in Science and Mathematics and Attitudes Towards Music Technology, $r = 0.65$, and Confidence in Engineering and Attitudes Towards Music Technology, $r = 0.56$. This data proves a moderate to strong correlation between female confidence in STEM fields and creative play and music through this intervention.

Chapter 6. Conclusion

This study's goal was to explore the roles an analog synthesizer can have in the modern STEM classroom. By focusing on the musical history imbued in the analog synthesizer, lessons were able to remain culturally relevant while allowing students to explore hands-on practical STEM skills (bread-boarding, electronics, computing). This study aspired to show a positive correlation between increase in STEM confidence and interest in music technology through the use of an analog synthesizer, specifically the Moog Werkstatt. Additionally, the study aimed to use these combined techniques to show an engagement of under represented groups in STEM education.

The data observed post-intervention offers preliminary evidence that the most viable age demographic of those studied for the current incarnation of this curriculum lies in the 8th – 9th grade STEM classroom. This learning environment should favor a project-based learning model opposed to an inverted classroom to maximize student comprehension and confidence building. The data presented in Section 5.1.1 suggests that classroom subjects that best fit the presented curriculum favor STEM electives over those of Music electives; however, more exploration is needed in this domain to say this with confidence. However, this predilection could be because the opportunity for creative play in the STEM classroom was much more warmly received as opposed to hands-on STEM learning opportunities in the Music classroom, an already hands-on creative environment.

In the most successful portion of this study, sixty 8th graders showed an increase in both STEM comprehension and engagement through hands-on learning experiences with an analog synthesizer. The number of participating students allowed this study to delineate results along gender lines to show that females displayed greater self-efficacy in engineering post-intervention. We conjecture this increase is due to spatial and tactile engagement through music with little pressure through competition, in contrast to the robotics classroom. Minorities and females tend to perform poorer in competitive STEM environments, so by bypassing this paradigm for a musically creative one self-confidence in STEM fields was increased (Milto et al., 2002). By integrating the analog synthesizer into the classroom, this study encourages musical creativity alongside learning hands-on STEM skills, a creative engagement that appears to take a special foothold with young female students.

The initial construction of the curriculum was one of a multitude of target objectives with no formal pacing guide. Post-intervention instructor questionnaires tend to show that this model would have been better served to follow a strict pacing guide with far fewer target objectives to allow for an easier deployment by the instructor. This initial decision was made to allow for multiple deployments across a wide variety of subject matters by allowing the instructor to personalize their own classroom experience. However, data shows that teachers prefer a less personalized approach to allow for easier and quicker deployment. This more concise curriculum would be more limited in scope, but may increase curriculum fidelity.

Other areas of interest include providing professional teacher learning opportunities to familiarize instructors with the material pre-intervention. Professional learning for educators could take the form of workshops or weekend interventions. Although outside of the original scope of this project, these professional learning opportunities are an integral part of a formal deployment of this curriculum, as is evident in the data from GSMST. The fidelity of curriculum implementation hinges on the background familiarity of the instructor in a variety of technical fields. By increasing educator confidence in the material through workshops and PLUs, a better outcome in these specific situations could be achieved.

An exploration of the fundamentals of this curriculum and its learning modalities in non-formal learning environments is warranted. Informal opportunities include after school clubs, specialized interventions for select students, and engagement of youth members of hacker/maker spaces. This time limited instruction would restrict the material covered; however the general spirit of the research could be achieved by promoting STEM interest and literacy through the analog synthesizer. Although outside of the scope of this study, the informal learning opportunities present are a point of future interest.

When isolating the data presented in Section 5.3, this study presents preliminary data that supports the initial hypothesis. That is not to say that the research did not fall prey to certain caveats present in educational pilot studies (see Section 5.1). A major variation in educational styles, project-based learning vs. inverted classroom, proved especially

difficult. Future research is justified in the domains of professional learning for educators as well as informal learning environment deployments.

However, even in the shadow of these curriculum failures, preliminary data was found to support the hypothesis during the *Introduction to Computational Media* course at Marist. An under-represented groups, namely females, built STEM literacy at the same rate as their male counterparts (see Tables 5 and 6) and self-efficacy (see Table 7 and Figure 22) in the high school classroom through integrating arts and STEM by way of an analog synthesizer. These groups not only grew a greater confidence in STEM, but there was a positive correlation between Confidence in Engineering and Attitudes Towards Music Technology (see Figure 23). This positive correlation leads this study to conclude that the creative and unique nature of this intervention had an influence in the receptivity of under-represented groups to STEM learning opportunities, specifically those presented through the musical lens of an analog synthesizer.

APPENDIX A

All items under Appendix A present work completed over the course of summer 2014 during a Moog Music internship.

A.1 VCO.MTH.4

Lesson Summary

Identify and compute Ohm's Law.

Vocabulary

Electricity - The physical scientific processes related to the flow of electric charge. Charge can be either positive or negative. The SI unit of electric charge is the coulomb C.

Conductor - A material that allows electricity to flow freely though it. Metals are great conductors, with copper being a commonly used conductor in electronics.

Insulator - A material that restricts the flow of electricity. No material is a total insulator; common examples include glass and paper.

Current - The flow of electric charge. The SI unit for measuring current is the ampere. Ampere, A, is defined as the flow of charge across a surface at a rate of one coulomb per second.

Voltage - The electrical potential difference between two points, denoted by a V. A single AA battery holds 1.5V

Resistor - An electronic component that restricts the flow of electrical current and voltage. Resistance of the material is measured in Ohm's signified by Ω.
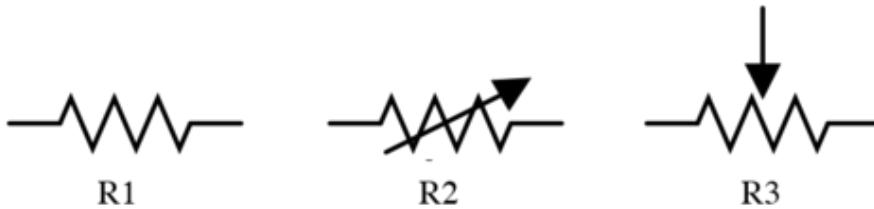
R1 = Resistor, R2 = Variable Resistor, R3 = Potentiometer.

