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Using Piezoelectric Technology to Harvest Energy from Drums and Inspire an Engaging High School Classroom Experience

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Using Piezoelectric Technology to Harvest Energy from Drums and Inspire an Engaging High School Classroom Experience

by

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Report

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Dedication

This work is dedicated to my mentors and colleagues who have guided and encouraged me to pursue my passion of teaching science. I am so thankful to have always had exemplary role models of great educators throughout my tenure as a student, and in every stage of my professional career. Their ability to inspire me simply by their everyday dedication to their craft has moved me to never quit striving to perfect my talents in the teaching profession.

And also, to my Father, who lit the fire of a love for science very early in my life.

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I owe a debt to Brian Dudley, great friend and percussionist extraordinaire, for lending me a small sample of his drum collection with which I could experiment, and educating me on their use and maintenance. I also wish to thank Dr. James Latten, my undergraduate symphony conductor, for his invaluable advice on the physics of drums.

Abstract

Using Piezoelectric Technology to Harvest Energy from Drums and Inspire an Engaging High School Classroom Experience

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Using piezoelectric materials to harvest the energy of vibration is a popular and fast-growing field of study. This report details an attempt to use piezoelectric energy harvesting techniques to support an interesting and engaging lab experience for high school engineering students in which the vibration of musical instruments (specifically drums, for this report) is harnessed to power a string of decorative LEDs. The likelihood of the energy harvesting actually being successful enough to light the LEDs was not known before undertaking this lab, so the goals of the project became twofold:

1. Conduct the experiment from scratch to determine if a substantial amount of energy can be harvested from the instruments (enough to reach the goal of lighting the LEDs), and 2. Identify how this lab experience (or one similar to it, if the goal of lighting the LEDs is unattainable) can be beneficial to high school engineering students. The purpose of this report is to summarize the research that was carried out to harvest energy from

drums using piezoelectric technology, and to outline how similar lab exercises can be utilized in the high school engineering classroom setting.

Table of Contents

List of Figures

Chapter 1: Introduction

Piezoelectric units are gaining popularity in the realm of alternative energy harvesting. When deformed by bending or squeezing, piezoelectric materilas produce an electric charge. Piezoelectric materials are used in energy harvesting units, which can be placed in situations where movement in the environment can squeeze or bend them. The energy harvesting units contain circuitry which converts the electric charge into useful electrical current. Before the advent of piezoelectric technology, the kinetic energy of a vibrating object was usually considered to be wasted and unusable because the physical motion could not be converted into electrical energy to be utilized for something else. Cantilever-style piezoelectric units, in which the material is anchored to a vibrating source and is bent to and fro if the anchor is displaced (much like a swimming pool diving board) are now employed in many different situations where vibration is available to be converted into electrical energy.

One situation where vibration is ubiquitous is the world of music. Musical instruments vibrate at many different frequencies and intensities to produce sounds, and may be an untapped source of energy harvesting if piezoelectric units could be employed without hindering the function of the instrument.

High school educators are constantly searching for ways to make their curriculum and class activities relevant and interesting to their students. Studies show that student learning is enhanced greatly when students are engrossed in topics that are interesting or directly applicable to them. Many high school students are engaged in the study of music, either in private lessons, group bands, or personal study. With its foundations in the physics of acoustics, music can provide a meaningful bridge for students to enter into the world of science and engineering.

Many high school students are involved in live musical performances, whether school-sponsored events like marching bands or personal endeavors such as garage rock bands. In many situations, the visual aspect of the performance is as important as the audible. Battery powered decorative strings of lights are already used by many musicians to enhance the visual aspect of their performance because the battery power allows them to be mobile. But batteries pose many disadvantages. They must be replaced or recharged periodically, and the large (relatively), bulky battery pack can be prohibitive for use with small musical instruments or nimble physical maneuvers. Size and weight are definitely issues when creating an accessory to be attached to musical instruments, even more so when movement is involved (e.g., a marching band). Piezoelectric units, by contrast, are smaller and harvest energy directly from the environment (the vibration of the instrument, in this case), allowing them to be a source of continual energy without being replaced like a battery. The environmental energy, vibration, is already in plentiful supply as long as the musical instrument is being played.

The primary purpose of this study was to determine if a piezoelectric unit, when attached to a drum, can harvest enough electrical energy to power a small string of LED decorative lights, thereby creating a "battery free" string of LEDs that are powered by the vibrations of the instrument while it is being played. The secondary purpose of this study was to investigate if this or a similar project could be beneficial in the high school engineering classroom setting. Groups that perform live music are always thirsting for new ways to catch the attention of their audience; and mobile, battery-free light strings that could be worn on musicians and/or their instruments would be a popular product indeed. In a high school classroom setting, engineering students who are also passionate about music performance may find a design challenge like this study of great interest to them. This study could also be modified and extended to have students combine the disciplines of acoustics and electronics to design piezoelectric decorative light units that function with a variety of musical instruments. The following report describes the relevant literature for this study, the design and setup of the lab procedures and data collection, and discusses the data and results. An additional section explores the possibility of extending this study to the high school engineering educational level to compliment cross-disciplinary design challenges in the curriculum.

Chapter 2: Review of the Literature

2.1 Kinetic Energy Harvesting

There is a vast source of kinetic energy in the world (the energy of moving things), and only a small percentage is currently being tapped and turned into electrical energy for use by humans (McCoy, 2011). A commonly known kinetic energy harvester is the wind turbine, which converts the flow of air into the spinning of a turbine, which generates electricity. The burning of fossil fuels and heat from nuclear power plants all have the same goal – to turn water into steam to perform the physical action of turning turbine blades to create electricity.

As an alternative to burning these fossil fuels, capturing and using the physical energy of motion in the environment has been a challenge to scientists and engineers for some time now. However, new energy harvesting techniques are being implemented to allow for the direct capture of motion and its conversion into electricity. These "vibration energy harvesters" or "VEH"s as McCoy (2011) calls them, capture the kinetic energy of the vibration of an object or system, which was otherwise thought to be lost to the increasing entropy of the Universe and no longer usable. Already, these VEHs are being used in small-scale energy harvesting to make formerly battery-dependent systems autonomous and also to power other "wired" systems without the need to be connected to a larger power grid. With the increased use of portable electronic devices in our culture, the need for locally harvesting small quantities of energy to make these electronic devices "independent" is in growing demand. Battery power is useful, but must be replaced periodically and cannot shrink at the same rapid pace as much modern microelectronic technology is doing. (Mateu and Moll, 2005)

Self-powered devices equipped with energy harvesting technology may draw their energy from many environmental situations in an active or passive manner (Mateu and Moll, 2005). Examples of active acquisition of power include common devices like radios or flashlights that have hand-cranked solenoids. Here, someone must perform an activity with the specific goal of powering the device. On the other hand, devices that harvest energy passively from their environment (including humans) simply scavenge ambient energy that is already being produced by other processes.

Vibration energy harvesters can collect energy from a variety of environmental sources, but due to the nature of thermodynamics and entropy, a larger quantity of energy must always be expended to obtain a usable amount of electrical energy (Mateu and Moll, 2005). This has always been a vexing problem when the active source of energy is costly or in limited amounts (e.g. fossil fuels). However, when energy harvesting tools are being utilized passively, collecting energy from ubiquitous events that would happen regardless of their energy harvesting potential, there is little worry of energy loss due to entropy. As long as the harvester can meet a minimum threshold of useful energy output, it is an encouraging success. The project featured in this report, harvesting energy from the playing of musical instruments, is a prime example of passive energy harvesting.

2.2 Piezoelectric Technology

The piezoelectric effect was discovered in 1880 by Jacques and Pierre Curie. They discovered that certain materials polarize and produce an electric current when squeezed or otherwise deformed (Schils, 2012). The molecular structure of piezoelectric material exhibits the qualities of an electric dipole, meaning that there is a separation of electrostatic charge thanks to the orientation of the molecules. When the material is deformed or strained in some way, the dipole orientation is shifted and an electric charge is produced (Anton and Sodano, 2007). This charge can be easily obtained from the material, making piezoelectric substances a popular choice for generating electricity.

Of the many varieties of vibration energy harvesters, those that employ piezoelectric technology have gained great popularity for their versatility in being incorporated into electronic devices and their ability to directly transform movement into electrical energy (Anton and Sodano, 2007). Part of the versatility comes from their ability to be manufactured in many different shapes and sizes, with different physical features influencing how the devices perform. A popular model that is utilized in the present project is the cantilever model. Thanks to their shape, cantilever models are the most popular models for harvesting vibration energy (Priya and Inman, 2009). This model consists of a wafer of piezoelectric material, which is anchored to a base on one side. The base is attached to the vibrating object from which energy is to be harvested, and the wafer vibrates in its fundamental bending mode (within the frequency of operation) as the base is displaced.

Piezoelectric technology is a fast-growing, exciting field. New applications for locally harvesting energy from the environment are frequently in the news. Many new uses of piezoelectric technology come from capturing the motion of the human body itself, in order to power personal electronic devices of all sorts, ranging from MP3 players and cell phones to medical devices. A classic example of harvesting human energy is that of capturing the squeezing motion of footfall by placing piezoelectric materials in the soles of shoes (Klimiec, Zaraska & Zaraska, 2010). Another application is constructing piezoelectric material that can be woven like fabric, in order to create wearable garments that produce electricity from every subtle movement of the wearer (Amman and Hamouda, 2008). Very recently, research has suggested that certain piezoelectric devices may be able to replace the batteries in pacemakers, drawing their energy directly from the physical beating of the human heart (Karami and Inman, 2012). Not only does this provide a sustainable source of energy for pacemaker patients, it also negates the patient's need to have invasive surgery periodically to replace old batteries. The project featured in this report also aims at scavenging energy from human activity - the playing of musical instruments.

