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EML4551-2

Team No. 515: Music Machine

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Abstract

The abstract is a concise statement of the significant contents of your project. The abstract should be one paragraph of between 150 and 500 words. The abstract is not indents.

Keywords: list 3 to 5 keywords that describe your project.

Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

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Notation

A17	Steering Column Angle
A27	Pan Angle
A40	Back Angle
A42	Hip Angle
AAA	American Automobile Association
AARP	American Association of Retired Persons
AHP	Accelerator Heel Point
ANOVA	Analysis of Variance
AOTA	American Occupational Therapy Association
ASA	American Society on Aging
BA	Back Angle
BOF	Ball of Foot
BOFRP	Ball of Foot Reference Point
CAD	Computer Aided Design
CDC	Centers for Disease Control and Prevention
CU-ICAR	Clemson University - International Center for Automotive Research
DDI	Driver Death per Involvement Ratio
DIT	Driver Involvement per Vehicle Mile Traveled
Difference	Difference between the calculated and measured BOFRP to H-

point

DRR	Death Rate Ratio
DRS	Driving Rehabilitation Specialist
EMM	Estimated Marginal Means
FARS	Fatality Analysis Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
GHS	Greenville Health System
H13	Steering Wheel Thigh Clearance
H17	Wheel Center to Heel Pont
H30	H-point to accelerator heel point
HPD	H-point Design Tool
HPM	H-point Machine
HPM-II	H-point Machine II
HT	H-point Travel
HX	H-point to Accelerator Heel Point
HZ	H-point to Accelerator Heel Point
IIHS	Insurance Institute for Highway Safety
L6	BFRP to Steering Wheel Center

Chapter One: EML 4551C

1.1 Project Scope

The objective of this project is to create a machine that can play a recognizable song using mechanical and electronic instruments. The music machine is intended as a public relations tool to foster community relations, recruit potential funding sources, and inspire future engineers. The key goal of this project

- The selected song(s) must be recognizable.
- The chosen instrument(s) must not mask the song.

Since the device will be displayed to the public, it must be robust enough to survive transport between locations. It must also be small enough to fit through standard interior doors and light enough that a single person can maneuver it.

Primary Market.

The primary market for this device would be Dr. Murray & Faye Gibson because we are creating this device for them. The students at the FAMU-FSU College of Engineering because the primary purpose of building this device is to use it as a public relations project to recruit future students. Finally, legislative officials would be another target market because presenting this to the local legislature could encourage financial support for the university.

Secondary Market.

This device can also be utilized in other scenarios, including presenting at schools for inspiring STEM students, demonstrating during STEM educational programs, or potentially representing the FAMU-FSU College of Engineering at the Smithsonian Museum.

Assumptions.

To complete this project before graduation we must make the following assumptions. We assume that the rights to the FAMU alma mater and the FSU alma mater are attainable. We also assume the that the overall size of the device will be no larger than a standard interior door. This device is also assumed to be used indoors and thus will not need to be weatherproof. Finally, it will be assumed that the device is not required to play more songs than the two aforementioned alma maters.

Stakeholders.

The stakeholders included in this project are Dr. Murray Gibson, Mrs. Faye Gibson, Dr. Shayne McConomy, and Dr. Patrick Hollis from the FAMU-FSU College of Engineering. Additional stakeholders include Tisha Crews Keller the Director of Marketing at FAMU-FSU College of Engineering, FAMU President Larry Robinson, and FSU President John Thrasher.

1.2 Customer Needs

Need statement:

A portable device which utilizes musical and visual elements to engage an audience for the purpose of representing the FAMU-FSU College of Engineering to the public.

For identifying our customer needs the following questions were posed to Mrs. Gibson and her responses are given in Table 1. From her responses we were able to identify the customer needs for the project. This machine will be portable, entertaining, and engaging. The idea is to allow the parts of the machine to be interchangeable to allow multiple songs to be played, but the main focus will be to have the machine play the alma mater of both FAMU and FSU. Its engagement will be enough that a person with minimal musical knowledge can figure out how to use it. It will be durable enough for it to withstand traveling between each university's main campus and the engineering school as well as have the option of powering it through a wall outlet or a self-charging system.

Table 1

Interpreted Customer Needs from Questionnaire with Sponsor

Question	**Customer Answer**	**Interpreted Need**
What is our budget for this project?	About $1700	Keep the cost of the build as low as possible
Would you like the music to be a specific song, a variety of songs, a combinable variety of songs (loops, etc.), or notes that can be played by the user?	Notes that can be played by the user: good for interactivity Specific song: recognition factor (Alma mater, theme and variation) Changeable (stretch goal)	Should play both alma maters (FAMU and FSU)
Would you like the music box to be interactive? To what degree?	Ideally some human involvement, degree can vary	Must be attention grabbing

Would you like the audio to come from traditional instruments, electronic sounds, non-traditional instruments (such as found object percussion), or some combination thereof?	Combination, physical component triggers electronic phrase, such as demonstrated by the modulin. Whimsy and fun	The audio may come from any source which generates user interest Must involve both mechanical and electrical components
What is the maximum and minimum size that you would like this device to be?	Fit through interior door (~30in)	Needs to be portable (30inx80in)
Are there any weight restrictions for this project?	Carry for demonstration	Must be maneuverable by one person
Is the device intended to be used long term (>1 year)	Yes	The device needs to be durable
Where will the device be used (indoor, outdoor, on concrete, etc.)?	Primarily indoors, so carpet, tile, or wood.	Does not need to be weatherproof
What is the intended source of power for this device?	Ideally cordless, back-up with corded power	Can be powered either through battery or corded
Particularly if interactivity is an intended component, who is the	Usable by non-experts	Should be self-explanatory to those with

target audience?		no music experience
What would you like to get out of this at the end of this project?	PR suitable, a usable entertaining device	Device must be of a quality the FAMU-FSU College of Engineering would be proud to display
Do you want the device designed to be portable or stationary?	Portable (not necessarily backpack size, but transportable)	Mobile and portable, easy to display/set-up
How would you like this device to be displayed? (Free standing, mounted, on ground, on table, etc.)	As long as the display is portable, display can be done in any way	The device should be simple enough that one person can set it up.
Should the appearance be stylized in a particular fashion?	Attractive and appealing to various audiences	Should be professional since it represents the universities, but no specific style required

1.2 Functional Decomposition

The functional decomposition represents the processes necessary for the music machine. Arrows show the flow moving between functions and sub functions and progresses through the outcomes of the music machine. The three main functions of the music machine are playing audio, displaying visual elements, and encouraging interactivity. Using the functional relation matrix, shown below in Table 2, the sub-functions were compared to each main function to determine which sub-functions overlapped. From this, we determined that providing power and signal is an element intrinsic to all of the main functions, so it will be a key focus in our later designs. Furthermore, interactivity often relates to both audio and visual elements. Though the exact degree will vary based on our design choices, it is important that the interactivity be considered at every phase.

Table 2

Functional Relation Matrix

	Play Audio	Display Visual Elements	Encourage Interactivity
Produce electronic audio	**X**		
Audio is triggered by physical condition	**X**		
Send electrical signal to activate correct elements	**X**	**X**	**X**
Move components to activate physical audio	**X**		**X**
Send electrical signal	**X**		

to move correct elements			
Dampen any unwanted sounds	**X**		
Identify dampeners	**X**		
Activate dampers	**X**		
Move object(s) of visual interest		**X**	**X**
Turn light(s) on/off		**X**	
Send electrical signal to activate correct lighting elements		**X**	
Activate elements			**X**
Read in user input			**X**
Utilize user input to manipulate elements		**X**	**X**
Transport device to audience			**X**

Supply power to element	**X**	**X**	**X**

The functional relation matrix above lists each task and depicts how each task relates to the objectives of the project. Using the functional relation matrix, it was determined that the sub-functions “Send electrical signal to activate correct elements” and “Supply power to element” are both related to each of the main functions. The sub-function “Move components to activate physical audio” is related to the main functions “Play Audio” and “Encourage Interactivity”. The sub-functions “Move object(s) of visual interest” and “Utilize user input to manipulate elements” are both related to the main functions “Display Visual Elements” and “Encourage Interactivity”.

1.4 Target Summary

Every category is broken down into needs which are both specified by the customer and interpreted by the team. Each need is broken down into targets in order to explain what will be measured. The targets that are most important to the customer, as shown below in Table 3, are the number of songs to be played (at least 1), audio volume and range (40-110 dB and 5 m^2), corded/battery power source (12V), volume and weight of the objects, and the force required to move the machine. The customer has specified that they would like for the machine to play at least one song and to be used in a variety of settings, making battery power very important. We will use no larger than a 12 V battery to power the entire machine because this is a common affordable battery size.

To ensure this criterion is met, the device will be designed with this limit in mind and tested with a multimeter. The audio volume and range will be measured using a decibel meter, which will be used at different distances in order to detect the range at which the machine can be heard clearly. In order to detect if the song is recognizable, multiple people will be selected to listen to the machine play while not knowing what song they will be listening to. The power source will be measured using a voltmeter. The volume, weight, and force required to move the machine are also important and must be such that the device is portable and can be brought to different locations. We have concluded that our volume will be no larger than 2.5 m^3 and the weight will be no more than 22 kg. Some of this volume is based on the smallest dimensions of a standard interior door, 1.98m by 0.81m. (DoorMore, n.d.) This is simple to test, as it only requires a measuring tape or a door. The weight is small enough that it can be measured using a standard bathroom scale. The force necessary to start moving the machine should also be less than 220 N. (Canadian Centre for Occupational Health and Safety, n.d.) This force was determined from the Canadian Center for Occupation Health and Safety's recommendations for hand pushed carts. To measure the force required, we will use a spring scale.

The units on the right side of the table shows exactly how each target will be physically measured. Each need will be measured by the respective unit of their targets, i.e. audio will be measured using units compatible with audio volume from either an electronic device or a physical component which creates a sound, while the machine's power source will be measured using voltage. Some of the targets and their metrics address multiple functions not stated here; for example, the power target will also fulfill the electronic lights display and, as a result, will aid in displaying visual elements.