Capacitor - An electronic component that stores and discharges the flow of electrical current and voltage. Capacitors use two layers of conductors, usually thin films of metal, aluminum foil or disks, separated by a polarized insulator made of glass, ceramic, plastic film, air, paper.   Capacitance is measured in farads, commonly displayed as micro farad or μF.
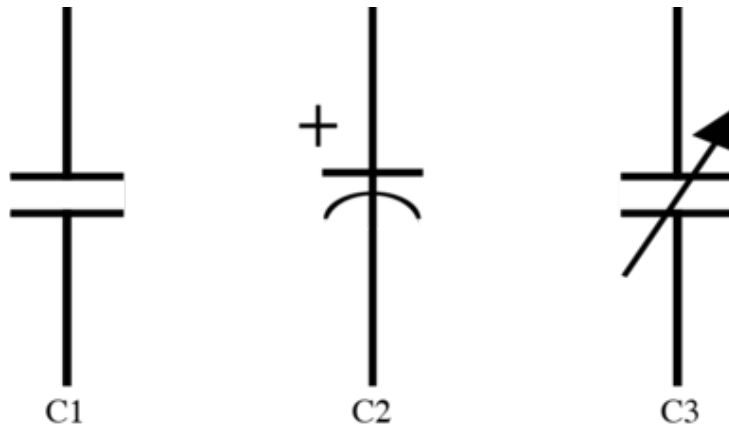
C1 = Capacitor, C2 = Polarized Capacitor, C3 = Variable Capacitor.

Circuit - A group of individual electronic components connected by conductive wires or traces which electric current can flow. The combination and order of components allow various tasks to be performed.

Ohm's Law - The current through a conductor between two points is directly proportional to the voltage across the two points. I is defined as the current through the conductor in units of amperes, V is the potential difference measured across the conductor in units of volts, and R is the resistance of the conductor in units of ohms.

Exercise

Hear varying resistance of an applied voltage to the VCO EXP IN.

We will be supplying 5V+ to our VCO EXP IN from our Arduino through a 680kΩ resistor. As we change resistor values we will be able to hear how current and voltage changes can alter our VCO settings.

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Hardware

We will need to connect our Arduino and Werkstatt together in the configuration shown in Figure 1.   We will be starting with a 680kΩ resistor. Once we have heard the change that 680kΩ provides try out other values to compare and contrast. What happens to the sound with less resistance? What happens to the sound with more? Why do you think that is?
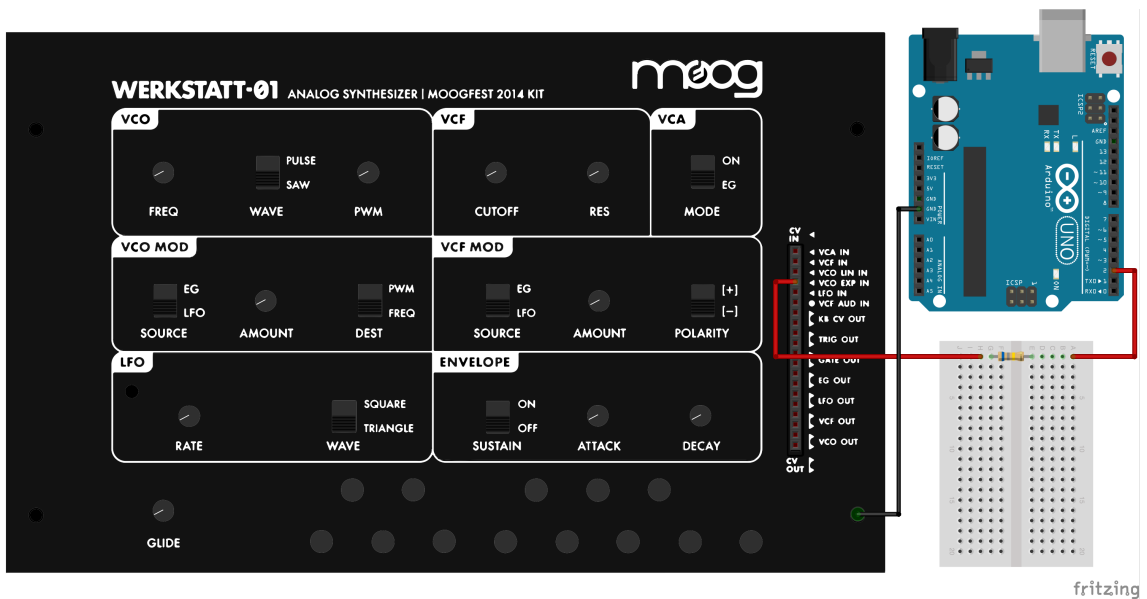
Figure 1. 680kΩ resistor

Here is a schematic overview of how voltage and current are related in our circuit.
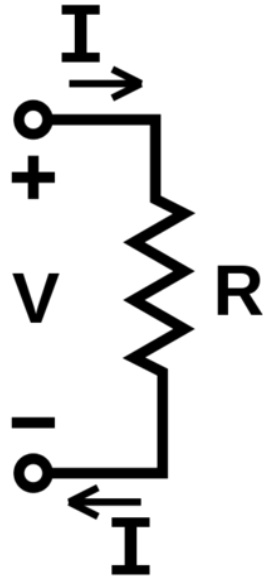
We can also swap our resistor for a potentiometer. Potentiometers offer a variable

resistance so we can hear the changes as we turn the knob.
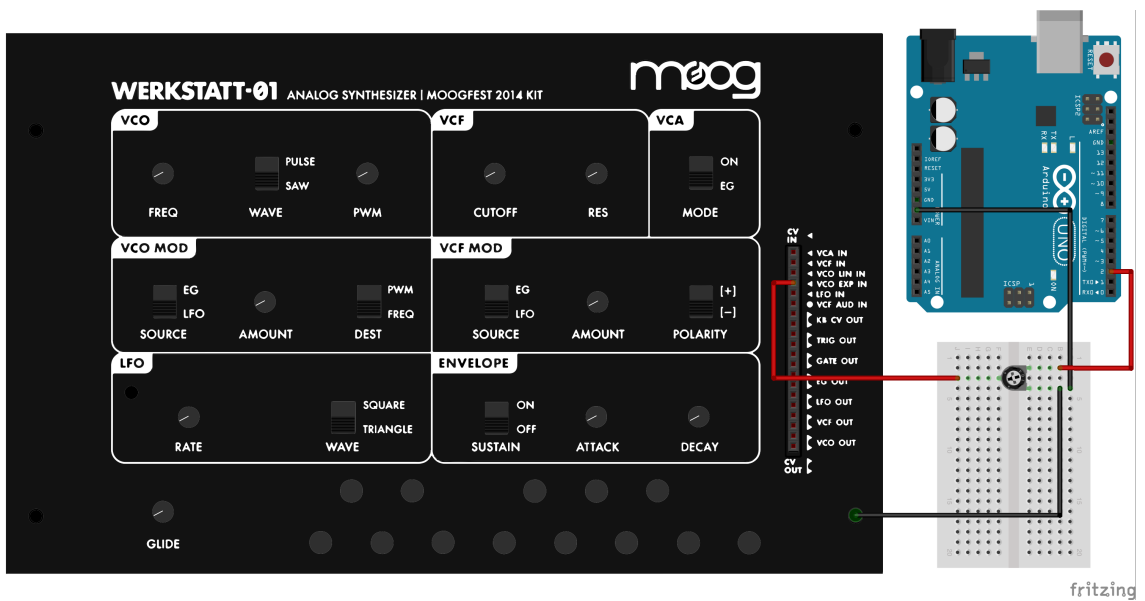
Figure 2. Potentiometer

Software

For our ohms law exercise we will be using an Arduino to speak to the program

Processing. The Arduino should already have the Standard Firmata sketch uploaded to it.