2.3 The Physics of Music

All musical instruments vibrate to produce sounds. Whether an instrument is struck, plucked, or has air blown through it or across it, it vibrates at a specific frequency that in turn vibrates the air around it. Human ears sense the vibration of the air and it is perceived as sound. (Parker, 2009). The nature of the pitch (specific note) and timbre (what makes a piano sound different from a tuba) is determined by the shape of the instrument, as well as what it is made of, and of course, how it is played. Loudness is also a quality of sound, and relates to the magnitude of vibration that occurs in the instrument. The more powerful the vibration, the louder the sound.

Drums, having a rightful reputation for being loud, are struck with sticks or the hand to be played. This causes intense vibration, and in turn, produces a very loud sound. Drums do produce a large amount of power when played – bass drums have been known to produce up to 20 Watts of energy with a single strike (Rossing, 2000). Because drums vibrate so mightily, they were an obvious choice to use for the project in this report.

Different styles and shapes of drums vibrate at different frequencies. This is why a snare drum, a bass drum, and a set of tom toms all sound unique. It is also known that piezoelectric energy harvesters can perform at their maximum efficiency when they are subjected to vibrations that match their own resonant frequency (Anton and Sodano, 2007). Therefore, in this project, care must be taken to match the range of frequencies the test drum produces with the optimal range of frequencies a piezoelectric harvester can use. If desired, the harvesters can even be finely tuned to pick up on a single resonant frequency. However, since drums never reliably produce the exact same frequencies while being played, it is better to allow the harvester to resonate within a range of frequencies that the drum is known to produce.

Chapter 3: Methods

Research conducted for this lab was split into two phases. In the initial phase, the goal was to analyze the power spectrum of the drums being used. The power spectrum clearly shows the peak frequencies the drums produce while being played. Without this knowledge it would be impossible to match the proper piezoelectric harvesters to the drums, since as mentioned in Chapter 2, piezoelectric harvesters can optimize their power output by having a resonant frequency similar to that of the environment that is vibrating. These drums were tested in the lab, because although there is general information available about the power spectrum of drums, each drum produces its own unique frequencies based on the drum's shape, size, materials, manufacturer, and how it is tuned.

The second phase of research was to evaluate the voltage output of the test drums, once an appropriately matched piezoelectric harvester was attached. Once initial results were obtained, it could then be determined whether or not it was feasible to power a string of LEDs with the current set up. Once feasibility was confirmed, the harvester was then attached to a circuit with a string of LEDs and true proof of the concept was achieved.

3.1 First Phase Equipment and Set Up

Two different drums were tested in this project. Although they differ in size, both could be considered "tom tom" style drums which are commonly used in a standard drum kit. One was a 12" tall grey, unmarked tom tom. It's top drumhead was a Remo

Weatherking Ebony Ambassador, the bottom drumhead was a Remo Weatherking Ambassador. The other drum was a 9” tall Ludwig tom tom. Its top drumhead was a Remo Weatherking Black Suede Emperor, and the bottom head was a Remo Weatherking Diplomat. Throughout the rest of this report, the Ludwig drum will be referred to as the “small” drum, while the unmarked drum will be referred to as the “tall” drum. To measure the power spectrum of each drum, an accelerometer was firmly attached to the bottom drum head and connected to a DC power supply and a National Instruments cDAQ data acquisition system, which collected the data and sent it to a program running on a computer. The lab setup is shown in Figure 1.

Figure 1: The Ludwig, or “small drum” shown with the accelerometer underneath connected to the NI cDAQ in the upper left corner.

The accelerometer, manufactured by Crossbow Technology Inc., was initially attached with sticky tape used for mounting posters on walls. However, the accelerometer did not stay attached after the first test, so a second method was developed. The second method involved covering both the accelerometer and the drum head with masking tape, and then attaching the two items with JB Weld. This method was satisfactory, but there was concern that the soft nature of the glue and tape was dampening some of the vibration from the drum to the accelerometer. Finally, the accelerometer was screwed directly to the drumhead, allowing for a firm, reliable attachment, as shown in Figure 2.

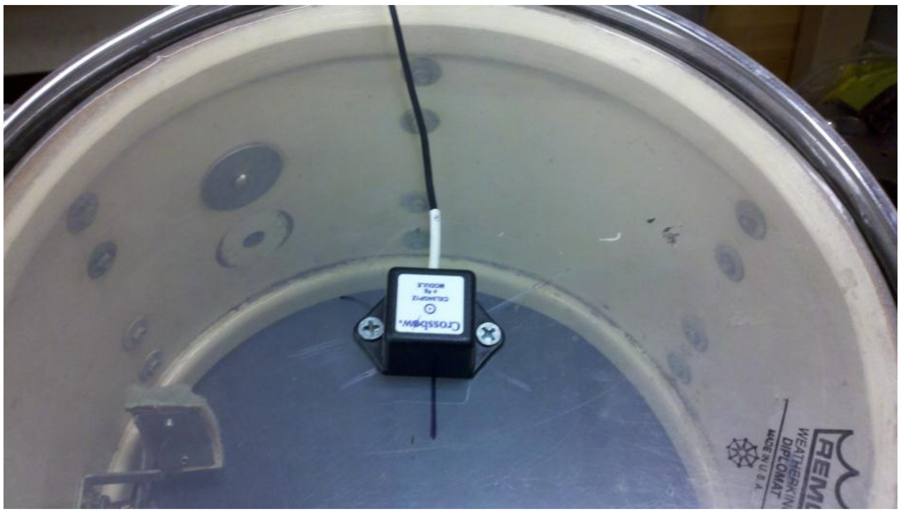

Figure 2: The accelerometer, attached to the center of the bottom drum head with screws.

The virtual instrument (see Figure 3) which processed the data performs a Fast Fourier Transform to convert the time-domain voltage signals generated by the accelerometer into a power spectrum. The power spectrum displays a range of frequencies and their magnitudes relative to each other. The most intense frequencies correspond to the natural frequencies of the drum, and in turn, indicate the range of frequencies the piezoelectric harvester should be tuned for.

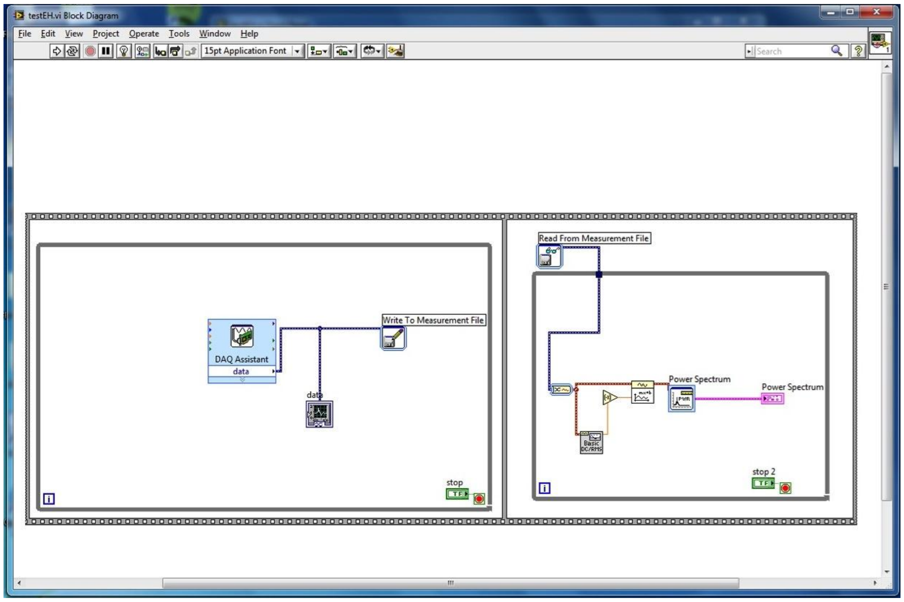

Figure 3: The virtual instrument that produces a power spectrum from the accelerometer data.

Both drums were tested with the accelerometer placed in the very center of the bottom drum head. This is because the drum head is a vibrating membrane, which fluctuates up and down. At the membrane's fundamental frequency, the center point travels the farthest distance up and down, causing the most intense motion (Rossing, 2000). This maximum vibration area provides the most power to the energy harvester, which was positioned in the same central location in the second phase of the project. Additionally, the accelerometer was deliberately placed on the *outside* of the bottom drum head. Although the bottom head is not being struck like the top head, the bottom head vibrates in tune with the top head when it is tightened over the body of the drum properly (this is how one "tunes" a drum). The bottom head can be loosened and removed, but at the cost of re-tuning the drum every time, which would ultimately affect the resonant frequency of the drum itself. Therefore, in order to maintain consistency in the tune of each drum, the accelerometer was attached to the outside, using screws that stayed in place and needed no nut on the other side.

Once the accelerometer was attached properly, the power spectrum for each drum was taken with multiple measurements. Different kinds of drum strikes were used in each measurement, to simulate the various ways in which a drum is hit during a performance. Quantitative measurement of the drum strikes is nearly impossible, therefore they were qualitatively categorized into: Soft Strike, Medium Strike, Hard Strike, Cadence. The first three categories consisted of a single strike to the top drumhead. The fourth category describes a sustained period of playing.

After power spectrum data for both drums had been collected, areas of their peak frequencies were compared, and a common range of frequencies for the two drums was identified. These common frequency ranges were compared to frequency ranges of commercially available piezoelectric energy harvesters, and the appropriate harvesters were purchased for testing.

3.2 Second Phase Equipment and Set Up

The second phase of research began when the piezoelectric harvesters were acquired. Three different frequency ranges of harvesters, manufactured by MIDÉ under the brand name Volture, were selected for testing. The small drum's peak power is in the 50–1550 Hz range, so it was matched to the Volture V21BL harvester which is rated for optimal performance between 45 Hz and 155 Hz. The tall drum's peak power is in the 100–300 Hz range, and was matched to the Volture V22B harvester which is rated for optimal performance between 120–360 Hz. Two of each of these harvesters were purchased for testing. Also, a single Volture V22BL harvester rated at 26-110 Hz was ordered as an additional low-frequency test option for the small drum, or possibly a bass drum. The harvesters are shown in Figure 4 below.