The mission-critical targets include the audible production of one song, the power supplying the entire machine, and the portability of the machine, including dimensions and weight, so that it may be used as a successful public relations project. To validate the design, the machine will be tested in multiple environments which will vary in terms of power options, acoustics, audience, and ease of access. This will generate an understanding of possible design improvements as well as ultimately deciding the level of success of the music machine. Resources needed to test the machine include locations differing in acoustics and ease of access, audiences of varying backgrounds, and the aforementioned testing mechanisms for portability and power.

Table 3

Critical Targets and Metrics

Category	Need	Target	Number
Audio	Move physical components to produce audio	Audible volume	40-110 dB (Virosteak, n.d.)
		Audible range	5 m2 (Stierwalt, 2017)
	Recognizable song	Number of songs	1 song
Power source	Supply power	Corded/battery	12 V
Portability	Size	Volume	2.5 m^3

		Weight	22 kg
		Max length/width	1.98m X 0.61m
	Ease to move	Force required to start motion	220 N (Canadian Centre for Occupational Health and Safety, n.d.)

1.5 Concept Generation

Concept 1.

Figure 1. Sketch of Concept 1.

Has 4 sections, one for each broad engineering category (Mechanical/Industrial, Civil/Environmental, Electrical/Computer, Biology/Chemistry)

- Have long marble run linking them all.
- Wheelbarrow-esque transport
- Layer underneath for batteries/unsightly mechanisms

Mechanical/Industrial

- Gear train to move sticks/mallets to hit elements
- Elements move in/out of way with servos/actuators
- Conveyor elements

Civil/Environmental

- Buildings raise/lower in time with the music
    - Could also correspond with the pitch
    - Waves

Electrical/Computer

- LED Cube lighting in time with and matching color to the pitch of the music.
- Sensor for clapping to set the tempo
- Speakers to play electronic audio
- Name of the college at the top using lights

Biology/Chemistry

- Protein spirals move marbles either up as a screw or act as a slide down.
- LED molecules
- DNA spiral
    - Lift marbles
    - Twirl for visual interest

Concept 2.

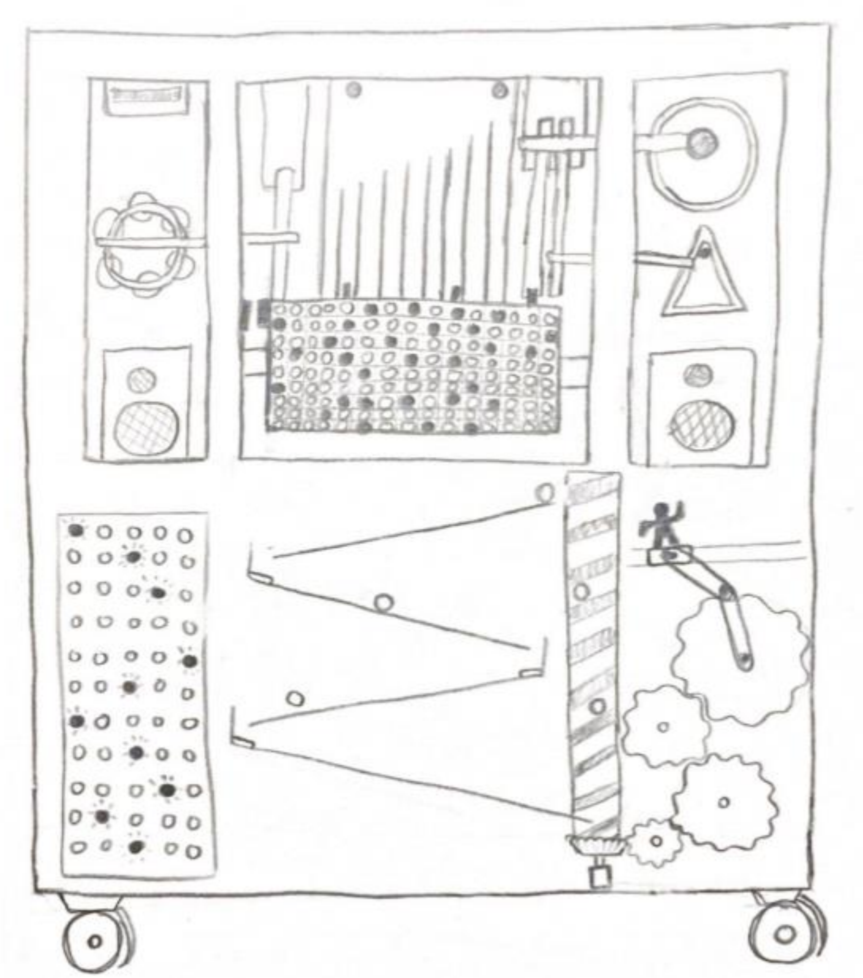


Figure 2. Sketch of Concept 2.

This concept is a play-off of the traditional orchestrion. To start power the machine we will use a 12V battery source, so the machine will have the ability to travel nearly anywhere without being tethered by a wall cord attachment. The music will be triggered by a large music roll which lies in the center of the machine. The music roll will be turned using a motor hidden in the inside of the device. The music roll will begin as a large roll with hole cutouts lined up in rows along the entire roll. In order to set the song bowels will be placed in these rolls to produce the song intended by the user. The dowels will be held in place using magnets or Velcro inside the holes in the music roll so that the dowels will stay in place after continuously running into barriers, and flipping upside down throughout the rotation. The main instrument used in this design will be an instrument that we would construct that would mimic lamellophones or the metal tines in a smaller scaled music box. Each time the music roll turns, one of the dowels will hit each of the tines to produce a sound. This instrument will sit in the center of the device, and it will be responsible for playing the melody of the song. There will also be other instruments in the upper portion of the machine that will help to accompany the melody. These instruments include a drum, a triangle, and a tambourine. In each case, a rod will be connected to the top of the machine in a way that allows it to swing forwards and backward when hit by a dowel coming from the music roll. When a particular rod is stuck its backward motion will trigger it to hit another mallet or stick that will cause it to strike a particular instrument (i.e. the drum, triangle, or tambourine).

This machine will also make sounds using non-traditional instruments. For example, in the center of the machine towards the bottom, there will be a few ramps with marbles rolling down them. The marble will start down the top ramp then make its way down, but after the first slope, it will have to drop down to a second slope where it will land on a metal plate. When the marble comes into contact with this metal plate it will make a noise that can add to the song. Once the marble makes it down all four slopes it will enter a spiraled elevator powered by a motor. As the motor spins it will bring all of the marbles back to the top where it will start the pattern over again. We should be able to adjust the tempo of the falling marbles by adjusting the motor’s speed. This device will also use electronic sounds in the song. On the music roll we will place a reed switch, which is a switch that is triggered by a magnet, at the portion of the roll where the song will be. There will also be a magnet placed on the side of the wall in the machine that will start off close enough to close the switch in its starting position. Once the song starts and the music roll begins to turn, the switch will turn on which will trigger the electronic accompaniment of the song to start as well. The electronic accompaniment will be played through speakers located in the device.

There will also be portions of the machine that will help to aid in maintaining public interaction. There will be a motion sensor attached to the top left corner of the machine, and this can be used to turn the machine on. This motion sensor could also help to draw an audience to the machine, for an example if the machine hasn’t been in use for a while then it can use to the motion sensor to sense when a person is around, then call them over by saying something like “Play me”. Non-musical visual elements were also added to help to intrigue an audience. For an example, in the bottom right of the machine, there are a set of gears going up the side of the machine for a visual effect. These gears are connected to the same motor the is turning the marble elevator by using a bevel gear. The gears then lead up to a crank-slider mechanism that controls a small figure that will slide side to side. On the bottom left side of the machine, there will also be a panel of LED lights that change based on the notes that are played by the electronic accompaniment, in order to help intrigue the audience. Lastly, this machine will be built on wheels. This will help when it comes to transporting this device.

Concept 3.

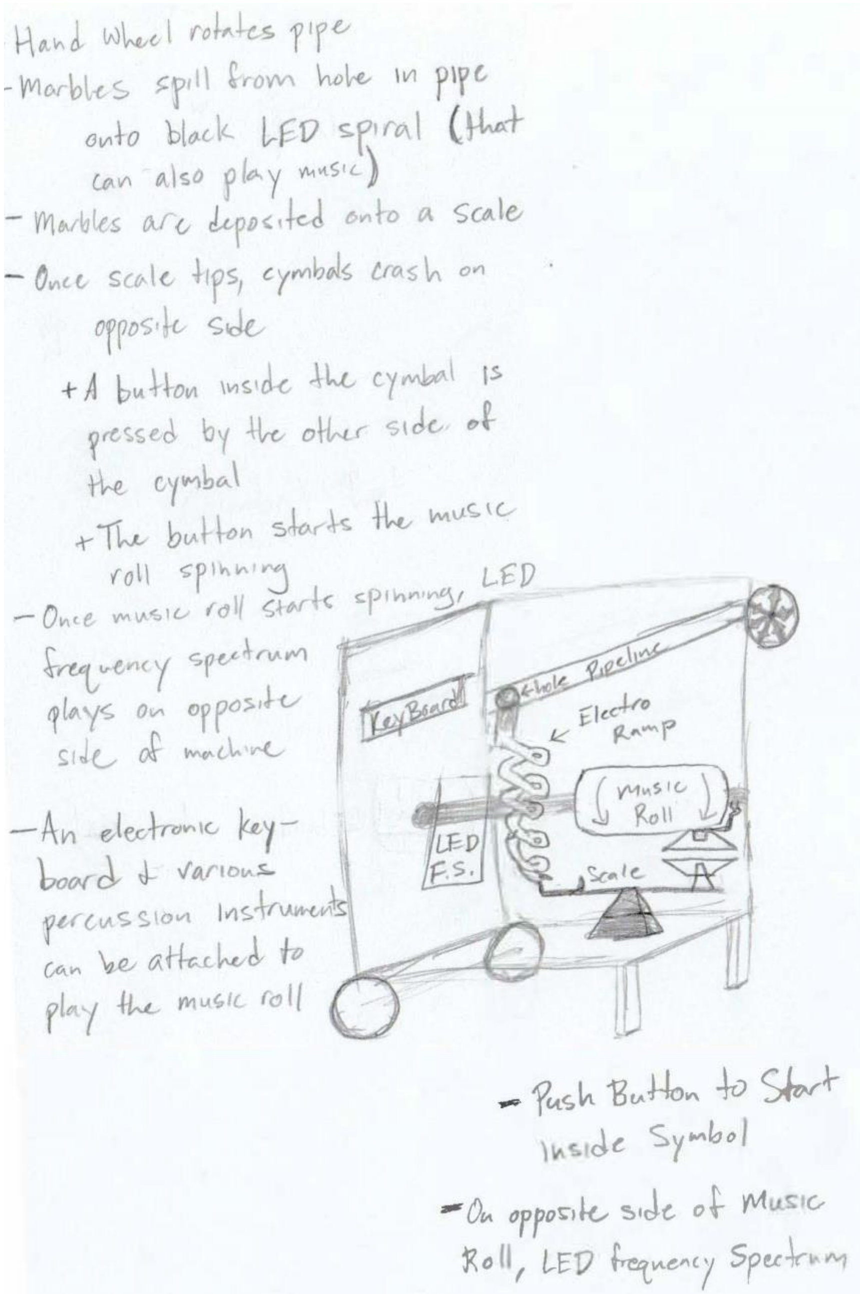


Figure 3. Sketch and description of Concept 3.