For more detailed information on the Arduino uploading process visit their <u>website</u>.

Open the Ohms_Law.pde program, ensure all connections are similar to Figure 1 or 2 and

click the run button. This program alternates between sending 5Vs+ out of our Arduino,

and sending no voltage at all. This oscillation will allow us to compare the differences.

 Change resistor values and hear the differences as voltage is changed.

For a more detailed walkthrough of the program refer to the comments in Figure 3.

```
Ohms_Law §                                                              ➡

/* Ohms Law Exercise
This sketch turns on and off a digital pin by alternating between
the digital signal HIGH (5V+) and LOW (0V)
Written by Chris David Howe
Moog Music Inc. 2014 */

//import required libraries
import processing.serial.*;
import cc.arduino.*;
Arduino arduino; //initiate Arduino class

int pin = 2; //define output pin
int time = 500; //define delay time in milliseconds

void setup()
{
  arduino = new Arduino(this, Arduino.list()[0], 57600);  //initiate Arduino
  arduino.pinMode(pin, Arduino.OUTPUT);  //initialize output pin
}

void draw()
{
  arduino.digitalWrite(pin, Arduino.HIGH);  //write a high voltage (5V+) to the output pin
  delay(time);     //delay by time
  arduino.digitalWrite(pin, Arduino.LOW);    //write a low voltage (0V) to the output pin
  delay(time);     //delay by time
}
```

Figure 3. Screen capture

Practice

The Werkstatt has a 12VDC power input source and accepts 1.2 Amps from the power

converter. What is its overall resistance?

The resistance of dry human skin is about 500,000 Ω while sweaty human skin is about

1000 Ω. How much current passes across someone's fingers if they touch the 5V output

on the Werkstatt when their skin is wet and dry?

A stereo speaker has a resistance of 8.00 Ω. When it is operating at full power (exactly 100 watts) it uses 35 volts of electricity. What is the current drawn by the speaker?

Standards

CCSS.MATH.CONTENT.HSA.CED.A.4

Subject

Mathematics

Unit

VCO

A.2 VCF.TECH.4

Lesson Summary

Combine filter, VCO, and interval knowledge to create an arpeggiator.

Vocabulary

Frequency - The number of cycles per unit time. The SI unit for frequency is hertz (Hz), named after the German physicist Heinrich Hertz; 1 Hz means that an event repeats once per second. Designated by a lowercase f.

Hertz - The unit used to represent frequency (Hz)

Pitch - A particular frequency of sound used in a musical context.

Note - A named pitch, in western musical notation we knows these as A, B, C, D, E, F, and G.

Semitone - The smallest audible change in western musical notation.

Interval - The difference between two pitches. Values are as follows: unison, minor 2nd, major 2nd, minor 3rd, major 3rd, perfect fourth, tritone, perfect fifth, minor 6th, major 6th, minor 7th, major 7th, and octave.

Arpeggio - A musical technique where notes in a chord are played in sequence, one after the other.

Arpeggiator - The synthesizer function in which an arpeggio is played based on specific interval values.

Array - A list of values used in a programming language to specify a variable that can be indexed.

Resistor - An electronic component that restricts the flow of electrical current and voltage. R1 = Resistor, R2 = Variable Resistor, R3 = Potentiometer.
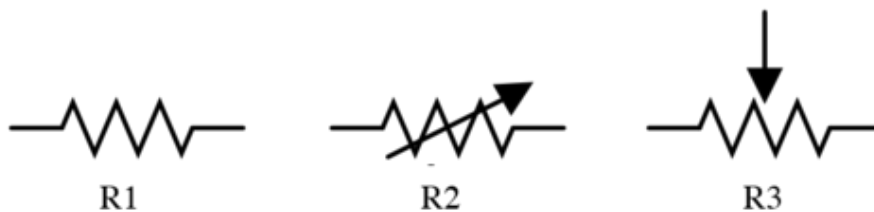
R1   R2   R3

Capacitor - An electronic component that stores and discharges the flow of electrical current and voltage. C1 = Capacitor, C2 = Polarized Capacitor, C3 = Variable Capacitor.
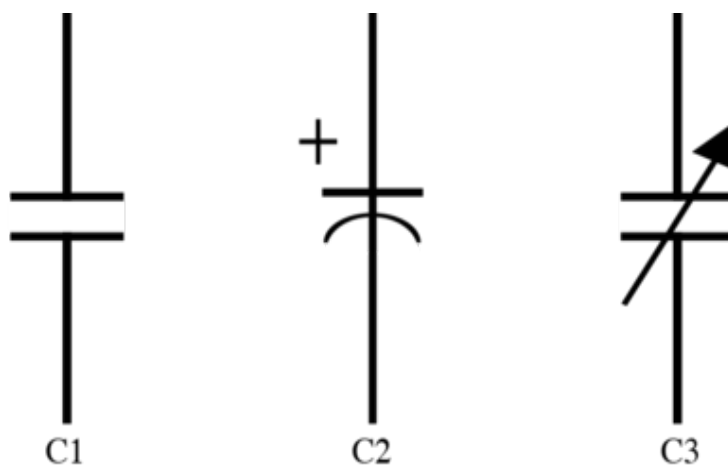
C1   C2   C3

Circuit - A group of individual electronic components connected by conductive wires or
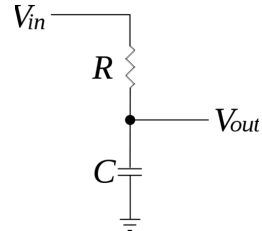
traces which electric current can flow. The combination and order of components allow

various tasks to be performed.