Figure 4: The Volture energy harvesters. From left to right: two V22Bs, one V22BL, two V21BLs.

The first challenge was to design a mounting apparatus to firmly affix the harvesters to the drumheads. Constraints on this design were similar to those of the accelerometer attachment methods; attach to the bottom drumhead, avoid removing the drumhead, place in the center of the drumhead, and provide a solid anchor to minimize dampening of the vibration as it is transmitted from the head to the harvester. The V21BL harvesters were broad enough to have mounting holes already drilled in them, while the other two models were too narrow for pre-drilled holes. The harvesters' spec sheet indicated a specific zone between the 4-pin electronic output and the actual piezoelectric wafers where they could be clamped without hindering their vibration. However, the specification sheet gave little advice on clamp fabrication or appearance.

Two different mounting methods were selected– one for the larger harvester with the pre-drilled holes, and one for the smaller, narrower harvesters. The harvester with pre-drilled holes, was anchored directly to the drum head using #4 screws in much the same way that the accelerometer was attached in the first phase of testing. In order to allow the harvester to vibrate freely, space must be left between the harvester and the drumhead. This was accomplished by placing a nut on each screw between the drumhead and harvester, as shown in Figures 5 and 6.

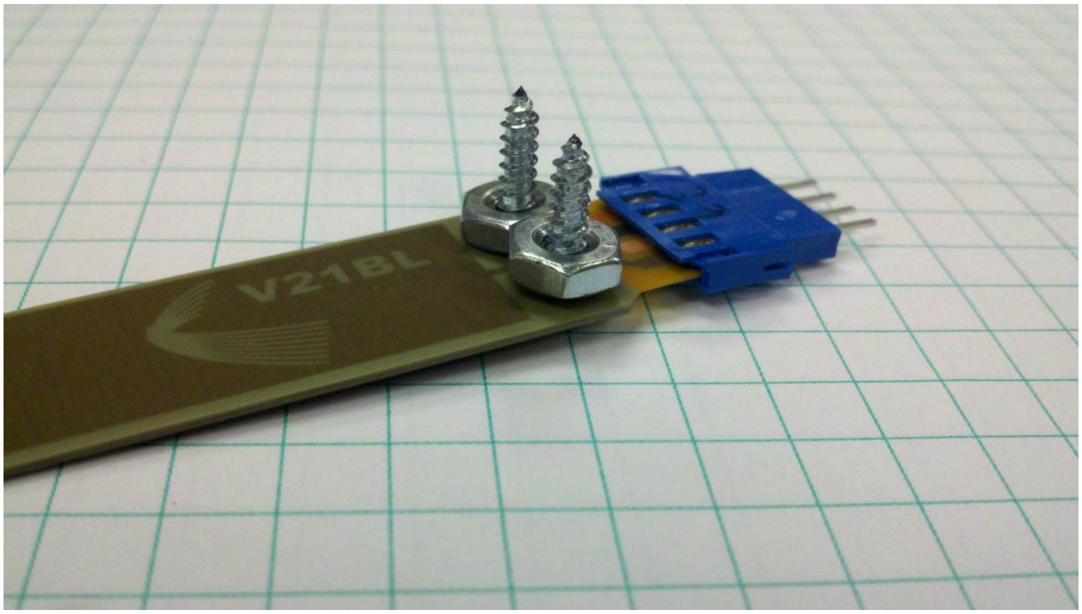

Figure 5: A V21BL harvester with screws inserted into the pre-drilled holes. Nuts were used to create space between the harvester and the drumhead.

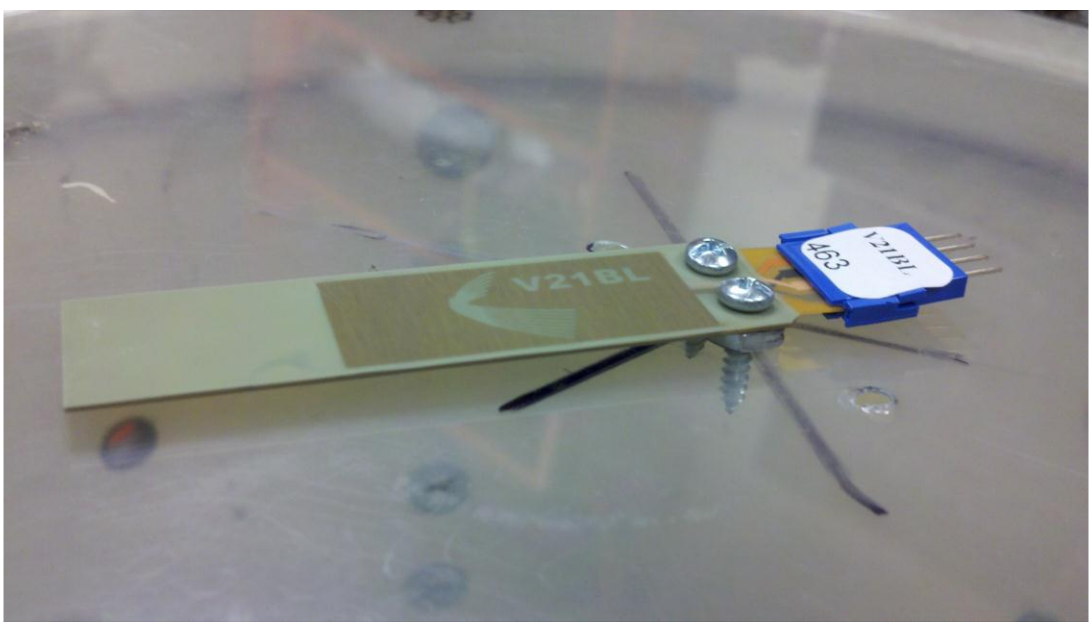

Figure 6: The V21BL attached to the drumhead.

To affix the narrower harvesters, a mounting apparatus was designed and fabricated specially for this project. The device consists of two ¼ inch thick plates of aluminum with holes drilled on either side for mounting screws. The plates are both 0.45 in wide and 2 in long. This corresponds with the constraint by the manufacturing to fit in the area between the electrical terminal and the root of the piezoelectric material on the bean. Again, screws were used to fasten the mount directly to the drumhead. Figure 7 shows the mount itself, and Figure 8 shows a harvester attached to a drumhead using the mounting device.

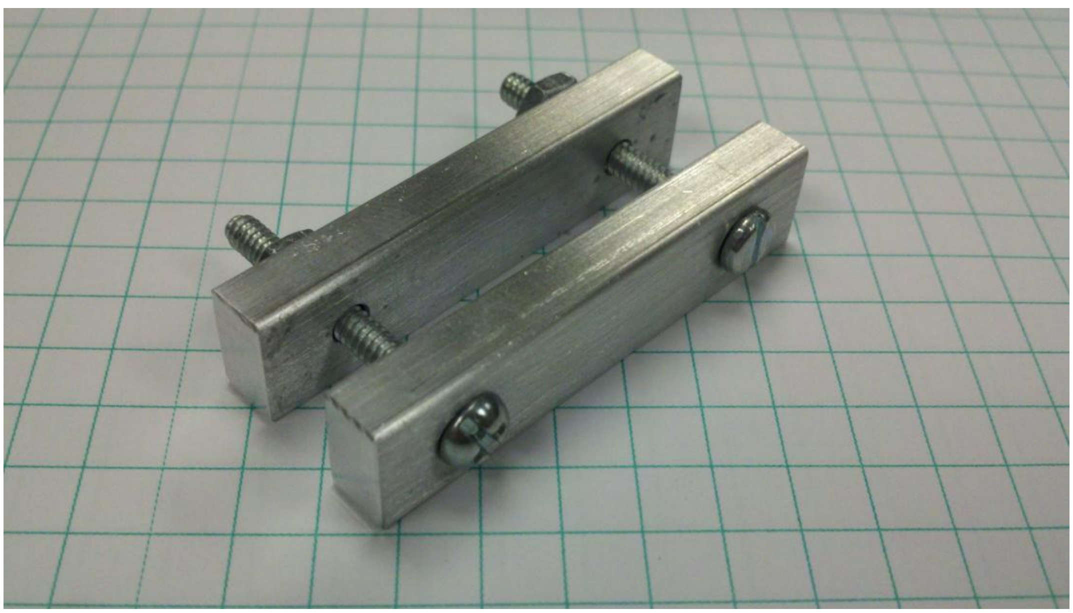

Figure 7: The aluminum mount, fabricated especially for this project. Each bar is ¼ inch thick, 0.45 inches wide, and 2 inches long. The holes are each drilled 0.35 inches from the outer edges of the bars.

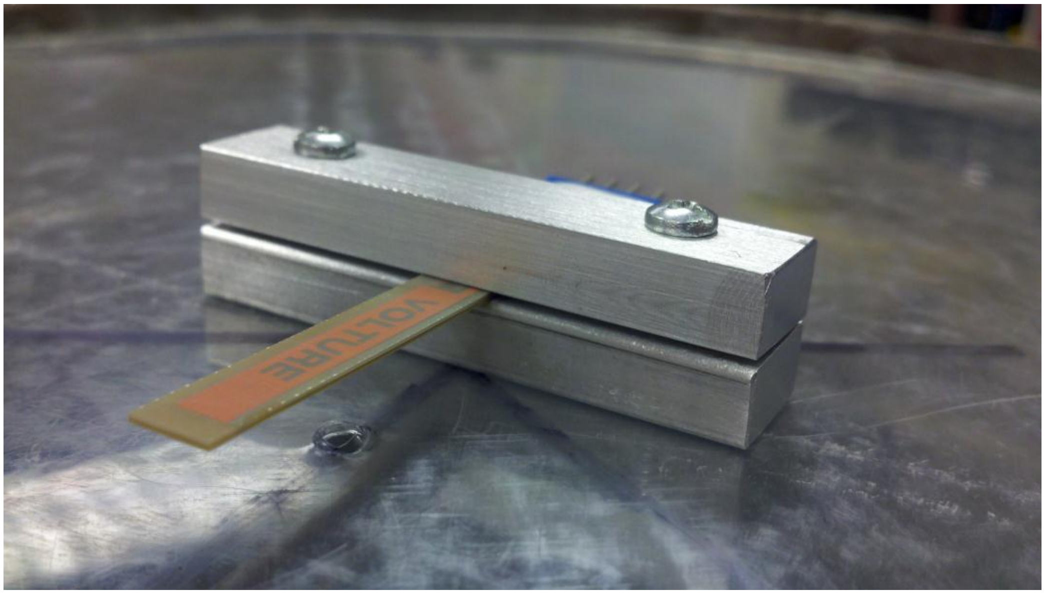

Figure 8: A V22B harvester attached to the tall drum with the aluminum mount.