Concept 4.

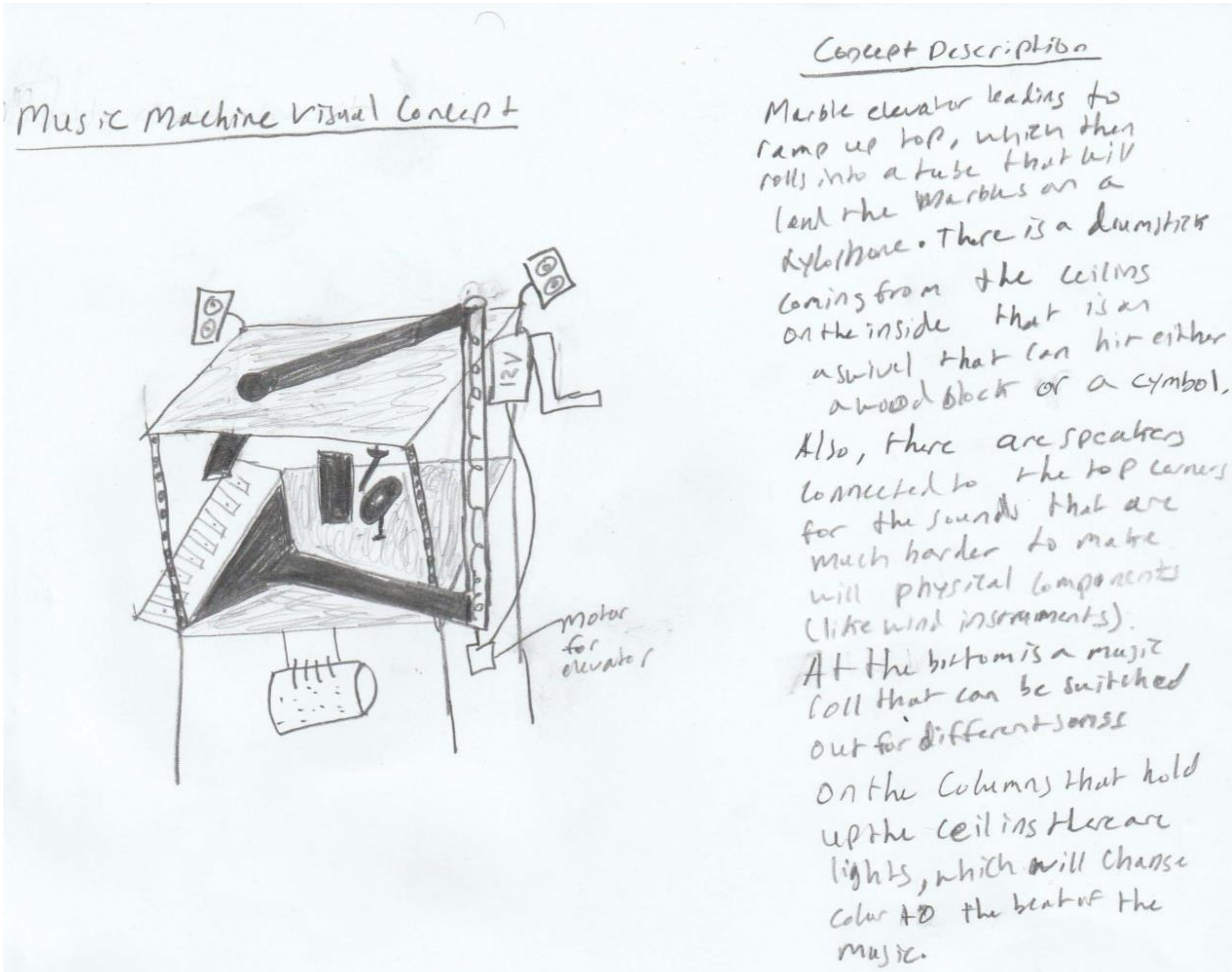


Figure 4. Sketch and description of Concept 4.

Concept 5.

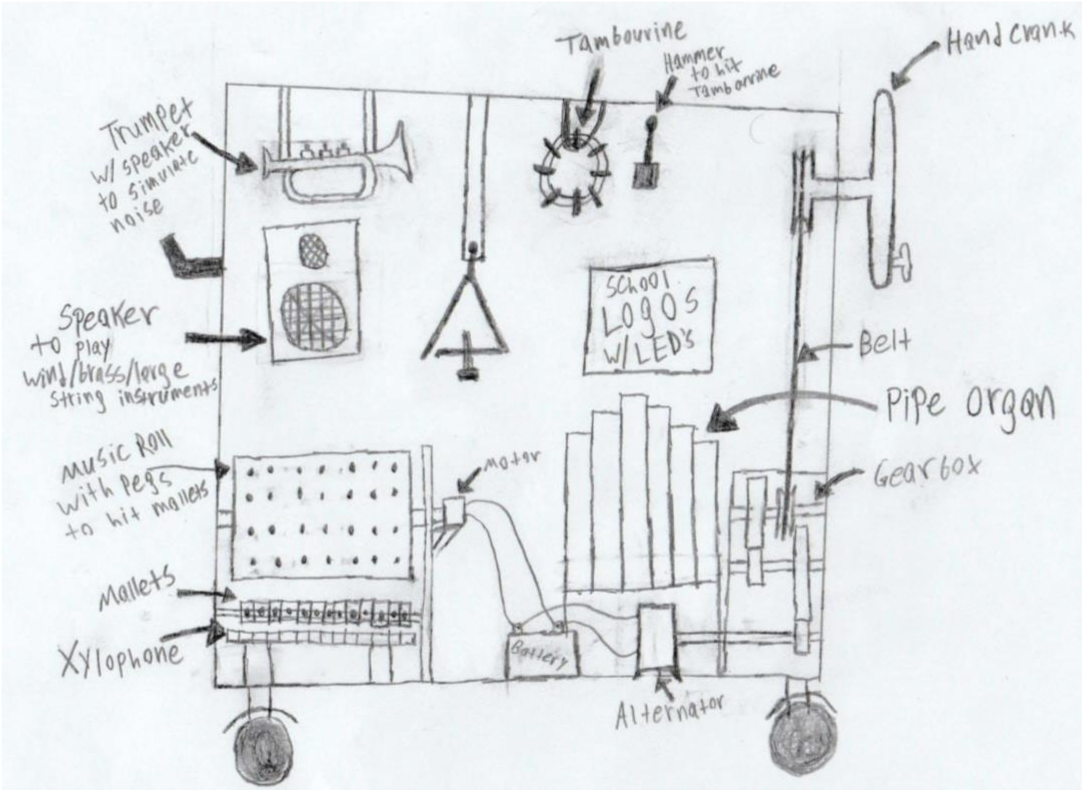


Figure 5. Sketch of Concept 5.

As shown above, Concept 5 is an easily transportable music device. The machine has four pneumatic casters. Two of the casters are rigid while the remaining two casters are swivel casters to allow the device to be turned. The pneumatic tires will ensure optimum transportability because of the wide range of surfaces these tires can handle. At the top right of the device is a hand crank that is connected to a gearbox in the lower right by a belt and pulley system. The complex gear train assembly is used to increases the gear ratio to allow the output shaft to rotate at a sufficient rpm to power the alternator. The alternator is attached to the battery that supplies power to the music machine's electrical components. The music box has both mechanical and electrical components which will be discussed in further detail. As shown in the bottom left corner of the device there is a programmable music wheel with pegs protruding from the wheel. As the wheel rotates the pegs will make contact with the pivot block they will lift the mallet and as they slip off the pivot block the mallet will drop making contact with the xylophone. There will also be a pipe organ inside the music machine that will be played using an air compressor not shown in the above drawing. In the top left corner of the device, there will be a trumpet that will appear to be being played but will have a small speaker inside of it to simulate the noises the trumpet would make. Below the trumpet, there will be a speaker that will be used to produce the noises that are more difficult to produce with instruments such as wood, brass, and other large instruments. To the right of the trumpet and speaker is a triangle that will be played using a motor to swing an arm to hit the triangle. To the right of the triangle, there will be a tambourine that will be played by using a motor to swing a hammer to hit the tambourine. There will also be an area where the FAMU-FSU College of Engineering, FSU, and FAMU logos will be displayed with LED lights that will be in sync with the music being played.

Concept 6.

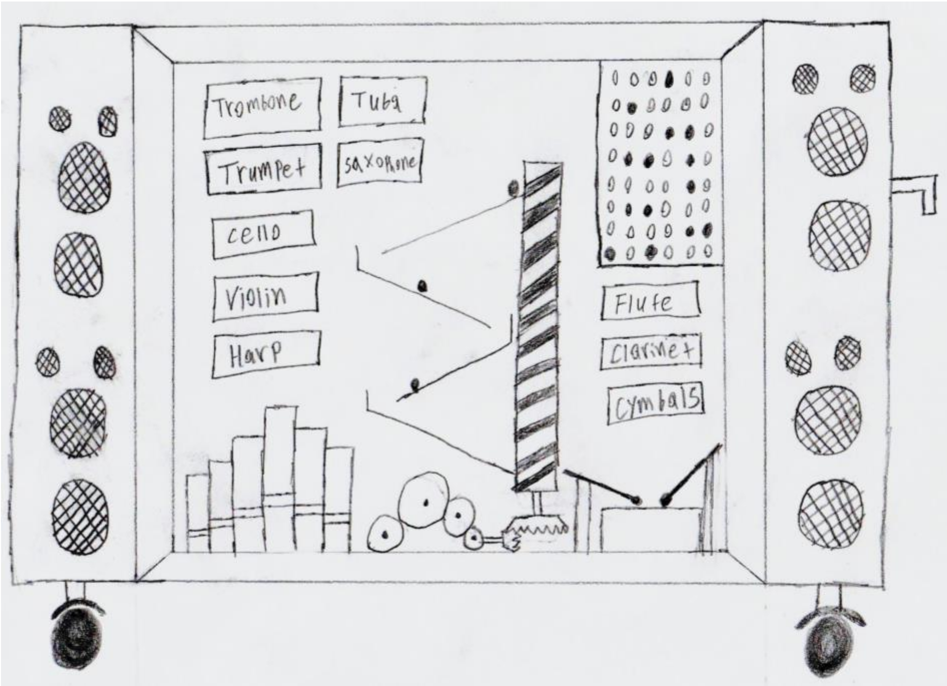


Figure 6. Sketch of Concept 6.