Low Pass Filter - A filter that passes low-frequency signals and reduces the amplitude of

signals with frequencies higher than the cutoff frequency.

RC Filter - A simple filter circuit using a single resistor and capacitor wired in series.

$$f_c = \frac{1}{2\pi RC}$$

f_c = Cutoff Frequency
R = Resistor
C = Capacitor

Exercise

We will be using our combined knowledge of the VCO, low pass filters, and musical

intervals, to create an arpeggiator/sequencer for our Werkstatt.

Hardware

First we need to create a low pass filter for our Arduino. Even though the Arduino

features a function named *analogWrite,* it is not really able to send a true analog signal.

 Instead the Arduino sends a PWM (Pulse Width Modulation) signal, and emulates an

analog voltage change by changing the duty cycle. The *analogWrite* function takes an

input value from 0-255 and sends a 5V+ signal with a duty cycle corresponding to the input value. Although this technique may work for LED's and other components, we will need to filter our signal to achieve a true analog signal for our Werkstatt. The simple RC filter with one 10kΩ resistor and one 2.2μF capacitor will do the trick. We will be sending the signal from our Arduino into the Werkstatt's VCO EXP IN. Observe Figure 1 for exact jumper connections.
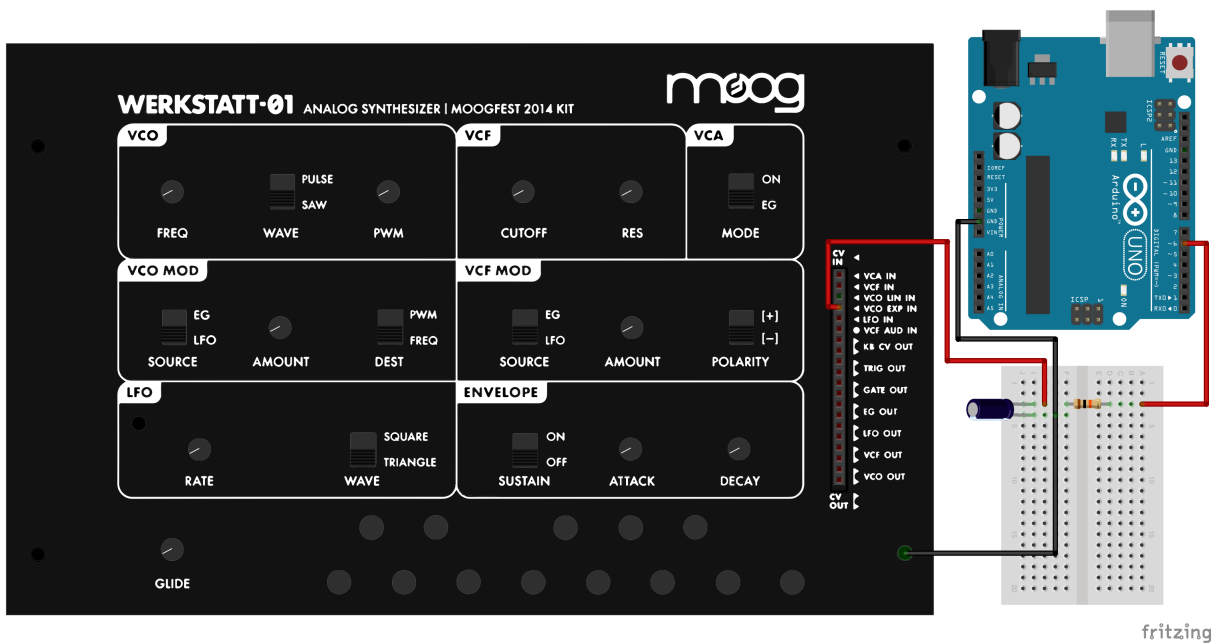

 Figure 1. RC filter coming from Arduino to the Werkstatt's VCO EXP IN.

We need to use a PWM capable output pin on the Arduino. Notice on the Arduino next to the number 6 pin there is a small ~. This symbol indicates that it has the ability to send a PWM signal, and therefore we can use the *analogWrite*function.

Now that our circuit is complete we are ready to open the Processing program

Arpeggiator.pde.

Software

For our arpeggiator we will be using an Arduino to speak to the program Processing. The

Arduino should already have the Standard Firmata sketch uploaded to it. For more

detailed information on the Arduino uploading process visit their website.

Arpeggiator.pde works by cycling through two arrays at the same index. Before we can

reliably use the Arpeggiator.pde sketch for this task we need to tune the VCO EXP IN.

There will be a trimmer pot on the Werkstatt that needs to be calibrated when running

the stock settings of Arpeggiator.pde . These two values need to be a perfect octave for

interval accuracy. Observe Figure 2 for an exact location of the VCO EXP TRIM

potentiometer.
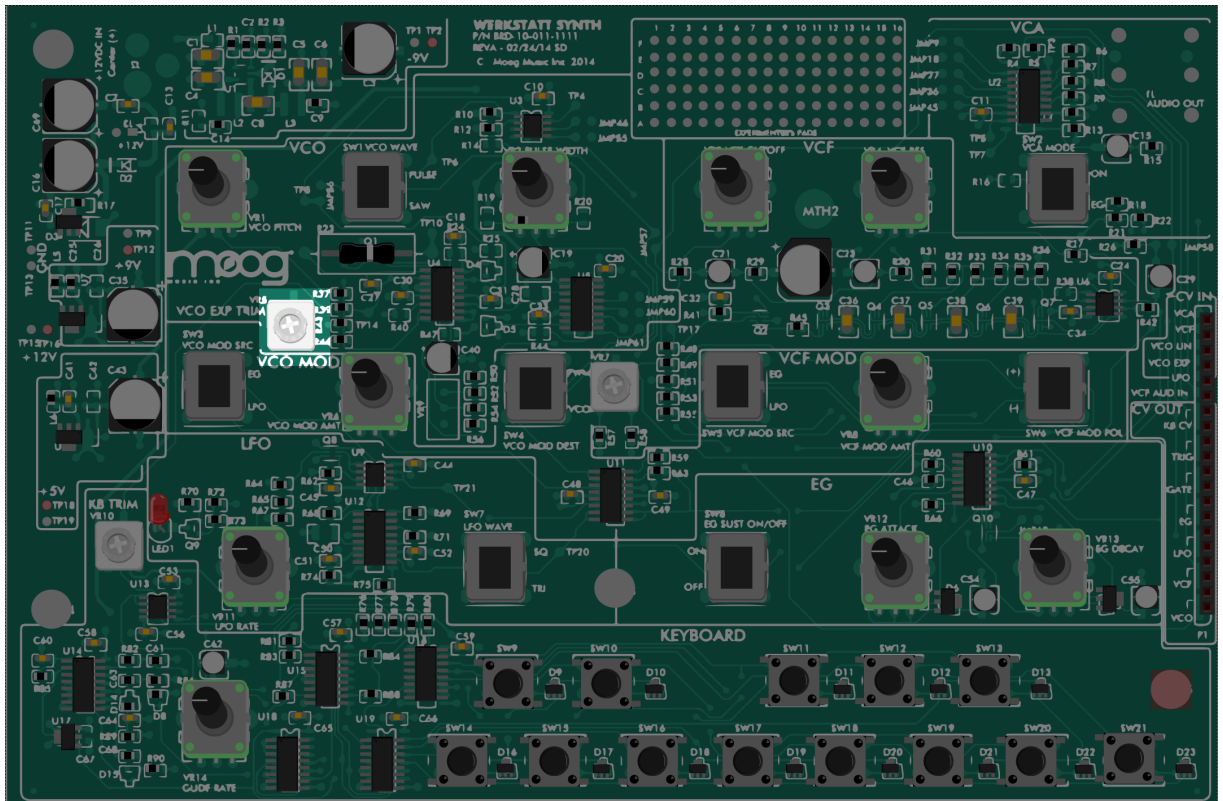
Figure 2. VCO EXP TRIM potentiometer located at VR5.