Once the harvesters were firmly attached to the drums, they were connected to the National Instruments cDAQ, and a VI that measures and logs voltage (see Figure 10 for wire connection between the harvester and the cDAQ). The VI produces a graph of voltage over time, and can be set to record over any length of time. For the testing sessions the VI was set to record for 5 seconds, which proved to be sufficient to capture the energy production due to single strikes.

In the same fashion as the first phase of testing, the drums were tested with a variety of soft and hard strikes. As shown in Figure 9, the data results showed a clear production of voltage for every strike on the drum, but graphs appeared to be cut off after 10 volts. Investigation into this limitation revealed that the cDAQ was physically incapable of working with signals exceeding 10 volts.

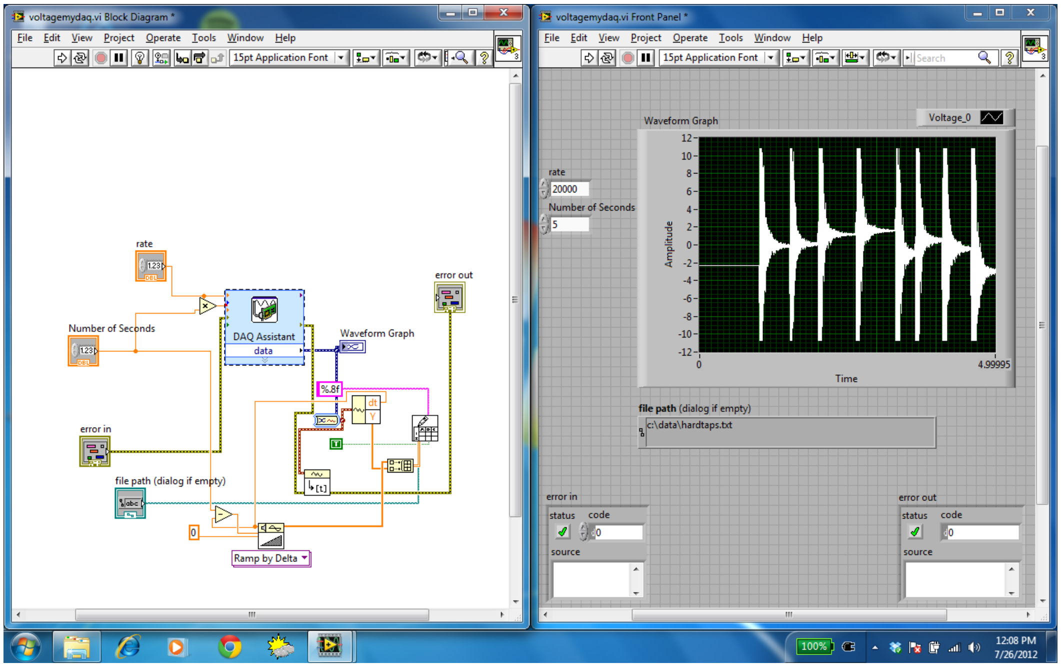

Figure 9: (Left) The LabView VI that reads and records voltage. (Right) An example of the voltage during a trial. Note that the data is cut off at 10 volts in the positive and negative directions.

In an attempt to discover the true maximum voltage output of the drums, they were attached to an oscilloscope. This instrument could display voltage in real time, but could not record data. After a number of trials, it was clear that some powerful strikes on the drums were producing up to and possibly beyond 20 volts. This was clearly enough energy to light a string of LEDs.

Figure 10: The harvester, attached to the bottom of the small drum (the drum is currently upside down) with a 4 pin connector ending in one output and one input wire.

The battery-powered string of LEDs used for this experiment is a commercially available holiday decoration consisting of 18 small white LEDs. The battery pack utilizes four AA batteries in series, supplying a total of 6 volts to the lights. Between the batteries and the LEDs was one resistor rated at 33 Ohms. Therefore, during normal operation, the LEDs were supplied with roughly 1 Watt of power and 0.18 Amps of current. The harvesters on the drums supply a varying amount of voltage at any given time, so there was no need to change the value of the resistor or modify the circuit in any way.

The input and output wires from the harvester were connected with alligator clips to the front and back of the inside of the battery pack, effectively replacing the batteries with the energy harvester in the circuit. The lights in the laboratory were dimmed as much as possible, and the string of LEDs was placed inside of an open, black backpack to shield them from the remaining ambient light. Upon striking the drum several times, it was clear that the LEDs were lighting up in sync with the drum beats. As expected, harder strikes produced a brighter flash, while softer strikes produced dim lights. Both the tall and small drum were tested in this fashion, using their respective energy harvesters. Both drums yielded successfully lit LEDs, with one instance being featured in Figure 11.

Figure 11: A screen capture taken from a video showing the LEDs lighting up as the drum is being played.

Chapter 4: Results and Data Analysis

4.1 Power Spectrum of Drums

The power spectra of both drums changed little with regard to the kind of strike that was administered to it. Normalized amplitude was plotted against frequency, which demonstrated the relative strengths of the frequencies recorded. The most pronounced difference in the small drum data is the comparison of the frequency peak just above 50 Hz. While it is of great significance for the soft strike (Fig. 12) and moderate strike (Fig. 13), it is greatly dampened during the hard strike (Fig. 14). However, this difference in magnitude is only in comparison to other frequencies during the same strike. Note that the y-axis scale for the soft strike data is an order of magnitude lower than that of the moderate and hard strike.

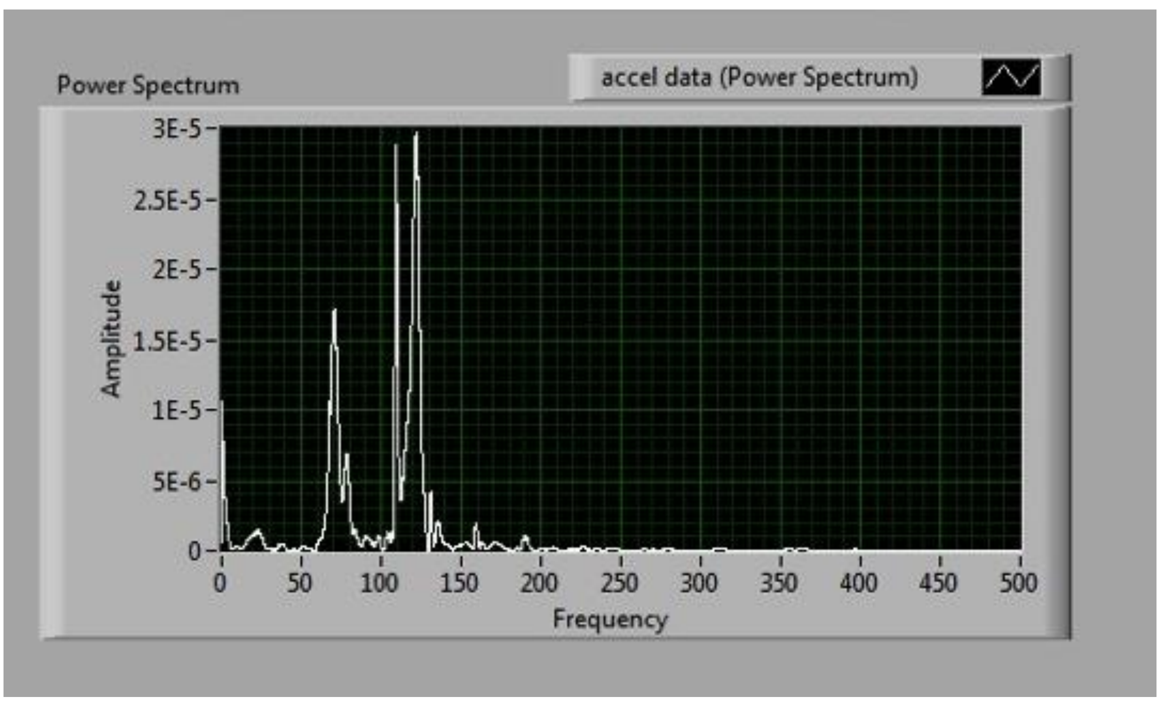

Figure 12: Power spectrum of Small drum, soft strike.