As shown above, Concept 6 is an easily transportable music device. The machine has four pneumatic casters. Two of the casters are rigid while the remaining two casters are swivel casters to allow the device to be turned. The pneumatic tires will ensure optimum transportability because of the wide range of surfaces these tires can handle. This device features a soundproof enclosure which dampens all the noise produced inside the box. The basic concept behind this device is that the device could feature very complex instruments that would be difficult to produce the correct notes autonomously. The device would give the appearance of playing these instruments but the sounds being produced would not escape the box. Instead, there would be hidden speakers on each side of the device that would play the sounds electronically. This device could feature many different instruments such as a trombone, trumpet, tuba, saxophone, cello, violin, harp, flute, clarinet, cymbals, pipe organ, drum, etc.. In the middle of the device there is a series of ramps that a marble will fall down then feed back into the marble elevator that will carry the marble back to the top to repeat the process. The marble elevator is driven by a bevel gear that is driven by the gear set connected to a motor. On the top right side of the machine, there will also be a panel of LED lights that change based on the notes that are played by the electronic accompaniment, in order to help intrigue the audience.

Concept 7.

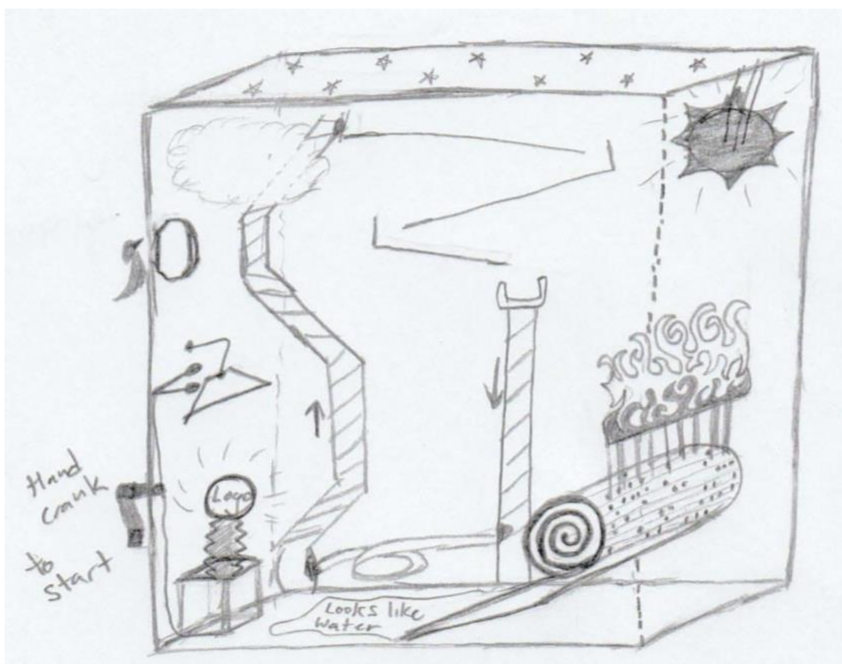


Figure 7. Sketch of Concept 7.

This whimsical machine incorporates eye-catching colors, the elements of earth and nature, and amusing toys to capture and hold the audience’s attention. A hand crank prepares the machine, winding up a Jack-in-the-box toy while simultaneously causing a drumroll on cymbals with drumsticks directly above it. Once the Jack-in-the-box pops up, the drumroll stops, and a music roll begins to spin, hitting tines on a flame-decorated board. Also triggered is a marble path; marbles will go through a cycle which can be stopped and started again at any time through programming. The marbles will progress from the cloud, onto a ramp which will feature short drops onto other ramps, eventually falling into a tower of LEDs. When the marbles roll down the LED tower, lights will glow in various colors, breaking the consistency of the other machines and the music and recapturing the audience’s attention. The marbles are then deposited into a ramp which will take them to a crooked, colorful marble elevator which leads up to the cloud once again, where the marbles will wait until the next programmed release.

There is a constant light source inside of this music machine, disguised as the sun in the top corner. Finally, there is a woodpecker on the outside of the music box which can be programmed to peck the glockbox during a musical performance or while the machine is on, but not playing a song. Finally, there are several opportunities for the FAMU-FSU College of Engineering logo to be placed around the machine, as well as places for decorations and fun shapes and objects to be placed.

Concept 8.

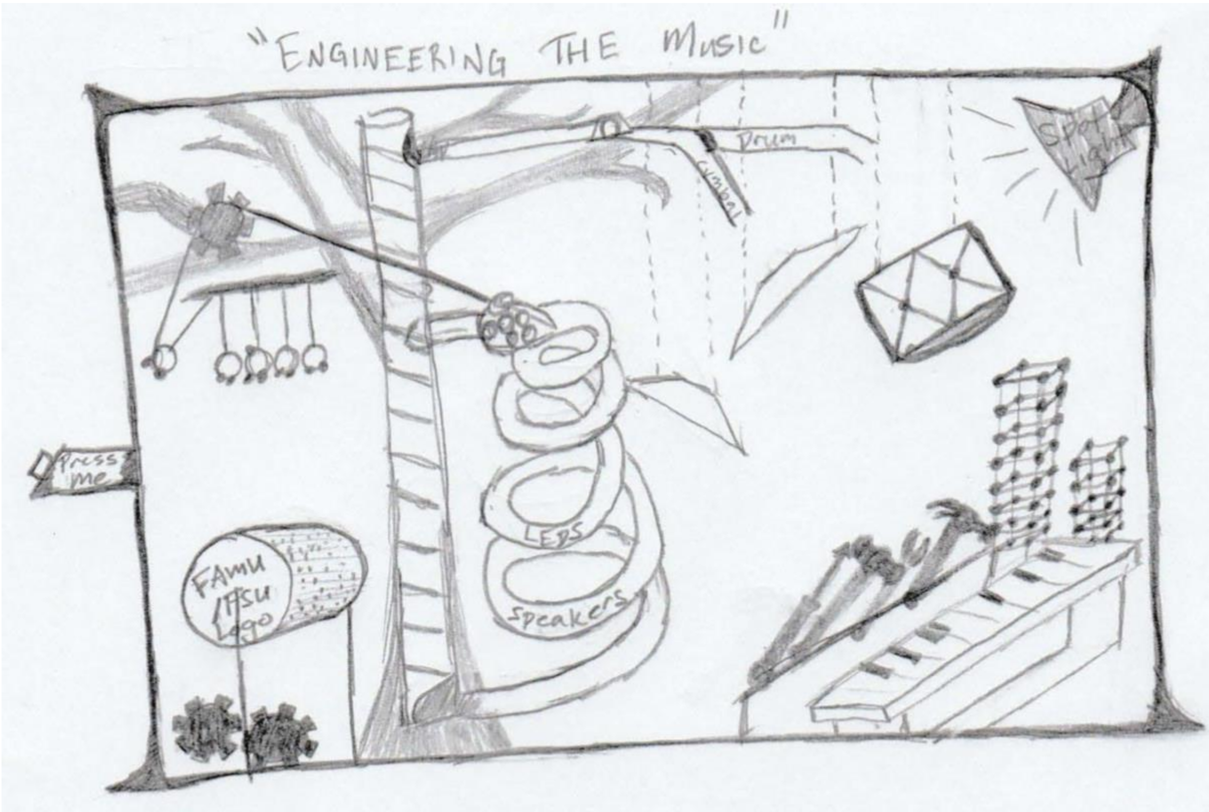


Figure 8. Sketch of Concept 8.

Entitled “Engineering the Music”, this design features various departments of the FAMU-FSU College of Engineering in many of the musical elements, both electronic and mechanical components. The audience is encouraged to interact with the machine by pressing the button that says “Press Me”, which will start a sequence of machines and electronic signals that play the music. A microprocessor will use a pulley to pull the first ball of Newton’s Cradle, while simultaneously pulling open a small lever that kept marbles from rolling down a curved marble ramp. The ramp will have LEDs and programmed sound effects that will be triggered when the marbles pass over the sensors. Once at the bottom, the marbles are loaded into a marble elevator which will pass the marbles back onto the marble slide, (the lever will be closed by now to keep the marbles from continuously rolling down the marble slide).

Additionally, the marbles will be carried up to the top of the elevator where the remainder will be deposited onto another slide. This one leads out to two paths, one where the marbles will fall onto cymbals and another where the marbles will fall onto a drum. The lever controlling whether or not the marbles will be let onto a path, and which path they will travel, can be pre-programmed to match the song on the music roll. In the bottom right corner, various mallets shaped like tools will be programmed by a microprocessor or the music roll to strike the appropriate key on the keyboard or xylophone when appropriate. Just behind this contraption is a building-like structure made of LEDs which can also be programmed to light up in patterns, to match the music, or to create designs that look like falling shapes or patterns. There is a light in the top corner of the machine which provides an internal spotlight to draw audiences and emphasize the movement and design of the machine.

Various components were designed to feature or exhibit the main characteristics of the various departments of engineering. Environmental engineering can be seen in the marble elevator, designed to look like a tree. Mechanical engineering is featured in the mallets shaped as various tools as well as the gears that will be needed throughout the design. Civil and industrial departments are recognized in the LED cubes which represent buildings or systems. Chemical and biomedical engineering is depicted in the carefully crafted Newton's Cradle, which features various molecules as the hanging marbles. "Engineering the Music" is designed to draw attention to the FAMU-FSU College of Engineering and all of its departments in a way that people from all backgrounds can relate to and appreciate.