Once all jumpers match Figure 1 press the run button in Processing. You will hear Arpeggiator.pde cycle through two notes, the unison and the octave. Turn the VCO EXP TRIM knob until the octave is in tune. Once these two notes are perfect octaves all other intervals will be matched as well.

A quick description of how to interact with Arpeggiator.pde is as follows.

```
int notes[] = {tonic, octave}; // VCO EXP config
```

The notes[] array holds any interval you want to access and is referenced as follows:

tonic, minor2nd, major2nd, minor3rd,

major3rd, fourth, tritone, fifth, minor6th, major6th, minor7th, major7th, octave.

```
int note_values[] = {e, e}; //VCO EXP config
```

the note_values[] array holds all note duration information for each corresponding

interval in the notes[] array and is referenced as follows:

w, h, q, qt, e, et, sx, sxt, th, sxf. These are defined as:

w = whole

h = half

q = quarter

qt = quarter triplet

e = eighth

et = eighth triplet

sx = sixteenth

sxt = sixteenth triplet

th = thirty second

sxf = sixty fourth

the bpm setting sets the tempo of the arpeggiator in beats per minute. Arpeggiator.pde

comes preset at 100 beats per minute.

For more information about Arpeggiator.pde refer to the comments in Figure 3.

```
Arpeggiator    bpm    drawText    variables                                          →

//import required libraries
import processing.serial.*;
import cc.arduino.*;
Arduino arduino;//initiate Arduino class
int pin = 6;//define output pin
PFont f;//define font
/*
notes are assigned in intervals: tonic, minor2nd, major2nd, minor3rd,
major3rd, fourth, tritone, fifth, minor6th, major6th, minor7th,
major7th, octave.
*/
int notes[] = {tonic, octave}; // VCO EXP config

// note values: w, h, q, qt, e, et, sx, sxt, th, sxf
int note_values[] = {e, e}; //VCO EXP config

int bpm = 100; //define bpm(beats per minute)

void setup() {
  arduino = new Arduino(this, Arduino.list()[0], 57600);    //initiate Arduino
  size(320,240);   //initiate window with dimensions 320,240
  f = createFont("Arial",16,true);   //define font information
}

void draw() {
  drawText(255, 255, 255);
  //for loop that iterates through each note volage
  //value and delays by the corresponding note value
  for (int i = 0; i < notes.length ; i++)
    {
      float value = bpm(bpm, note_values[i]);
      arduino.analogWrite(pin, notes[i]); //write value to the Arduino
      int note = notes[i];
      delay( floor(value) );   //delay by note value
    }
}
```

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Figure 3. Screen capture

Once the arpeggiator is working and tuned, experiment with different array values.

Below is an example of an ascending-descending minor 3rd chord comprised of

sixteenth notes at 120 beats per minute.

```
/*
notes are assigned in intervals: tonic, minor2nd, major2nd, minor3rd,
major3rd, fourth, tritone, fifth, minor6th, major6th, minor7th,
major7th, octave.
*/
int notes[] = {tonic, minior3rd, major5th, octave, major5th, minor3rd};

// note values: w, h, q, qt, e, et, sx, sxt, th, sxf
int note_values[] = {sx, sx, sx, sx, sx, sx}; |

int bpm = 100;
```

Practice

One notes relationship to another note is referred to as an _____ .
- ○ Semitone
- ○ Note
- ○ Hop
- ○ Interval

Compute the duty cycle of the pulse wave in Figure 4.

- ○ 10%
- ○ 25%
- ○ 50%
- ○ 100%

Figure 4.