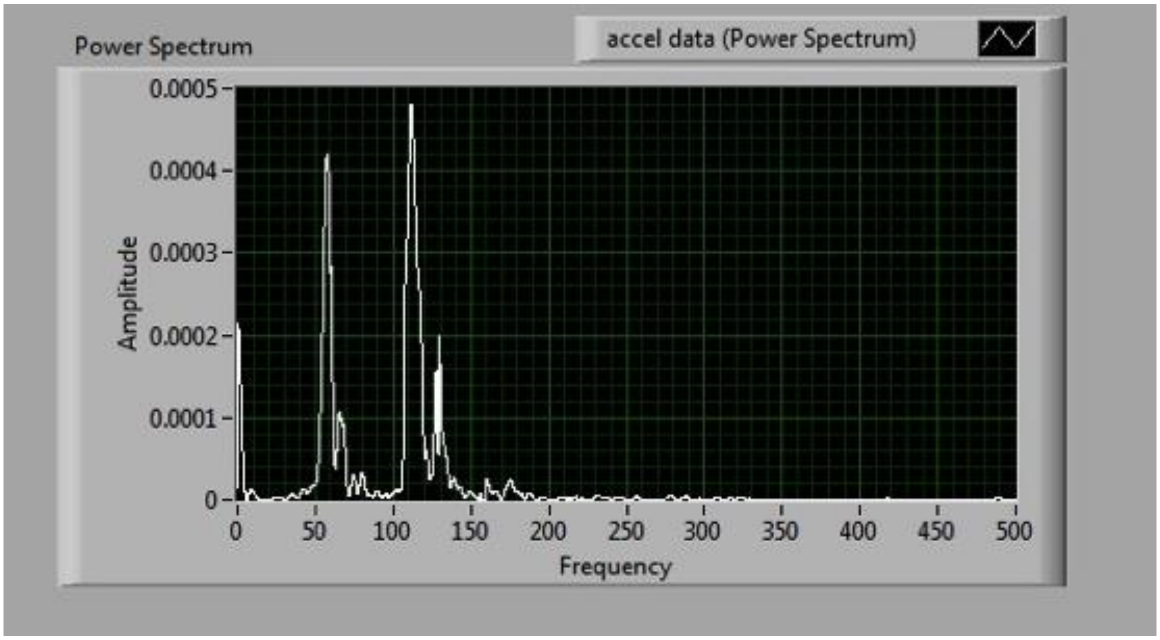

Figure 13: Power spectrum of small drum, moderate strike.

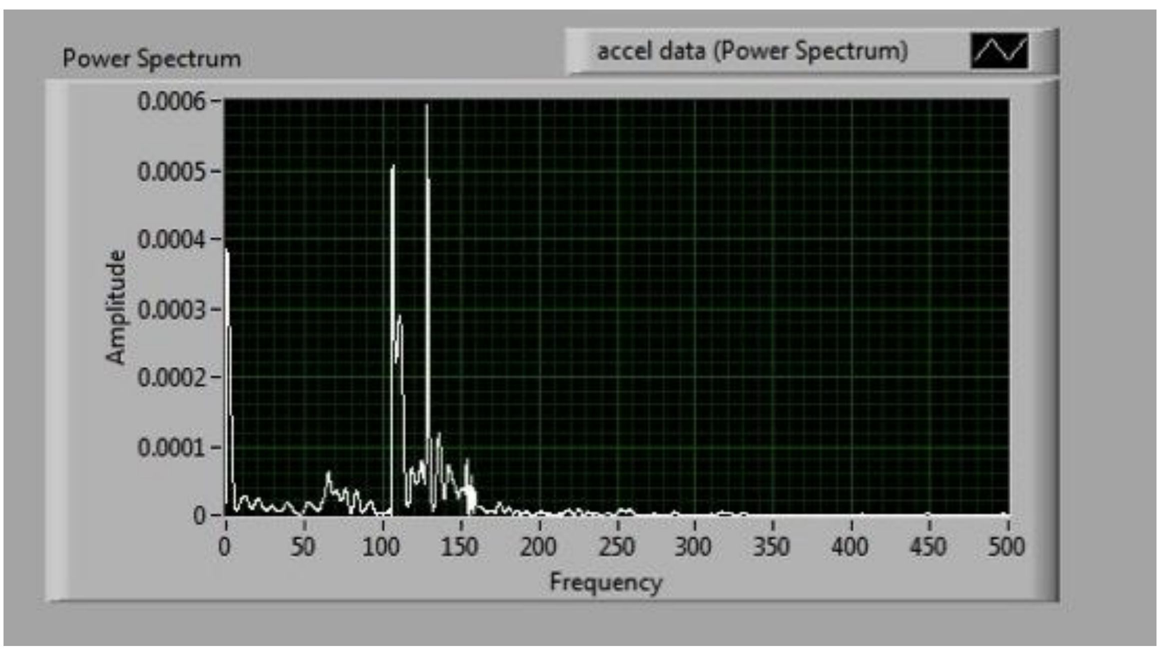

Figure 14: Power spectrum of small drum, hard strike.

The data for the tall drum exhibits similar peaks for all three strikes around 250 Hz and just under 300 Hz, except that it is of greatest magnitude in the soft strike (Fig. 15), reduces in magnitude in the moderate strike (Fig. 16), and becomes even less intense for the hard strike (Fig. 17). Two major peaks between 100 Hz and 150 Hz on the soft strike merge to one peak in the moderate strike, and gains great intensity and sharpness on the hard strike. Again, note the change in y-axis values among the three sets of data. Although the peaks change relative to the other peaks within their data set, the overall amplitude of the frequency increases as the strikes become harder.

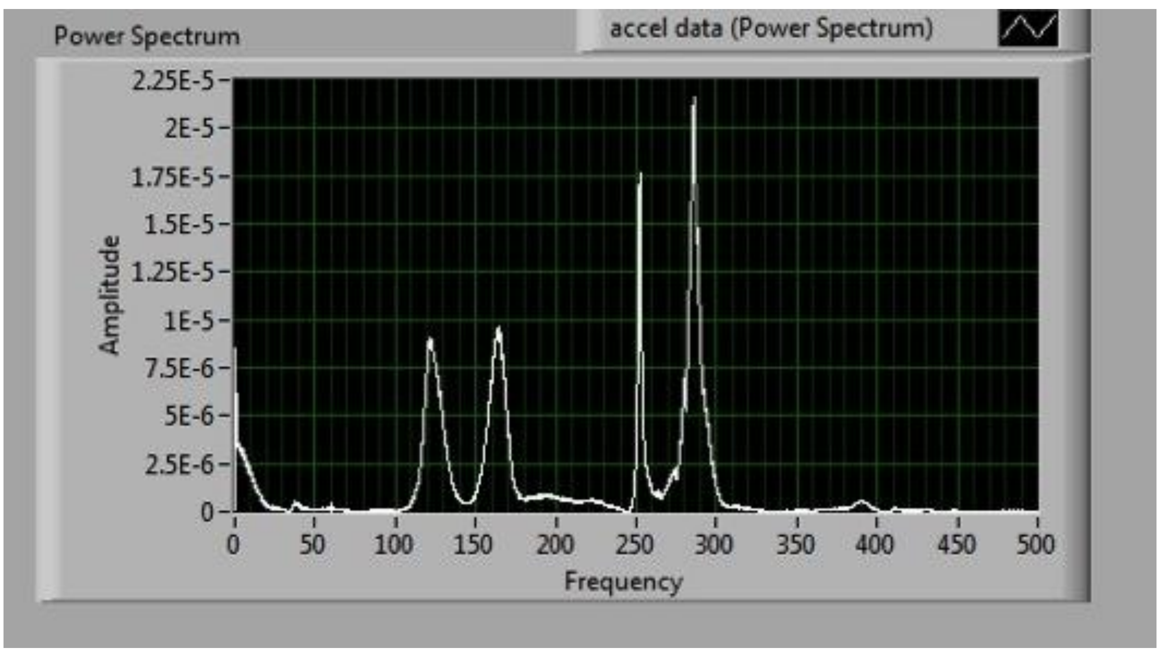

Figure 15: Power spectrum of tall drum, soft strike.

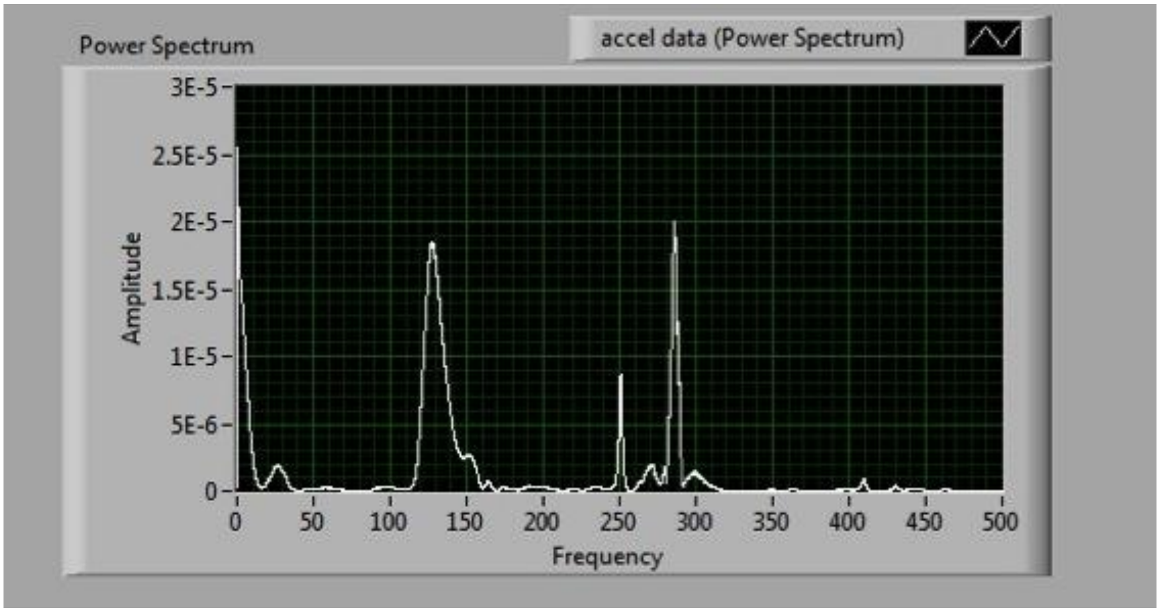

Figure 16: Power spectrum of tall drum, moderate strike.