Concept 9.

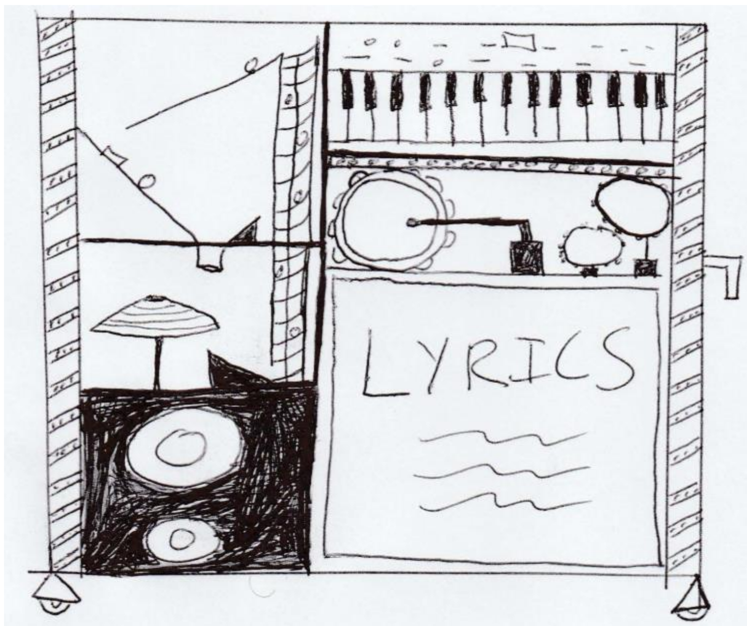


Figure 9. Sketch of Concept 9.

Marble elevator leads marbles onto a sensor pad which allows the speaker to play a certain tune. After sensor pad the marble is dropped onto an electronic drum pad that can be programmed to play anything when hit. The marbles are then brought back to the top by the marble elevator. The speaker below is used to play the sounds made by the marble hitting the sensor and electric drum pad as well as any other tunes of which is decided it should play.

The upper left consists of an electric keyboard with strip of lights going across the bottom. The keyboard can also be configured to play any song that is prerecorded on it. Underneath the piano are more drum pads that are hit by a drum stick that is on a motor that rotates quickly and with enough force to hit the drum pads and create a sound. The drum pads on the right are on a motor that makes them go either up or down so the drum stick can hit the correct one for whatever song is being played. Underneath the drum pads is a screen with the lyrics of whatever song is playing so that the crowd may sing along to the song that is being played by the machine. On each corner of the machine are strips of lights going up the columns that shine to the beat of the music for a better visual effect.

This machine combines physical components with electrical components as well as interactivity with whomever may be using it. Because these components are played electronically, they can be programmed to play many different songs. Since this involves electric drum pads, that means there is still a physical aspect to the machine because the drum pads must be hit in order to work. Also, there is a lever on the side of the machine which can be used to charge the battery. There will be a plug as well in order to connect the battery directly to an outlet.

1.6 Concept Selection

Following the concept generation phase there was a total of nine developed concepts. These nine concepts needed to be cut down to a single concept. In order to do this without introducing bias from each of the group members, and to ensure that the customer needs and engineering characteristics were taken into consideration, several concept generation tools were used. Through the concept selection process, a house of quality, Pugh charts, and an analytical hierarchy process (AHP) were employed to narrow down the concepts. Each of these analyses will be broken down further in the following sections.

House of Quality

For the House of Quality, we utilized the previously established engineering characteristics from our Targets and Metrics section. To create the weights for the customer needs, we used a pairwise comparison chart. This can be seen in Table 13. Once the weights were established, we compared the customer needs to the engineering characteristics and indicated the strength of the correlation, as shown in the table below.

Table 4

House of Quality

Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		Direction of Improvement:			▲	▲		▼	x	▼				▲	x					▼	x	▼	▼	▼			
Relative Weight	Weight / Importance	Demanded Quality	Audible volume (dB)	Audible range (m^2)	Number of songs	Attenuation percentage (Unwanted Sounds)	Sense sound (For attentuation)	Max power (Voltage from wall)	Corded/battery (Max Voltage)	Minimum Voltage	Mass of objects of Visual Interest	Size of objects of Visual Interest	Number of lights	Customizability of lights	Power required for lights	Number of moving elements	Number of electrical systems	Number of electronic instruments	Volume (m^3)	Weight	Max length/width	Force required to start motion of device	Force required to maintain motion of device	Power through components (Watts)	Number of motion sensors (Max, min)	Number of audio sensors (max, min)	Cost
3%	2	Keep cost low	▲	▲	Θ				O	▲	O	O	Θ	Θ		O	O	Θ	▲	▲					▲	▲	Θ
16.7%	11	Play a song	Θ	Θ	Θ			▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	O	Θ	▲	▲	▲	▲	▲	▲	O	Θ
6.1%	4	Attention grabbing	Θ	Θ	Θ	▲	▲	▲	▲	▲	▲	O	O	▲		Θ	O	▲	▲								Θ
1.5%	1	Interesting audio	▲	▲	O	▲	▲									▲	▲	Θ						▲	▲		Θ
12.1%	8	Mechanical components	▲	▲	Θ	▲		Θ	Θ	O	Θ	Θ				O			Θ	Θ	Θ	Θ	Θ				Θ
10.6%	7	Electrical Components	O	O		Θ	Θ	Θ	Θ	Θ	▲	▲	Θ				Θ	Θ		▲	▲	▲	▲		Θ	Θ	Θ
6.1%	4	Portable									Θ								Θ	Θ	Θ	Θ	Θ				Θ
4.5%	3	Durable									▲	▲				Θ	Θ	O				▲	▲				Θ
3%	2	Portable Power						Θ	Θ	O					Θ		Θ	O						Θ	▲	▲	Θ
9.1%	6	Easy to Use			▲						▲	▲				▲						Θ	Θ				Θ
13.6%	9	Presentable	O	O	O							▲															Θ
13.6%	9	Professional	O	O	O							▲															Θ
		Difficulty																									
		Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
		Weight / Importance	334.8	334.8	436.4	115.2	103	254.5	263.6	166.7	219.7	204.5	157.6	50	43.9	168.2	209.1	215.2	322.7	193.9	190.9	277.3	277.3	45.5	119.7	151.5	900
		Relative Weight	5.8%	5.8%	7.6%	2%	1.8%	4.4%	4.6%	2.9%	3.8%	3.6%	2.7%	0.9%	0.8%	2.9%	3.6%	3.7%	5.6%	3.4%	3.3%	4.8%	4.8%	0.8%	2.1%	2.6%	15.6%

Quality function deployment functions, such as the House of Quality, are used to manage design trade-offs. This chart uses four levels of relationships: neutral, strong, moderate, and weak. Blank spaces signify a neutral relationship, theta (Θ) is used for a strong relationship, O for moderate, and triangle (▲) for weak. Each type of relationship gives value to the weight at the left of each row and at the bottom of each column. The columns are comprised of design targets that we wish to meet while the rows are qualities used to compare the importance of each target. From this comparison, it became evident that cost was the most important factor going forward. This is not unexpected since every aspect of the design relates to cost in one way or another. The second most important characteristic is the number of songs. This is also not unexpected since a fundamental requirement of the device is to play at least one song. Tied for third were the audible volume and the audible range since these criteria are fairly similar. Due to this similarity, when we moved forward into the Pugh matrices, we decided to only add the audible volume because the volume would, in the end, determine the range at which the machine could be heard. This was done for other targets that were similar and had a similar ranking like max power and corded battery. Their relative weights were similar and they both have to do with powering the machine, so we decided to add only the max power target. The targets with the highest relative weights were then added to the Pugh chart, sans the duplicates mentioned above.

Pugh Charts

The purpose of a Pugh chart is to determine which concept of the final design will be rated the most successful in achieving the key purposes of the project. This is done by comparing each design to a datum. Initially, a similar device which is already out on the market is chosen. For our purpose, we used a calliope for the first comparison, since it was a musical device used to draw crowds and create a spectacle, as shown in table 5. After the first iteration we wanted to eliminate 1/3 of our concepts. So concepts 3, 5, and 7 were eliminated since they had the fewest positives and, in the case of concepts 5 and 7, more negatives than the other designs. We then proceeded with concept 6 as the datum since it had the same number of positives, but it had one more negative than the remaining concepts.

Table 5

Pugh Chart iteration one

		Concepts								
Selection Criteria	Calliope	1	2	3	4	5	6	7	8	9
Number of songs	Datum	S	S	S	S	S	+	S	S	S
Audible Volume		-	-	+	+	-	-	-	+	+
Volume		+	+	+	+	+	+	+	+	+
Max Power		+	+	+	+	+	+	+	+	+
Number of Electronic Instruments		+	+	+	+	+	+	+	+	+
Weight		+	+	+	-	+	+	+	+	+
Number of Moving Elements		+	+	-	+	-	+	+	-	+
Customizability of Lights		+	+	+	+	-	-	-	+	+
Cost		+	+	+	+	+	+	+	+	-
# of Plus		7	7	6	7	5	7	6	7	7
# of Minus		1	1	1	1	3	2	2	1	1

The second iteration of the Pugh chart can be seen below in table 6. After this we wanted to eliminate 2 more of the remaining concepts. Concept 4 was a particularly obvious choice, as it had more negatives than positives, and fewer positives than any design except for concept 3. Concept 3 was eliminated because tied with concept 4 for the least positives, even though it tied with all other concepts for the number of negatives. Concept 8 was then selected as the datum, this was because it had the most positives at the end of this iteration, and we wanted to make sure that we were comparing the strongest perceived design to all other designs to potentially showcase any of its weaknesses, or any strengths coming from the remaining designs.