Time (seconds)
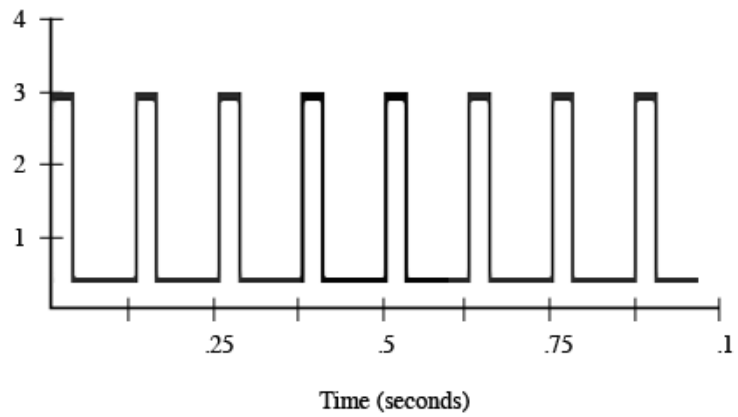
Standards

NGSS.ETS1.B

Subject

Engineering

Technology

Unit

VCF

A.3 TARGET OBJECTIVES

A.3.1 VCO Target Objectives

VCO.MTH.1
Illustrate a Sawtooth/Triangle wave and identify amplitude, frequency, slope, and peicewise linear functions.
VCO.MTH.2
Recognize and implement algebraic formulas associated with wave dynamics and duty cycles.
VCO.MTH.3
Compare and contrast Sin and Cosine
VCO.MTH.4
Identify and compute Ohm's Law.
VCO.MUS.1
Define the role of the VCO in a synthesizer and describe the historical importance using specific song examples.
VCO.MUS.2
Analyze and compute the relationship between frequency, notes, and MIDI.
VCO.MUS.3
Recognize written notes and octaves.
VCO.MUS.4
Define timbre and harmonics in its relation to musical examples and the scientific and mathematical qualities of specific timbres.
VCO.MUS.5
Evaluate the frequency/note/harmonic relationship in terms of the historical musical examples presented in VCO.MUS.1.
VCO.SCI.1
Identify the relationship between simple harmonic motion and sound.
VCO.SCI.2
Illustrate a Sine wave and identify amplitude, phase, and frequency.
VCO.SCI.3
Describe and recall variations in wave types.
VCO.SCI.4
Describe and illustrate properties of electricity.
VCO.SCI.5
Compare and contrast light and sound.
VCO.TECH.1
Illustrate a Pulse wave and identify amplitude, phase, frequency, and duty cycle.
VCO.TECH.2
Identify harmonic variations in various duty cycles.
VCO.TECH.3

Construct a similar setting to examples from VCO.MUS.1 and evaluate the scientific principles behind that specific timbre.

A.3.2 VCF Target Objectives

VCF.MTH.1
Formulate and compute a RC filter in the audio line.
VCF.MTH.2
Formulate intervals using ratios.
VCF.MTH.3
Compare various resistor values in the filter, contrast the simpler RC filter to the Moog transistor ladder, recognize differences.
VCF.MUS.1
Define the role of the VCF in a synthesizer and describe the historical importance using specific song examples.
VCF.MUS.2
Recognize resonance within the Werkstatt's filter and identify the harmonic property changes.
VCF.MUS.3
Discuss the role of the arpeggiator in electronic music citing examples.
VCF.MUS.4
Define root note, interval, and semi-tone.
VCF.MUS.5
Identify the tonal relationships within the arpeggiator in terms of musical interval and mode.
VCF.SCI.1
Analyze resonance as it pertains to wave phenomena.
VCF.SCI.2
Define and describe atomic properties of transistors in relation to the Moog ladder filter.
VCF.SCI.3
Assess the electrical quality of capacitance.
VCF.TECH.1
Identify and illustrate a RC filter in the audio line.
VCF.TECH.2
Define anode and cathode.
VCF.TECH.3
Define the importance of the filter in the history of electronics.
VCF.TECH.4
Combine filter, VCO, and interval knowledge to create an arpeggiator.
VCF.TECH.5
Identify the tonal relationships within the arpeggiator in terms of voltage.
VCF.TECH.6
Construct a similar sounding VCF setting in relation to VCF.MUS.1 and evaluate the scientific principles behind the timbre.

VCA.MTH.1
Define and formulate amplitude in decibels (dB).
VCA.MTH.2
Evaluate and formulate compression as a ratio to dB reduction.
VCA.MTH.3
Recognize the logarithmic relationship in dB and its difference between linear
relationships.
VCA.MUS.1
Define the role of the VCA in a synthesizer and describe the historical importance of
specific song examples.
VCA.MUS.2
Analyze tremolo in popular music.
VCA.MUS.3
Construct a similar setting to VCA.MUS.1 and evaluate the scientific principles behind
that specific timbre.
VCA.SCI.1
Combine information from VCO.SCI.2 and relate amplitude to wave dynamics lesson.
VCA.SCI.2
Define the inverse square law and its relationship to pressure as well as electromagnetic
waves.
VCA.SCI.3
Construct an optical compressor.
VCA.TECH.1
Define and identify various dB scales (dbA, dbB, dbC).
VCA.TECH.2
Combine circuits from VCF.TECH.1-6 to create an optical compressor.

APPENDIX B

All items under Appendix B present work completed during the 2014-2015 academic year at Georgia Tech under MUSI7100 and thesis hours.

B.1 Content Knowledge Assessment – Advanced Electronics Marist

Werkstatt Pilot Study Pre CKA

Student ID#

For the following questions, use these constant values:

Coulomb = 6.245 * 10^18

Charge of single electron = 1.6 ^ 10^-19

k = 9 * 10^9 Nm^2 / C^2

What is the Force F between two objects with a negative charges of 4 x 10^-9 C and 3 x 10^-9 C at the distance of 5 centimeters?

○ -4.8 * 10^-15 N

○ 4.8 * 10^-15 N

○ -4.32 * 10^-5 N

○ 4.32 * 10^-5 N

○ I don't know

Calculate the drift velocity in a piece of wire where the current is 1.75 A, the free electron density is 5 * 10^28 m^-3 and the diameter of the wire is 4mm.

○ 1.74 * 10^-5 m/s

○ 4.35 * 10^-5 m/s

○ 5.46 * 10^-5 m/s

○ I don't know

What is the resistance in Ohms for the following color scheme:
Red, Black, Orange

○ 330 Ohms

○ 10,000 Ohms

○ 20,000 Ohms

○ 200 Ohms

○ I don't know

RESISTOR COLOR CODE

first digit
second digit
# of zeros
tolerance

Examples:
green-blue-brown - 560 ohms
red-red-red - 2 200 ohms (2.2k)
brown-black-orange - 10 000 ohms (10k)

0 - Black	5 - Green	20% - none
1 - Brown	6 - Blue	10% - silver
2 - Red	7 - Purple	5% - gold
3 - Orange	8 - Grey	
4 - Yellow	9 - White	
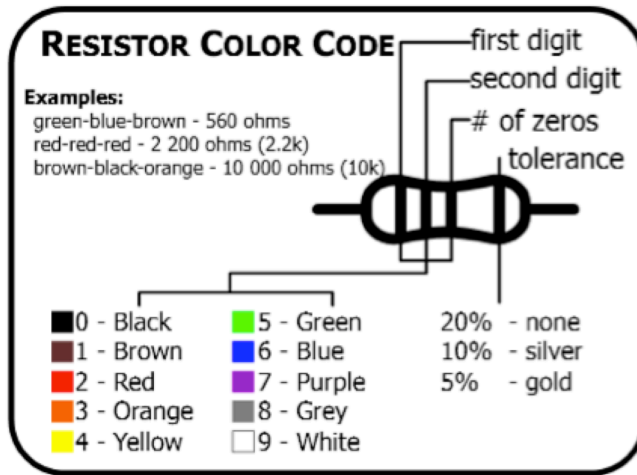
Given the following circuit with a 12 Volt DC power source:
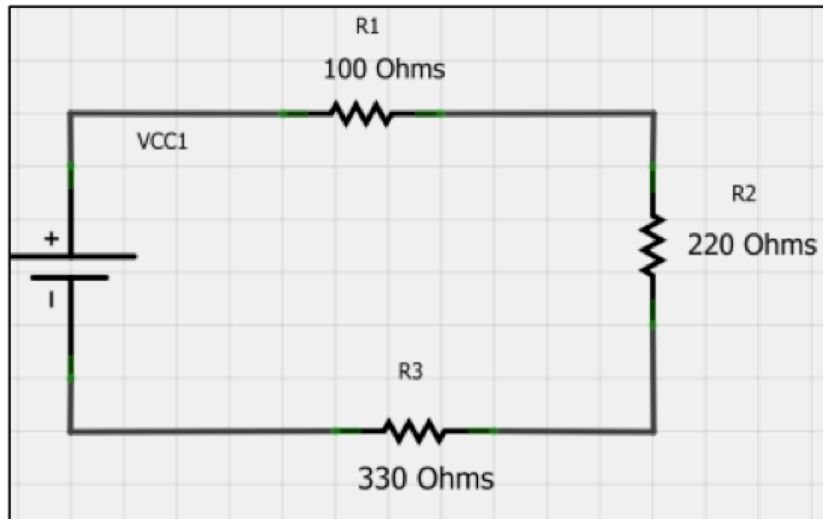
a. What is the total resistance in the circuit?