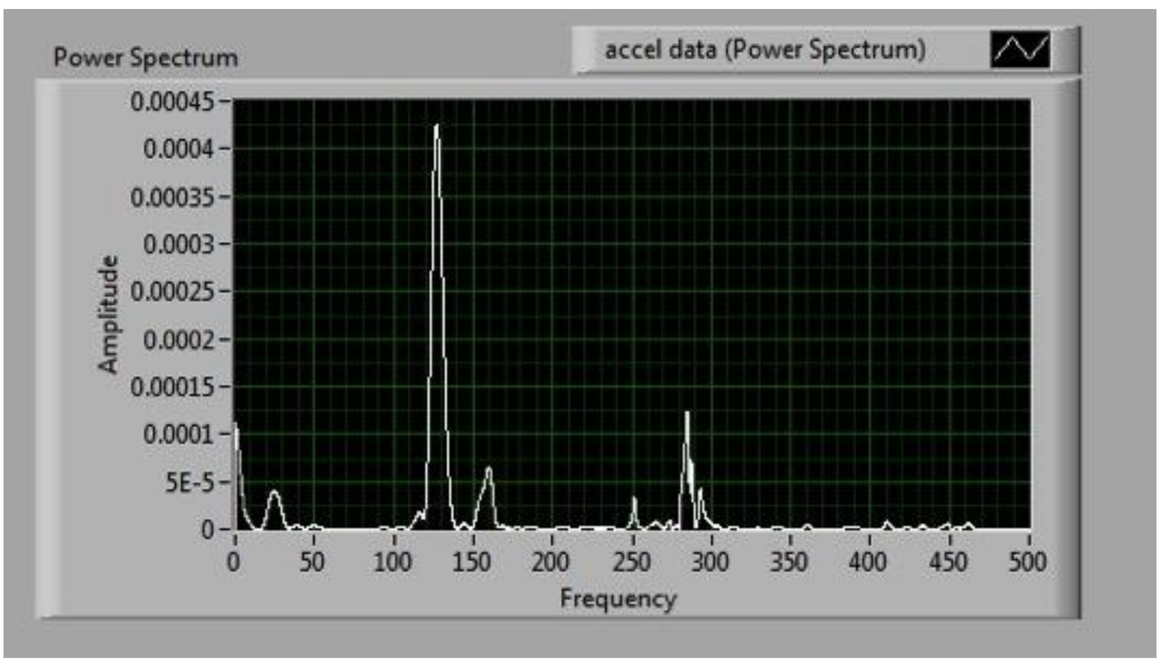

Figure 17: Power spectrum of tall drum, hard strike.

Despite these small variations, general patterns are easily seen for both drums. The broad band of peak frequencies for the small drum was judged to be between 50 Hz and 150Hz, while the broad band of peak frequencies for the tall drum was judged to be between just above 100 Hz to 300 Hz. This allowed for a good match between harvesters and drums. The small drum was matched with the harvester whose range was 45–155 Hz. The tall drum was matched with the harvester whose range was 120–360 Hz.

4.2 Voltage Output of Drum/Harvester System

As mentioned in Chapter 3, the NI cDAQ topped out at 10 volts. Almost every test of voltage output for both drums yielded results that appear to go beyond the 10 volt limit. Voltage was plotted against time, and each test was 5 seconds in duration. Each peak in voltage represents a strike on the drum. The only instance of a drum/harvester system not reaching or exceeding 10 volts was the soft strike on the tall drum (Fig. 20), which reached a peak output of +6 volts and -8 volts.

The "resting" voltage of the drum/harvester system was not always 0 volts. Sometimes the harvester generated voltage even without the drum being struck. This may have been caused by ambient vibrations in the room or an anomaly in how the harvester is mounted to the drum.

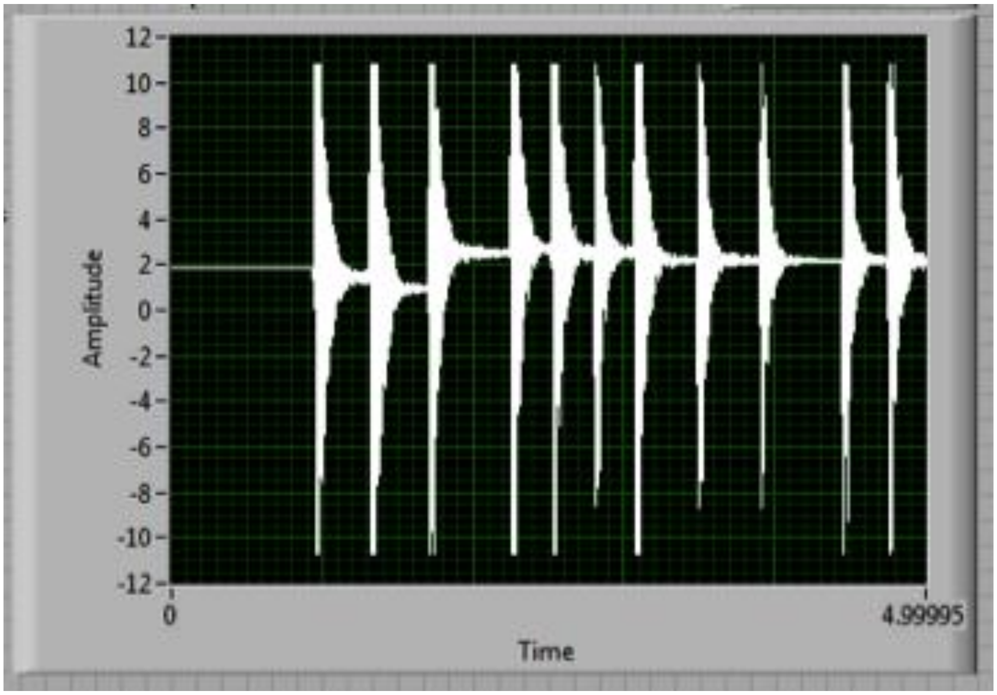

Figure 18: Voltage output of small drum, soft strikes.

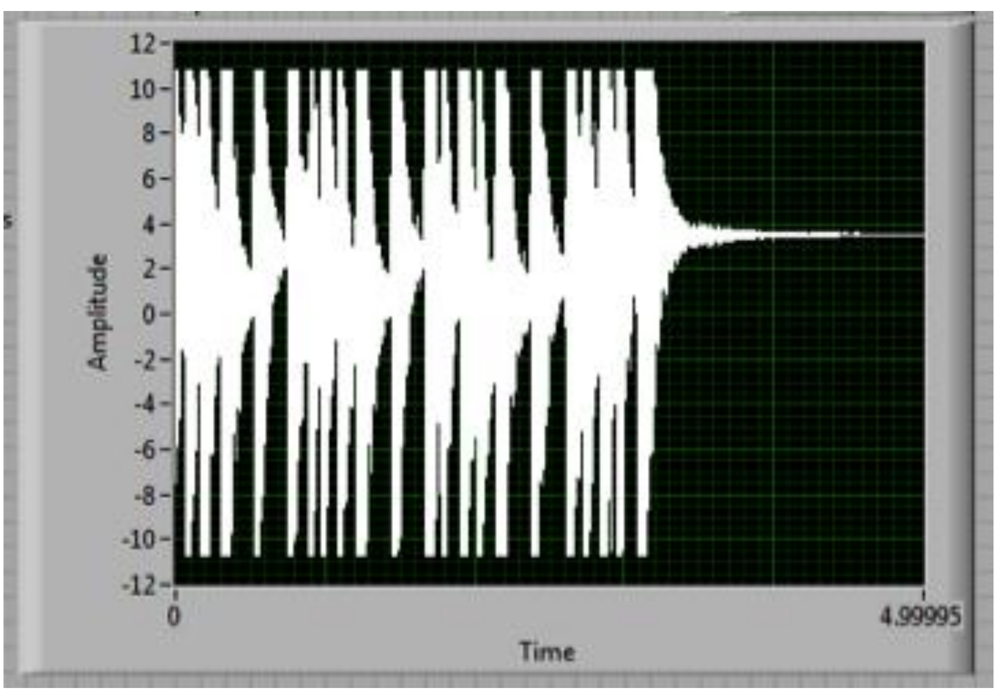

Figure 19: Voltage output of small drum, hard strikes.

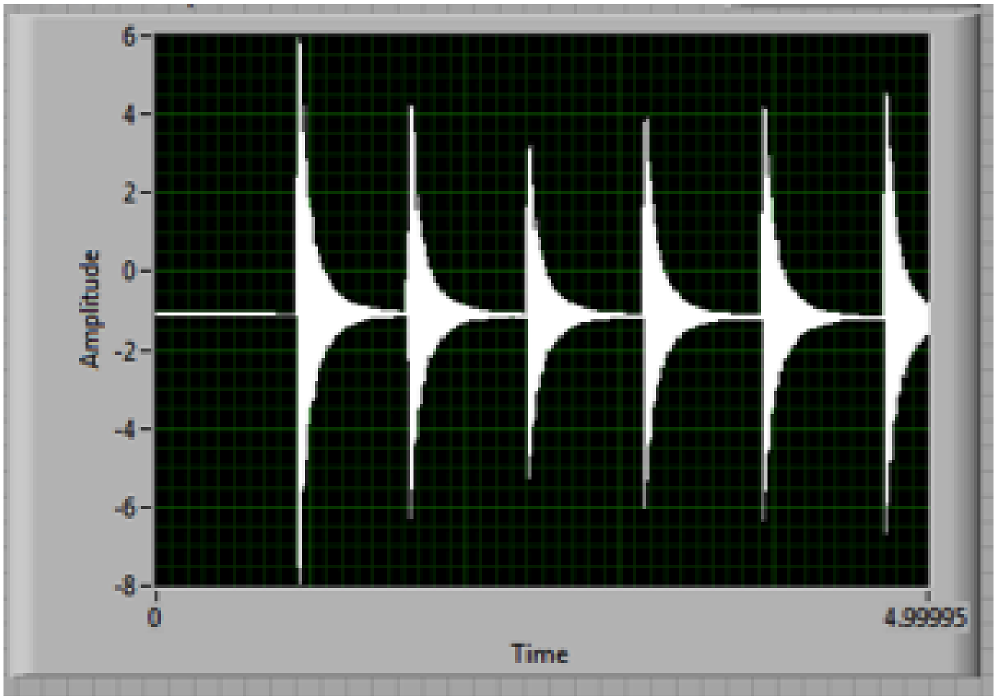

Figure 20: Voltage output of tall drum, soft strikes.