Table 6

Pugh Chart iteration two

		Concepts				
Selection Criteria	6	1	2	4	8	9
Number of songs	Datum	-	-	-	-	S
Audible Volume		-	-	-	-	-
Volume		+	S	+	+	+
Max Power		+	+	+	+	S
Number of Electronic Instruments		+	S	-	+	+
Weight		+	+	+	+	+
Number of Moving Elements		+	+	S	+	-
Customizability of Lights		S	S	-	+	+
# of Plus		5	3	3	6	4
# of Minus		2	2	4	2	2

As you can see from Table 7 below, concept 9 was somewhat tied with concept 8, with 4 areas where it was better, but 4 areas where it was worse. The other two concepts were worse than concept 8 by a large margin, especially concept 1, which only had 1 area where it surpassed concept 8. At the same time concept 6 performed worse than concept 8 in five areas, which was the most out of any of the remaining concepts. Because of this after the final iteration of the Pugh chart it was decided that concepts 8 and 9 were the best two concepts when compared to the original nine. The three best concepts from this Pugh chart were taken on to the Analytical Hierarchy Process, described in the following section.

Table 7

Pugh Chart iteration three

		Concepts		
Selection Criteria	8	1	6	9
Number of songs	Datum	-	+	+
Audible Volume		S	+	+
Volume		-	-	+
Max Power		-	-	-
Number of Electronic Instruments		+	-	+
Weight		-	-	-
Number of Moving Elements		S	-	-
Customizability of Lights		S	S	-
# of Plus		1	2	4
# of Minus		4	5	4

Analytical Hierarchy Process (AHP)

An important part of the Analytic Hierarchy Process is ensuring that ratings are objective and unbiased. This method allows any bias that may occur unintentionally or on purpose to be observed through calculations, allowing the members of the project to decide if the ratings are accurate or leaning in favor of one specific idea through favoritism. The first comparison required is comparing the key engineering characteristics to each other to determine their final weights.

Table 8

Normalized criteria comparison matrix

Normalized Criteria Comparison Matrix [NormC]						
	Cost	Number of songs	Number of Electronic Instruments	Weight	Number of Moving Elements	Criteria Weights {W}
Cost	0.349	0.484	0.288	0.176	0.474	0.354
Number of songs	0.070	0.097	0.096	0.176	0.158	0.119
Number of Electronic Instruments	0.349	0.290	0.288	0.412	0.158	0.299
Weight	0.116	0.032	0.041	0.059	0.053	0.060
Number of Moving Elements	0.116	0.097	0.288	0.176	0.158	0.167
Sum	1.000	1.000	1.000	1.000	1.000	1.000

Through comparing these, it was determined that cost was the most important, and therefore most heavily weighted, criteria to consider. The number of electronic instruments was calculated as the next most important criteria, followed by the number of moving elements, the number of songs, and the weight, as can be seen in Table 10 under the column marked Criteria Weights. The consistency ratio for this matrix was 0.076, the math for which can be seen in the appendix, so this ranking is indeed mathematically fair. It is interesting to note that these rankings do not necessarily correspond with those established by the House of Quality above.

Once the criteria were weighted, it was then necessary to evaluate each of the concepts which made it through the Pugh matrices in accordance with the weighted criteria. This process can be exemplified by the table below, for the “cost” characteristic.

Table 9

Normalized cost comparison matrix

Normalized Criteria Comparison Matrix [NormC]				
	Concept 6	Concept 8	Concept 9	Concept Weights {W}
Concept 6	0.111	0.130	0.077	0.106
Concept 8	0.556	0.652	0.692	0.633
Concept 9	0.333	0.217	0.231	0.260
Sum	1.000	1.000	1.000	1.000

The table above depicts the normalized criteria comparison of the final three concepts with regards to the "cost" criteria. As can be seen, each concept is rated against the other concepts as well as itself. When rated against itself, each concept is actually given a value of 1.00, but once this value is normalized, the value changes to an equivalent number that represents part of the sum of one. Beyond 1, each concept can be given a ranking of 3, 5, 7, or 9 to indicate how much more important it is than the concept to which it is being compared. For this table, there was a consistency ratio of 0.037 (supporting calculations in the appendix), so the rating was considered to be fair and the process moved forward for each of the other criteria. These calculations can be seen in the appendix, but since they are largely repetitive it was deemed unnecessary to display them all here.

Once all 3 final concepts were evaluated according to all 5 critical criteria, it was possible to determine which of the top three concepts was decidedly best while ensuring minimal bias. By using the criteria weights to aid in comparing which of the final three concepts was the overall best design, and then averaging these results for each concept, the small table listed first under

Table 10, was generated. Based on this information Concept 8 is considered the best, followed by Concept 9, then Concept 6.

Table 10

Final Analytical Hierarchy Process Chart

Concept 6	0.179
Concept 8	0.476
Concept 9	0.345

Final Rating Matrix				Criteria Weights {W}
	Concept 6	Concept 8	Concept 9	
Cost	0.106	0.633	0.260	0.354
Number of	0.467	0.067	0.467	0.119
Number of	0.140	0.286	0.574	0.299
Weight	0.143	0.714	0.143	0.060
Number of	0.211	0.686	0.102	0.167

As shown in Table 10, the top block depicts the various final calculations led to a weighted total which determined that Concept 8 was the "best" design in terms of achieving the best in the most important criteria. Concept 9 was a close second in being successful in achieving the criteria, and Concept 6 was last. The second table shows the normalized rankings for each of the concepts listed and the criteria the rankings pertain to. Basically, the sum of each row will be one in order to ensure each concept is ranked on one scale; this makes comparing them over different criteria much easier. The last column of the second table gives the final weights of each criteria.

Final Decision

Using the pairwise comparison, house of quality, Pugh charts, and the analytical hierarchy process (AHP) it was determined that Concept 8 was the best concept out of the eight other concepts generated. As shown in the Pugh Charts Concept 8 performed better than the Calliope and all other eight concepts. Through the use of the analytical hierarchy process it was clear that the best concept for this project was Concept 8. Concept 8 out performed Concept 6 and Concept 9 when compared to the criterion that was determined to have the most significance.

1.8 Spring Project Plan

Since we have such a large-scale project and wanted to ensure that the project was complete by the beginning of March, we decided to work on creating all of the CAD drawings over winter break. We will start by creating the CAD for the individual components the week after finals week of the fall semester. While we are working on the individual components, we will start creating the CAD subassemblies as the components needed for each of the subassemblies are completed. A subassembly will be needed for things like the marble machine or the music wheel. We will take a short break for the holidays. When we come back from the break, we will begin creating the full CAD assembly in the week before the beginning of the spring semester. While creating the CAD assembly we may find that some of the subassemblies do not fit together so we will take some time going back a fixing and finalizing the remaining

We will begin ordering the materials to build the structure of the machine at the beginning of the spring semester after the CAD assembly is created. Around this time, we will also start 3D printing any materials if needed. We allowed ample time for this to be completed to account for print time and possible print failures. We will add in all of the musical components last so that we can test to see how they work with all of the building and 3D printed materials.

During the testing phase of the project in March, if it is necessary to order additional materials for repairs this will also be done.

At this phase of the project design, there are no assembled full-scale subsystems to test. At this point the gathered materials will be assembled to create the individual components which make up these subsystems. These components will be tested to ensure the raw materials and electrical and mechanical equipment gathered will be adequate for its intended role in the machine. At this point, any material ordered that is deemed unfit for the intended purpose will be returned and a suitable replacement will be researched and ordered. Towards the end of this phase, the full-scale subsystems will be assembled.

After the CAD components are completed, the materials are gathered, and the prototypes of the small-scale systems are completed we will begin to assemble the full-scale prototype. The assembly of the full-scale prototype is broken down into eight individual steps. They consist of the assembly of the lighting components, assembly of the structural components, assembly of the moving components, assembly of audio subsystems, wire the components, wire electrical systems to the controller, wire mechanical systems to controller, and add final aesthetic touches.

Virtual Design Review 4 is the first presentation of the second semester for the senior design project; here, students have the opportunity to show their progress from last semester and demonstrate early prototypes. The project will have a detailed design overview, as students should be finalizing all components and beginning to assemble them into a final prototype. Testing these subsystems and troubleshooting any problems will occur during this time.

For a project as complex as ours, the testing phase is key. While testing will, of course, occur throughout the building process, we have also designated a testing period for each of the subsystems including lighting, portability, moving, audio, power, and more. It is also essential to our project that the elements perform in synchronization with the audio being played, which will require further testing than simply ensuring the functionality of the subsystems. This is a key reason for our inclusion of test periods for the system controls of both mechanical and electrical elements. Due to the importance of all these systems being thoroughly tested, we have allotted a total of nearly 2 weeks to test the prototype as a whole. Each subsystem has several days allocated to it so that the issues can be fully explored and resolved before moving on to the next subsystem.

This step is included to ensure that the team has time to resolve any last-minute problems or revise the machine for a more efficient or practical function. All decisions under question will be decided upon and the final design will be produced as a result. This product will be a feature in the following Virtual Design Review's.

During this time the team may be out of contact; it can be used to hash out any problems that may have occurred. The final design will be reviewed, and its quality assessed, any possible revisions to improve it may be carried out during this time. The team may also use this time for other preparation in order to ensure a smooth graduation.

Final Documentation

As the final design has been completed and solidified, the team will spend this time to complete and assemble all documentation. This includes all of the documentation from both semesters in which the project was carried out. All documents required for the final submission will be revised and compiled into the final evidence manual which will outline the entirety of the music machine's project. Additionally, a virtual representation of the machine's progress and the final design will be displayed on a website created by the team.

Virtual Design Review 5 will be our second to the last presentation for the music machine. Within it will include an overview of our project as well as our initial design from the fall semester. Also, we will be presenting our entire design process and a detailed operation process in order to explain how each component of the machine works and comes together as a whole to create a song. Virtual Design Review 6 will be our presentation for Engineering Day. By this time the machine will be fully tested for any issues and be completely operational. We will be available to explain our process just as we did in Virtual Design Review 5, but we will have our machine on display to allow others the opportunity to try it.

The end of the semester will consist of finals week and graduation. All documentation for the project will have been finalized and the website completed. By this point, our machine will have already been fully completed and demonstrated. It is at this time that our sponsors decide where it will be displayed in order for the College of Engineering to have it readily available for use as a public relations tool with other college campuses.

The milestones for spring semester include: Semester begins, Virtual Design Review 4, Slack Time (Spring Break), Virtual Design Review 5, Engineering Design Day, Finals Week, and Graduation. The activities that are necessary to see those milestones met are covered in Table 11 below. The Gantt chart in Figure 10 below gives a visual representation of the project's timeline.

Table 11

Displays the start date, end date, and duration of milestones and activities.