b. What is the total current in the circuit?

Given the following circuit
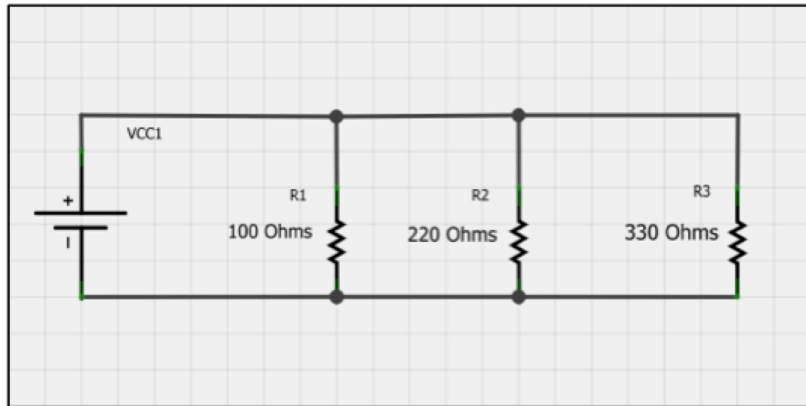
What is the equivalent resistance of a parallel circuit consisting of R1 = 100 ohms, R2 = 220 ohms, and R3 = 330 ohms?

[   ]

An electrical heater has a rating of 120 Volts and 1500 Watts. What is the current draw of the electrical heater?

○ .08 Amps

○ 12.5 Amps

○ 1.8 * 10^5 Amps

○ 15 Amps

○ I don't know

Frequency is the measure of...

○ Slope

○ Tonal quality

○ Time

○ Cycles per second

The unit used for frequency is...

○ Farad

○ Ohm's

○ Hertz

○ Sine

Compute the amplitude of figure 2.

○ 1

○ .1

○ 3

○ 10

Figure 2.

Time (seconds)
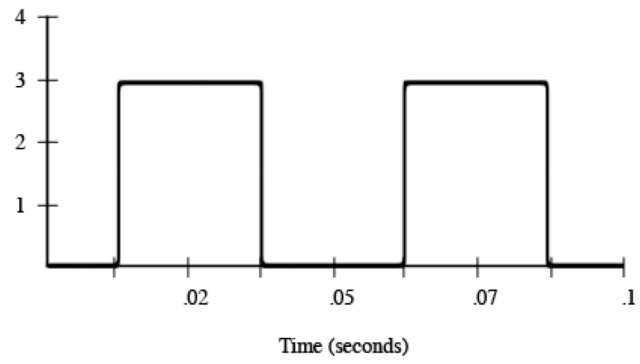
Compute the frequency of Figure 3.

◯ 1000 Hz

◯ 80 Hz

◯ 8 Hz

◯ 4 Hz

Figure 3.

Time (seconds)

Compute the duty cycle of the pulse wave in Figure 4.

○ 10%

○ 25%

○ 50%

○ 100%

Figure 4.

Time (seconds)
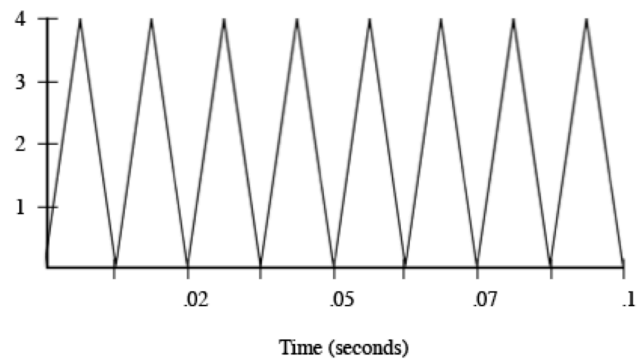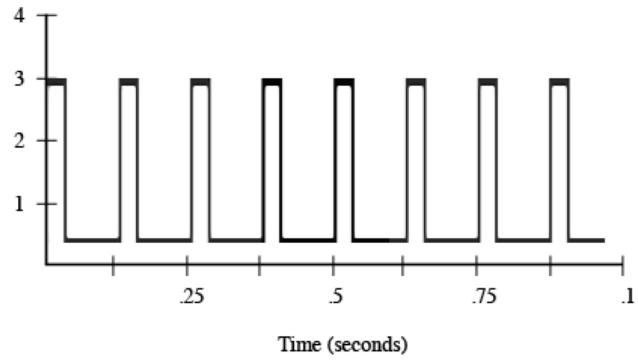
What is the phase offset of the sine wave in Figure 5.

○ 0 °

○ 360 °

○ 90 °

○ 180 °

Figure 5.

Time (seconds)
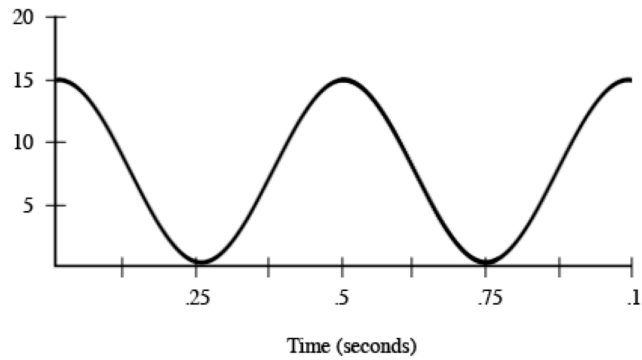
Sound pressure and seismic P (primary) waves are examples of _____ waves.