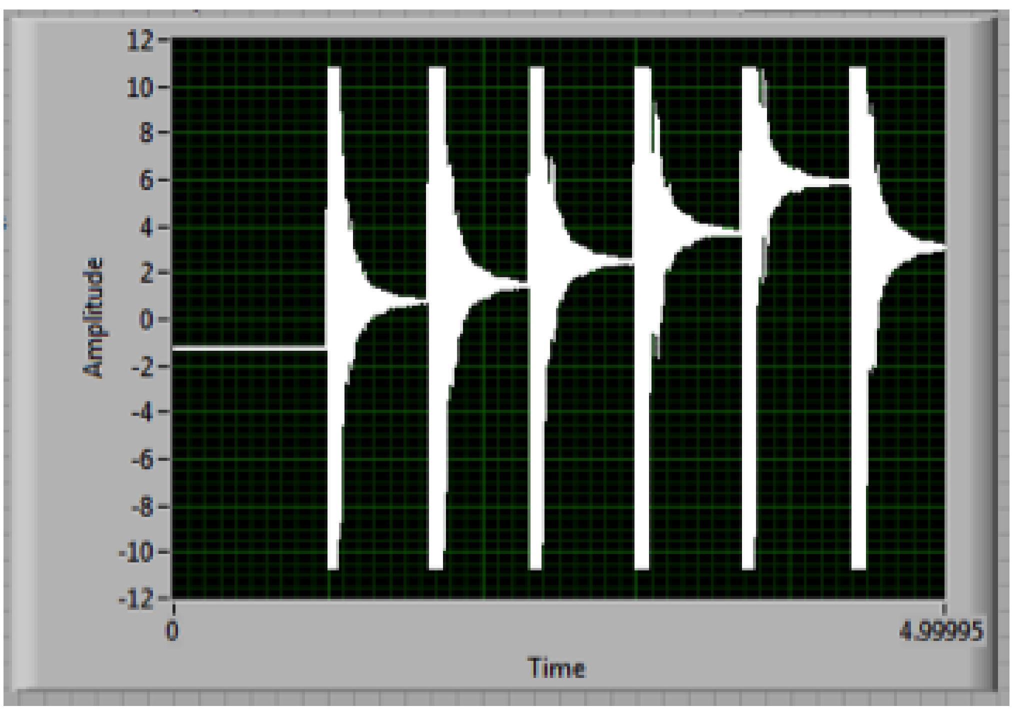

Figure 21: Voltage output of tall drum, hard strikes.

Chapter 5: Conclusions and Discussion

5.1 Proof of Concept

This project can be considered a success because proof of concept was established. Indeed, both drums powered the string of LEDs when matched with their respective energy harvesters. As hypothesized, the lights illuminated according to the timing and intensity of the strikes to the drum. Also, the methods created and implemented to undertake this project are successful in that a basic process for analyzing new drums and to match them to harvesters has been established. The entire project was carried out in a limited amount of time, and mostly utilized basic, easily accessible lab equipment.

However, there were some faults in the lab that hindered more extensive data collection. Most critical is the fact that both V21BL harvesters, matched to the small drum, broke after limited testing with the LEDs. Both harvesters fractured at the same location, where the 4-pin connector meets the mounting screw holes. Is it suspected that the cause of this breakage is due to the wires and 4-pin connector restraining the harvester from vibrating completely freely. On many occasions prior to the breaking, the harvesters vibrated the 4-pin connector loose. After trials with intense drum strikes, many times the wires came out entirely and had to be reattached. Immediately before breaking, the 4-pin connector was secured to the harvester with masking tape to avoid this problem. Without the ability to shake free from the stiff wires, the harvesters were forced to absorb that extra energy and snapped apart.

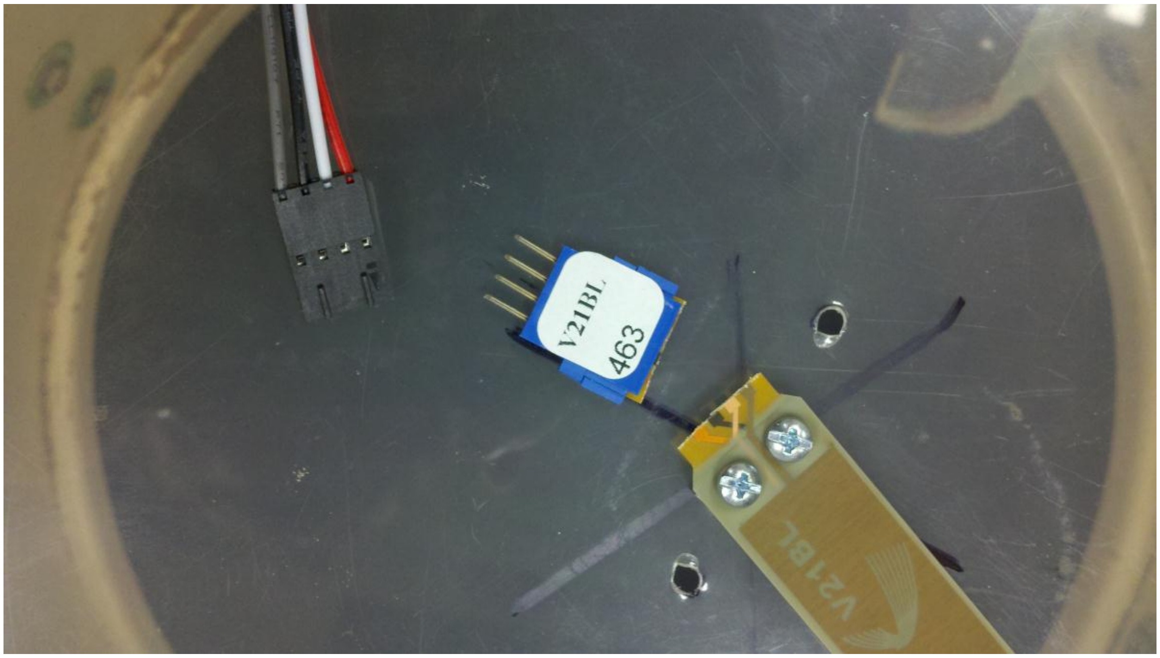

Figure 22: One of the V21BL harvesters, broken after extensive drum strikes. The 4-pin connector (top right) may be the culprit.

5.2 Sources of Error

The sensitivity of the Crossbow Technology accelerometer was 0.501 volts per g, but absolute measurements were not used. All power spectrum graphs displayed relative intensities of the vibration as a function of frequency. LABView and the cDAQ used to collect voltage data could not process data beyond +/-10 volts. Therefore actual peak voltage output of the drum/harvester systems could not be completely determined. More important is the frequency resolution of the spectral measurement, which was on the order of 5 Hz. This is sufficiently narrow compared to the useful frequency ranges of the harvesters and has no significant effect, and hence was ignored.

In absence of an instrumented drum stick, there was no readily accessible way to standardize the strength of drum strikes used in testing. All strikes, categorized by the researcher herself as “soft”, “moderate”, or “hard”, had to be judged qualitatively.

5.3 FUTURE RESEARCH

This small project has opened up a huge realm of possibilities for continued testing. Now that proof of concept has been established, how much further can this idea be taken? First of all, this project was limited only to drums. Any musical instrument could be analyzed with an accelerometer to match an appropriate energy harvester to it. Drums were selected for this project due to the intensity of their vibration, but perhaps simply a good pairing of “vibrationally complementary” harvesters and instruments could yield significant voltage output. Purely in the world of drums and percussion instruments, there is a wide array of styles and sizes that could be tested for power output.

One aspect of research that could be continued is tuning the harvesters. Each harvester has the ability to be physically modified such that it is optimized for a specific resonant frequency. Because the original power spectrum data for the drums covered a broad band of frequencies, the harvesters in this project were left unaltered. In this unaltered state, the harvesters were more versatile, but less efficient. In future research, perhaps more precise power spectrum data can be acquired for a drum, and the matching harvester can be tuned to its peak frequency.

Another area of the research that held too many possibilities to be explored by this project alone was the method of mounting the harvesters. Although the methods used in this project proved to be at least basically successful, much improvement could no doubt be made. Certainly, because some of the harvesters broke at the end of testing, better ways to affix them to the drums should be developed. Also, designing a mounting system that is the most efficient in transmitting the whole power of vibration from the drum to the harvester with minimal energy loss is extremely desirable.

Chapter 6: Applications to Practice (The Project)

6.1 Accessibility and Appropriateness to the High School Setting

Every activity in this research project could be replicated in the high school classroom. The tools and materials were few in number, and either commonly found in labs or easily purchased online. The only exception to this is that that the piezoelectric harvesters were somewhat expensive (in the $50 to $90 range). Many schools have access to LABView and cDAQs, as they are of common use with high school robotics teams. However, other virtual instrument devices that can measure voltage and accelerometer data such as the Vernier LoggerPro series of equipment are also widely used in high school science classrooms.

This project, conducted virtually identically to how it has been reported here, could certainly be appropriate as an engineering activity at the high school level. The project itself is open-ended in nature, since there are so many possibilities for how to maximize electricity output. Providing the students with the needed equipment and outlining the goals (1. Find the power spectrum of the instrument, 2. Find the maximum output voltage of the instrument/harvester system) could lead to students designing their own methods for how to take and record data. Undoubtedly, with enough thought students could come up with a better drum striking system than the "soft, moderate, hard" categories that were used here.

Students would be exposed to numerous lab skills that would serve them throughout the rest of their academic careers as well as in the professional world. As described in the previous paragraph, this is a great open-ended project to allow students to design their own methods and lab procedures. Just trying to devise a mounting apparatus for the energy harvester could be an entire lesson in engineering and design. Exposure to and use of LABView is also a great way to give students experience with programming and computer logic. Basic skills in electronics also come into play when designing methods to incorporate the instrument/harvester system into the LED circuit.