	Start Date	End Date	
Semester begins	1/7/19	1/7/19	Milestone
CAD components	12/17/18	1/8/19	Activity
Gather Materials	1/4/19	3/15/19	Activity
Prototype small scale subsystems	1/22/19	2/7/19	Activity
Assemble full prototype	2/7/19	3/3/19	Activity
Virtual Design Review 4	2/21/19	2/21/19	Milestone
Full prototype testing	3/3/19	3/16/19	Activity
Finalize Design	3/15/19	3/18/19	Activity
Slack Time (Spring Break)	3/18/2019	3/22/2019	Milestone
Final Documentation	2/21/2019	4/17/2019	Activity
Virtual Design Review 5	3/21/2019	3/21/2019	Milestone
Engineering Design Day	4/18/2019	4/18/2019	Milestone
Finals week	4/29/2019	5/3/19	Milestone
Graduation	5/4/2019	5/4/2019	Milestone

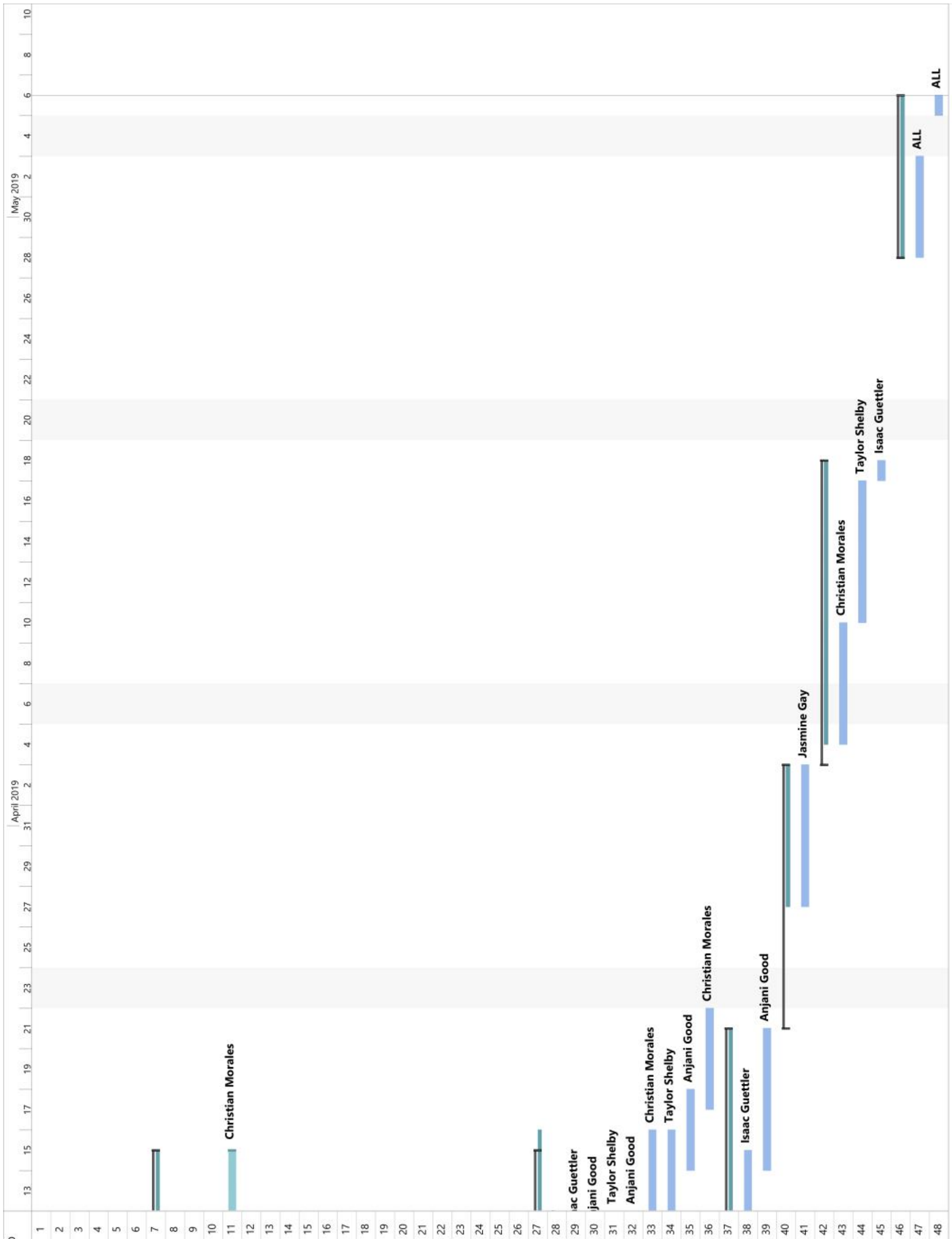
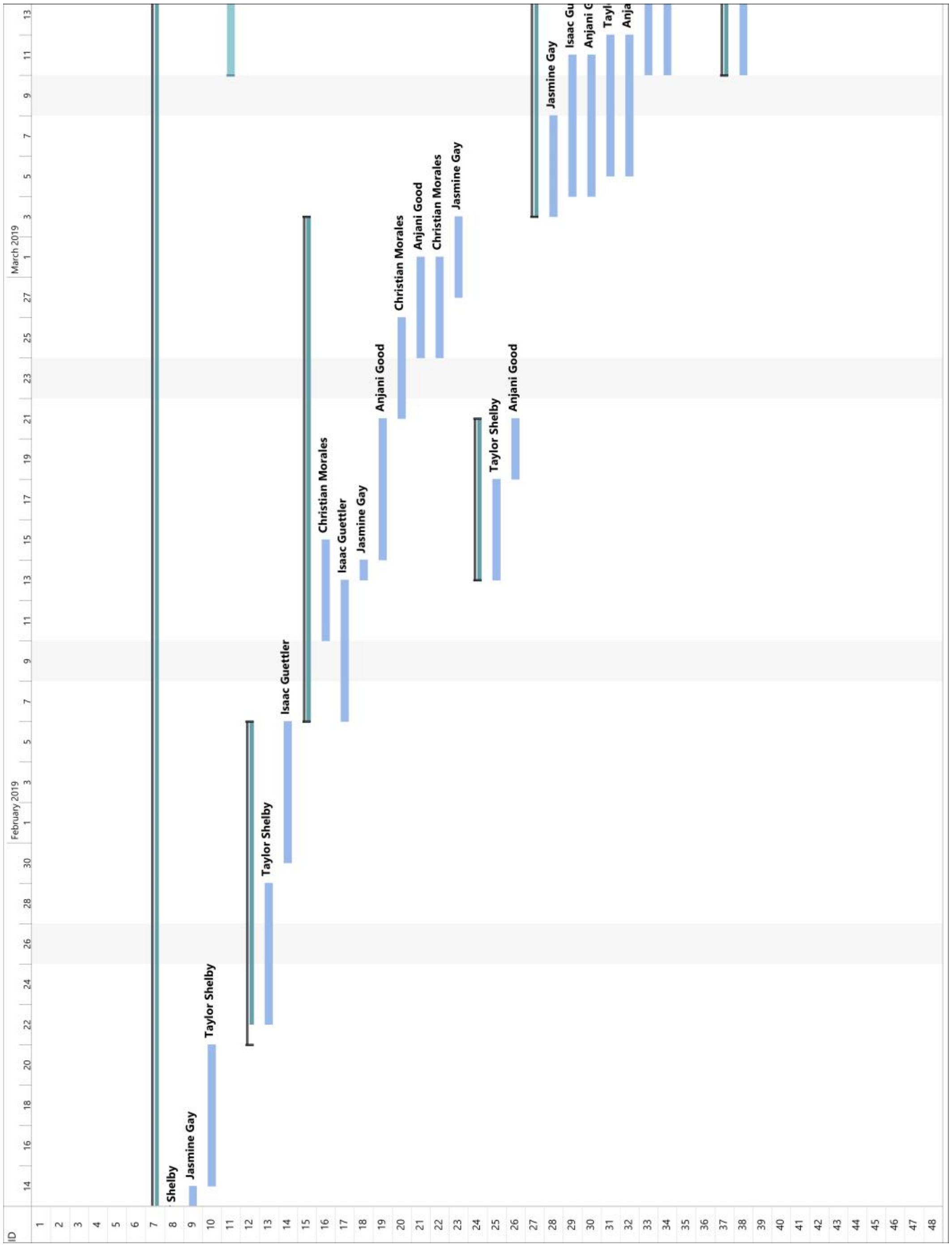
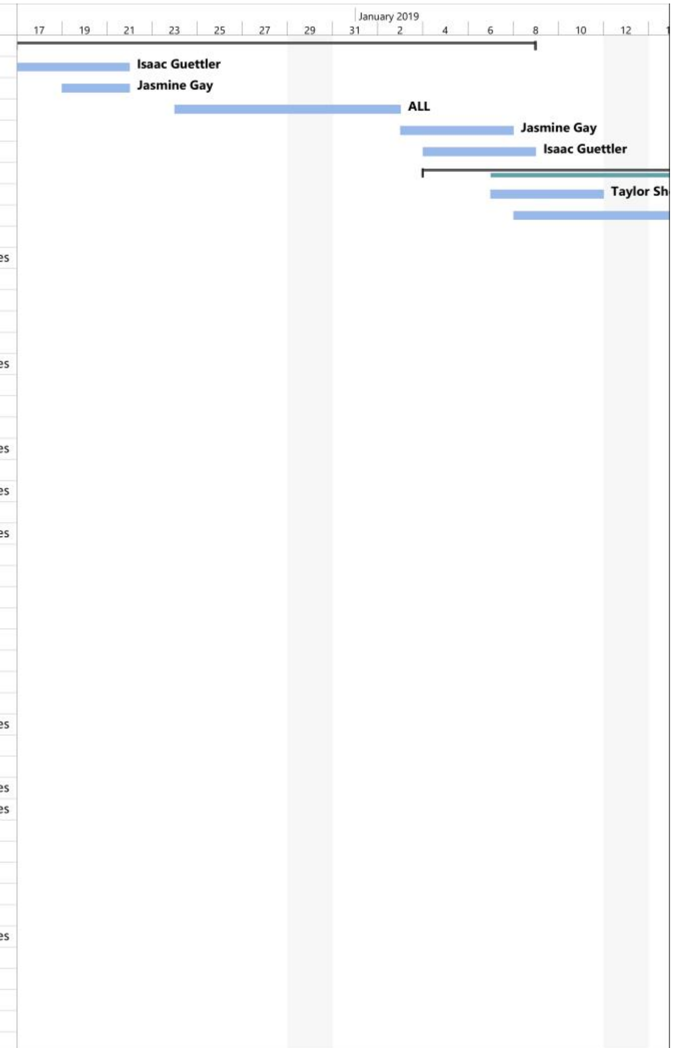


Figure 10 Gantt chart representation of the project timeline.