◯ Rotational

◯ Longitudinal

◯ Transverse

◯ Horizontal

Seismic S (secondary) waves and electromagnetic (light) waves are examples of _____ waves.

◯ Transverse

◯ Rotational

◯ Horizontal

◯ Longitudinal

Frequency and musical pitch have a _____ relationship.

◯ Vertical

◯ Linear

◯ Inverse

◯ Logarithmic

_____ is the quality of a musical note or sound or tone that distinguishes different types of sound, also known as tone color or quality.

◯ Timbre

◯ Pitch

◯ Voltage

◯ Resistance

A material that allows electricity to flow freely though it is a _____.

◯ Insulator

◯ Conductor

◯ Resistor

◯ Capacitor

A material that restricts the flow of electricity is a _____.

◯ Insulator

◯ Jumper

◯ Capacitor

◯ Conductor

The SI unit for measuring electrical current is the _____.

◯ Ohm

◯ Farad

◯ Volt

◯ Ampre

The unit for measuring electrical resistance is the _____.

◯ Ampre

◯ Farad

◯ Ohm

◯ Volt

The unit used to measure capacitance is the ____.

◯ Ohm

◯ Volt

◯ Ampre

◯ Farad

Ohm's Law is defined as...

◯ I = VR

◯ I = R2π

◯ I = V/R

◯ R = V2π

The Werkstatt has a 12VDC power input source and accepts 1.2 Amps from the power converter. What is it's overall resistance?

◯ 10

◯ .05

◯ 250

○ 1

Sound pressure loudness is measured in _____.

○ Value

○ Decibels

○ Intensity

○ Amps

The maximum absolute value of the signal is the _____.

○ Decibel

○ Intensity

○ Value

○ Amplitude

Decibels are measured in reference to _____, the lowest threshold of human hearing.

○ 20μP

○ 250k

○ 100Ω

○ 2.2μf

The RC Filter formula is defined as...

○ f = I/R

○ f = 2 / RCπ

○ f = 100K*3.3

○ f = 1 / 2πRC

What rounded value R would be used with a 2.2 μf capacitor to create a cutoff frequency of 60 Hz.

○ 100Ω

○ 10Ω

○ 1200Ω

○ 125kΩ

A RC filter with a R value of 100Ω and C value of 2.2μf will have a cutoff frequency of _____.

○ 723.43 Hz

○ 8450.5 Hz

○ 155.22 Hz

○ 10.3 Hz

_____ is the point from which current leaves a polarized electrical component, typically a negative terminal.

○ Triode

○ Anode

○ Diode

○ Cathode

____ is the point from which current enters a polarized electrical component, typically a positive terminal.

○ Triode

○ Diode

○ Cathode

○ Anode

A ____ is the smallest step in western musical notation.

○ Semitone

○ Note

○ Interval

○ Hop

One notes relationship to another note is referred to as an _____ .

○ Note

○ Interval

○ Semitone

○ Hop

(Submit)

B.2 Retrospective Pre/Post Questionnaire

Moog Pilot Study Pre/Post Retrospective Survey

Student ID# *

[   ]

Which of the following best represents your racial or ethnic heritage?

☐ American Indian or Alaska Native

☐ Hawaiian or Other Pacific Islander

☐ Asian or Asian American

☐ Black or African American

☐ Hispanic or Latino

☐ Non-Hispanic White

☐ Middle Eastern or Arab American

☐ Other: [   ]

Which of the following best describes you?

☐ Male

☐ Female

☐ Other: [   ]

Confidence in STEM fields

I feel confident in Science related tasks.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I am not the type of person who can understand Science.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I understand higher level Mathematics and apply my knowledge frequently.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I never use Math.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I am confident in making things and enjoy solving engineering problems.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Even though I enjoy making things, engineering seems unusually hard for me.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Attitudes towards STEM fields

I would be happy to excel in Science.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Being first in an engineering competition would make me happy.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I would be proud to recognized for my skills in Mathematics.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

People would think I was some kind of nerd if I was good at Science or Math.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

It would make people like me less if I were good at Science of Math.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I don't want people to think of me as an engineer.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Confidence and Attitudes in Music

I am a confident musician and can read musical notation.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I love playing music, but I am not the type of person who can read notation.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I listen to music often, but don't consider myself a musician

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I do not enjoy music.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I would be happy to be recognized as a top musician/composer.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Music has nothing to do with Science or Math.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Technology and Engineering are not as creative as Music or Art.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Motivations for success

When a math problem is presented that I can't immediately solve, I stick with it until I have the solution.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Once I start working on an engineering task, I find it hard to stop.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

When an engineering problem is left unanswered I continue to think about it afterward.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I don't understand how people enjoy science or math.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Math is useless.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Science is boring.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Moog

I currently own a Moog product and use it often.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I am interested in the Moog product line but can't afford anything offered.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I am not familiar with Moog Music or their instruments.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Before	○	○	○	○	○
After	○	○	○	○	○

Goals

I intend to take STEM related electives next year.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I intend to go to college.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I intend to go to get a degree in a STEM field.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

Someday, I would like to have a career in a STEM field.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

STEM field jobs pay well.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I intend to get a degree in Music or Art.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I would like to pursue a career in Music or Art.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before	○	○	○	○	○
After	○	○	○	○	○

I would like to pursue a career in…

- ☐ Medicine
- ☐ Technology
- ☐ Math
- ☐ Science
- ☐ Law
- ☐ Engineering
- ☐ Music
- ☐ Art
- ☐ Entertianment
- ☐ Sports
- ☐ Education
- ☐ Other: [_____]

Submit

B.3 Focus Group Discussion Guideline

1. What kind of music do you enjoy?

2. Do you think musical artists you enjoy use instruments like the Werkstatt?

3. Did you have any previous synthesizer exposure before this study? What was it?

4. Do you own a synthesizer? What kind?

5. Do you prefer digital or analog systems?

6. Were you ever interested in how music synthesis worked?

7. Before this study did you expect such an overlap in music, science, and mathematics? Why or why not?

8. Do you find electronics and computing any more or less interesting after this study?

9. Do you think being an engineer is as creative as being a musician?

10. What would your dream job be?

11. Do you prefer performing on an instrument or recording with an instrument? Why?

12. Would you rather create and play your own instrument or play a previously created instrument? Why?

13. What was the best part about participating in this study?

14. What would you change about this study for use with future students?

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