6.2 Interdisciplinary Educational Opportunities

It is quite obvious that one of the most valuable aspects of this project is its interdisciplinary nature. In order to undertake this design challenge, students must master basic concepts in the fields of mechanical frequency and vibration, energy transfer, electronics, piezoelectric technology, and programming (in the case of creating virtual instruments in LABView). A teacher overseeing this project could very well introduce entire lessons and short demonstrations/labs covering these topics, either at the beginning of the entire project, or dispersed throughout the classes as subjects become relevant.

The nature of this project also provides a unique opportunity to explore the science of music. While investigating the power spectrum of the instrument in question, students engage in direct observations of how they produce various frequencies, and learn that certain resonant frequencies are the signature of that particular shape, size, and note. Instead of just learning about the relationships between energy intensity and loudness, or size of the instrument and pitch of a musical note, students get to see it and interact with it directly – creating authentic learning experiences.

6.3 Engaging Students

Students who are engaged in the curriculum are more likely to be academically successful (Leach and Zepke, 2011). Great teachers are always searching for new ways to connect what they teach in class to the real world so that their students have something they can relate to and to which they can apply their knowledge, i.e. being an engaged learner. Music is an enormous part of teen pop culture, and many high school students engage in some kind of musical activity or performance. A lab or project that incorporates musical instruments will almost certainly be engaging to those students with an affinity for music. Those who actually play an instrument can be encouraged to make that the focus of their research – as this lab could be modified to investigate any vibrating instrument, whether it is percussion, string, or horn.

Chapter 7: Applications to Practice (The MASEE Program)

The UTeach*Engineering* Master of Arts in Science and Engineering Education (MASEE) program has been stupendously influential to me as an educator. Three years ago, I could not have imagined what an impact this program would make on me and my teaching practice. I came to the MASEE program already having the experience of teaching a high quality engineering course called SciTech for two semesters. Although I had no prior experience in engineering education (my bachelors degree is in physics and education) I was coached and mentored by my three co-teachers, each of whom had a different science background (chemistry, physics, and industrial arts) but was a seasoned veteran of the class. With this experience already under my belt, I was unsure of how much more I would benefit from a program like MASEE. But the depth and breadth of engineering and pedagogy skills I acquired from this program have transformed me into a professional engineering educator.

7.1 Developing Engineering Awareness

I feel very prepared to teach about engineering practices in my classroom. However, I do not feel as prepared to talk about careers in engineering. Although this program called my attention to the vast variety of engineering vocations/applications such as electrical, mechanical, agricultural, chemical, biological, civil, etc., I do not believe the program prepared me to have extensive knowledge about career opportunities that I can share with my students. In order for me to help my students be more aware of potential careers in engineering, I would have to conduct my own research to supplement lessons.

The two aspects of engineering practices I plan to focus on in my own teaching are: the Engineering Design Algorithm (EDA), and the specific stage of assessing and redesigning the outcome of a project.

Blatantly teaching the EDA is already a major part of SciTech, the engineering class that I teach. We teach students the importance of metacognition, i.e., understanding how one logically goes though a series of steps to solve a problem. However, I would like to demonstrate more “real world” examples of engineers and designers using this step by step process, rather than just teaching it in the abstract. One portion of the MASEE program that had a pronounced impact on me was the customer needs redesign labs that were conducted “consumer report” style. I feel that this is one of the very best ways to demonstrate the “real world” process of engineering in a very systematic step-by-step way that students can easily understand. Balancing constraints and goals is best taught when the students are intimately familiar with those materials and functions. At this time, SciTech does not focus much on redesign as a method of teaching the EDA. I would love to incorporate one of the “consumer report” style labs into my class, perhaps for a day or two.

On the subject of redesign in general, I would really like to do more to incorporate that stage of the EDA into my class. For example, I have a few small design activities that only take one class period to complete. They require students to use random common objects to create Rube Goldberg-like devices to complete a task or goal set. The evaluation and redesign portion of the lesson is poor to non-existent, because the students take most of the class time to build the first (and usually only) iteration of their device. Yes, there are hasty redesigns made during the initial building stage, but this is usually based more on gut instinct than on actual reflection. As soon as the devices are completed and tested, the class is usually almost over. There is no time to conduct a thorough evaluation of how the devices performed or even begin to think about redesign to improve performance.

I would love to set aside time to add in an evaluation and redesign section to the project requirements. Students would reflect on how their initial project performed, and then make deliberate design changes and re-test those changes in a meaningful way. Another variation on this activity is to evaluate the design of a device that was made by a different group of students. This encourages students to be more objective and realistic about a device's flaws and merits.

7.2 Developing Engineering Habits of Mind

One of the most important habits of mind an engineer needs to cultivate is constant and accurate documentation. For practical and legal purposes, an engineer must keep track of every idea, sketch, conversation, and data collection. In the MASEE program, we were encouraged to simulate this with our engineering notebooks. Keeping formal records of class activities, notes, and lab data is the best way for us as teachers to know how important it is, and how to do it correctly. The MASEE notebooks had a great format, complete with a table of contents in the front, and spots on each page to place the date, title of the subject being worked on, and a place for witness signatures.

In my SciTech class, we have our students keep notebooks too. Although they are not as elegantly manufactured, they serve the same purpose – to get students into the habit of recording all of their thoughts, actions, accomplishments, and plans in one central place. In SciTech the notebook is treated as a legal document, providing a record of what the students are up to each day in class. Not only do they take class notes and record labs in their notebooks, but they also take ten minutes at the end of each class period to sit quietly and reflect on their progress in their notebook. They must talk about what they accomplished, what their teammates accomplished, what their goals are, and most importantly, they must plan how to achieve the rest of their goals and chart their progress against due dates. Although in the beginning of the class there is a lot of complaining about having to be so thorough and take so much time to write, by the end of the semester many students actively acknowledge how useful the notebook is, and how much more disciplined their thought processes are.

Another great habit of mind that engineers must possess is a willingness to work with others in a team. Every project that my cohort and I worked on through our three years in the MASEE program involved group work. Each teacher in the class had a different personality and personal preferences for how to accomplish a task, and when we were put into groups, we had to learn quickly how to adapt to each others' styles. Finding group partners' strengths and weaknesses, and getting the most out of each member was critical if the group project was to be successful. The MASEE program even went as far as to sometimes assign us groups based on personality tests. Although this idea works well in theory, I am not sure how realistic it is.

My students in SciTech must also work in groups nearly constantly. There are no personality match ups in my class though; it is a random assignment of students. When students complain about not being able to choose their partners, I remind them that in the "real world" you do not always get to choose your work partners, neighbors, or who you end up sitting next to on the bus when the zombie apocalypse strikes. A critical habit of mind of an engineer and most other successful professionals is the ability to work well with others and adapt to team members. Working in groups forces students to hone their skills in active listening, giving and receiving constructive feedback, compromising, being responsible to others, meeting deadlines, collaborating, and more. Again, when invited to share their experiences in SciTech, many students report feeling successful in working well with groups and learning how to be better team players.

7.3 Developing an Understanding of the Design Process

Personally, I never thought I was much of a "hands-on" scientist. As a physicist, I was far more comfortable with textbooks and chalkboards than I was with lab equipment. Teaching SciTech after my physics degree forced me to get acquainted with many tools of industry and the design process, as laid out in the EDA. But this summer's project truly reminded me what it was like to be the student – not the teacher.

The most important lesson in the design process that the research this summer taught me is that actual projects almost never work the way they are planned beforehand and that engineers must expect in advance to hit roadblocks at every turn and be ready to deal with them. Of course, I have always known that this was the case – I am constantly talking my students through their naïve disappointment when their projects do not work as elegantly as they had planned on paper. I try so hard to warn them ahead of time that practically nothing in the real world actually works the way it was originally planned in the designer's head or explained in the textbook. But my students never fully understand until they go through the whole process themselves, actually experiencing the need to redesign and redesign and redesign. Much in the same way, I too "knew" this to be true, but had not really experienced it in a long time. The experience this summer of having so many little aspects of my research go wrong or have no clear, immediate solution really drove this lesson home for me.

More than anything, I hope to carry these experiences of overcoming the many little failures back to my classroom to share with my students. The anecdotes I can provide will serve me as I try again each semester to guide my students through the redesign phase of the design process.

7.4 Developing Knowledge for and of Engineering Teaching

In the past three years of my participation in the MASEE program, I have implemented many small changes to how I teach SciTech. One concrete example is how I took a reading from one of my pedagogy classes about the "Nature of Science" and turned it into a class activity that teaches students how to understand what science is and more importantly, what it is not. I used the information in the reading to design a poster-making project that allows students (who are put into groups!) to interpret what they read and communicate their own understanding by creating a visual representation of it. The posters always provide great discussion material, and each group presents their poster to the class and discusses their misconceptions about science and how they reconciled them.

SciTech is an engineering class that has a 26 year history, winning numerous awards including the "Best Practices" from the American Society of Mechanical Engineers. Two of my co-teachers for this class are the ones who created it 26 years ago, and although they say they are constantly open to change, I see how they have become set in their ways and very attached to how the class is currently being taught. When I first joined their team, I had no prior engineering experience, so they taught me how to teach the course exactly the way they teach it. To even include the extra lesson on the nature of science that I described in the previous paragraph took a huge effort on my part to make a change to the set curriculum. Even after demonstrating how effective this one new lesson is, my teaching partners who are the original curriculum creators still do not incorporate it into their classes simply out of habit.

Now, after three years of the MASEE program I see so many opportunities to change the way things are done in SciTech, and even more so, I feel empowered to make those changes. I want to focus on assessment and redesign rather than just doing something once and moving on to the next thing. I want students to have more hands-on experiences with the tools and materials available to them before their big projects are assigned. I want them to have more open-ended projects and fewer classroom lectures. This upcoming school year, I will continue to engage my partner teachers in discussions that will hopefully lead to planning and redesigning new aspects of this course to bring it into the modern setting of engineering education.

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Vita

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