February 2019
March 2019
ID
Shelby
Jasmine Gay
Taylor Shelby
Taylor Shelby
Isaac Guettler
Christian Morales
Isaac Guettler
Jasmine Gay
Anjani Good
Christian Morales
Anjani Good
Christian Morales
Jasmine Gay
Taylor Shelby
Anjani Good
Jasmine Gay

ID	Task Name	Duration	Start	Finish	Resource Names
1	**1 CAD components**	**17 days**	**M 12/17/18**	**T 1/8/19**	Isaac Guettler
2	1.1 CAD individual components	5 days	M 12/17/18	F 12/21/18	Isaac Guettler
3	1.2 CAD subassemblies	3 days	W 12/19/18	F 12/21/18	Jasmine Gay
4	1.3 Holiday Break	8 days	M 12/24/18	W 1/2/19	ALL
5	1.4 Create CAD assembly	3 days	T 1/3/19	M 1/7/19	Jasmine Gay
6	1.5 Finalize CAD designs	3 days	F 1/4/19	T 1/8/19	Isaac Guettler
7	**2 Gather Materials**	**51 days**	**F 1/4/19**	**F 3/15/19**	Anjani Good
8	2.1 Order Building Materials	5 days	M 1/7/19	F 1/11/19	Taylor Shelby
9	2.2 3D print materials	5 days	T 1/8/19	M 1/14/19	Jasmine Gay
10	2.3 Order Musical Components	5 days	T 1/15/19	M 1/21/19	Taylor Shelby
11	2.4 Order additional materials	5 days	M 3/11/19	F 3/15/19	Christian Morales
12	**3 Prototype small scale subsystems**	**12 days**	**T 1/22/19**	**W 2/6/19**	Jasmine Gay
13	3.1 Test small-scale prototypes	5 days	W 1/23/19	T 1/29/19	Taylor Shelby
14	3.2 Build full-scale subsystems	5 days	T 1/31/19	W 2/6/19	Isaac Guettler
15	**4 Assemble full prototype**	**18 days**	**T 2/7/19**	**S 3/3/19**	Jasmine Gay
16	4.1 Assemble lighting components	5 days	M 2/11/19	F 2/15/19	Christian Morales
17	4.2 Assemble structural components	5 days	T 2/7/19	W 2/13/19	Isaac Guettler
18	4.3 Assemble moving components	1 day	T 2/14/19	T 2/14/19	Jasmine Gay
19	4.4 Assemble audio subsystems	5 days	F 2/15/19	T 2/21/19	Anjani Good
20	4.5 Wire power	3 days	F 2/22/19	T 2/26/19	Christian Morales
21	4.6 Wire electrical systems to controller	5 days	M 2/25/19	F 3/1/19	Anjani Good
22	4.7 Wire mechanical systems to controller	5 days	M 2/25/19	F 3/1/19	Christian Morales
23	4.8 Add final aesthetic touches	2 days	T 2/28/19	S 3/3/19	Jasmine Gay
24	**5 VDR 4**	**6 days**	**T 2/14/19**	**T 2/21/19**	Christian Morales
25	5.1 Detailed Design Overview	3 days	T 2/14/19	M 2/18/19	Taylor Shelby
26	5.2 Design Subcomponent Demonstrations	3 days	T 2/19/19	T 2/21/19	Anjani Good
27	**6 Full prototype testing**	**10 days**	**M 3/4/19**	**F 3/15/19**	Taylor Shelby
28	6.1 Test lighting components	5 days	M 3/4/19	F 3/8/19	Jasmine Gay
29	6.2 Test portability components	5 days	T 3/5/19	M 3/11/19	Isaac Guettler
30	6.3 Test moving components	5 days	T 3/5/19	M 3/11/19	Anjani Good
31	6.4 Test audio subsystems	5 days	W 3/6/19	T 3/12/19	Taylor Shelby
32	6.5 Test power	5 days	W 3/6/19	T 3/12/19	Anjani Good
33	6.6 Test electrical systems controls	5 days	M 3/11/19	S 3/16/19	Christian Morales
34	6.7 Test mechanical systems controls	5 days	M 3/11/19	S 3/16/19	Taylor Shelby
35	**7 Finalize Design**	2 days	F 3/15/19	M 3/18/19	Anjani Good
36	**8 Slack Time (Spring Break)**	5 days	M 3/18/19	F 3/22/19	Christian Morales
37	**9 Final Documentation**	**9 days**	**M 3/11/19**	**T 3/21/19**	Christian Morales
38	9.1 Website	5 days	M 3/11/19	F 3/15/19	Isaac Guettler
39	9.2 Revise evidence book	5 days	F 3/15/19	T 3/21/19	Anjani Good
40	**10 VDR 5**	**9 days**	**F 3/22/19**	**W 4/3/19**	Isaac Guettler
41	10.1 Final Design Demonstration	5 days	T 3/28/19	W 4/3/19	Jasmine Gay
42	**11 VDR 6 -Engineering Design Day**	**11 days**	**T 4/4/19**	**T 4/18/19**	Taylor Shelby
43	11.1 Presentation Preparation	4 days	F 4/5/19	W 4/10/19	Christian Morales
44	11.2 Completed Project Presentation	5 days	T 4/11/19	W 4/17/19	Taylor Shelby
45	11.3 Engineering design day	1 day	T 4/18/19	T 4/18/19	Isaac Guettler
46	**12 Semester wrap-up**	**6 days**	**M 4/29/19**	**M 5/6/19**	Anjani Good
47	12.1 Finals week	5 days	M 4/29/19	F 5/3/19	ALL
48	12.2 Graduation	1 day	M 5/6/19	M 5/6/19	ALL



Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Mission Statement

The Music Machine Team (Team No. 515) is committed to ensuring a positive work environment that supports professionalism, integrity, respect, and trust. Every member of this team will contribute a full effort to the creation and maintenance of such an environment in order to bring out the best in all of us as well as this project.

Team Roles:

Systems Engineer: Isaac Guettler

Manages the team as a whole; develops a plan and timeline for the project, delegates tasks among group member according to their skill sets; finalizes all documents and provides input on other positions where needed. The systems engineer is responsible for promoting synergy and increased teamwork. He keeps the communication flowing, both between team members and to the sponsors. The team leader takes the lead in organizing, planning, and setting up of meetings. In addition, he is responsible for keeping a record of all correspondence between the group. Finally, he gives or facilitates presentations by individual team members and is responsible for overall project plans and progress

Power Systems Engineer: Christian Morales

The power system engineer will oversee the generation, transmission, and distribution of electric power as well as the electrical devices connected to the power systems including generators and motors.

Mechanical Systems Engineer: Jasmine Gay

Takes charge of the mechanical design aspects of the project. Keeps line of communication with the Electrical Systems Coordinator. She is responsible for knowing details of the design and presenting the options for each aspect to the team for the decision process. Keeps all design documentation for record and is responsible for gathering all reports.

Electrical Systems Engineer: Anjani Good

She is responsible for the electrical engineering and/or computer engineering design part in support of the project. She maintains line of communication with the Mechanical Systems Coordinator. She keeps all electrical design documentation for record. She is also responsible for ensuring any electrical subsystems work together as intended.

Audio Engineer: Taylor Shelby

Research and determine required materials for music. If necessary, arrange music for device and provide sound mixing. Determine sizing of materials for creating desired pitches and sound quality.

All Team Members:

- Work on certain tasks of the project
- Buys into the project goals and success
- Delivers on commitments

- Adopt team spirit
- Listen and contribute constructively (feedback)
- Be effective in trying to get message across
- Be open minded to others' ideas
- Respect others' roles and ideas
- Be ambassador to the outside world in own tasks

If certain duties arise that are not covered under any of the above roles there will be a team meeting. In this meeting the new duties will be assigned at the discretion of the group as a whole based on availability and skill of the individual or individuals. If conflict arises and a decision cannot be reached the team will seek guidance from the team advisors.

Communication

The main form of communication will be over phone (GroupMe) and email among the group, with preference placed on phone communication. Additionally, regular meetings of the whole team will be held. For the passing of information, i.e. files and presentations, email will be the main form of file transfer and proliferation, with Google Drive as a unified storage location.

Each group member must have a working email for the purposes of communication and file transference. Members must check their emails and GroupMe at least twice a day to check for important information and updates from the group. Although members will be initially informed via phone, meeting dates and pertinent information from the sponsor will additionally be sent over email so it is very important that each group member checks their email frequently.

For communications which require a response, a response or deferment is expected within 24 hours.

If a member has a time conflict and the meeting must be canceled, an email must be sent to the group at least 24 hours in advance or a message on GroupMe an hour in advance.
Any team member that cannot attend a meeting must give advance notice of one hour informing the group of their absence. Reason for absence will be appreciated but not required if personal. Repeated (>4 per semester) absences in violation with this agreement will not be tolerated.

Team Dynamics

The students will work as a team while allowing one another to feel free to make any suggestions or constructive criticisms without fear of being ridiculed and/or embarrassed. If any member on this team finds a task to be too difficult it is expected that the member should ask for help from the other teammates. If any member of the team feels they are not being respected or taken seriously, that member must bring it to the attention of the team in order for the issue to be resolved. We shall NOT let emotions dictate our actions. Everything done is for the benefit of the project and together everyone achieves more.

Ethics

Team members are required to be familiar with the NSPE Engineering Code of ethics as they are responsible for their obligations to the public, the client, the employer, and the profession. There will be stringent following of the NSPE Engineering Code of Ethics.

Dress Code

For any meetings with the team, the advisor, the professor, or for phone meetings with the sponsor, casual attire is acceptable. Sponsor meetings and group presentations will be business casual to formal as decided by the team per the event. Business casual is defined as a button up shirt, dress or khaki pants, and a tie for men, and similar clothing for women. Business formal is defined as dress pants, a button up shirt, suit jacket, and a tie, and comparable clothing for women.

Attendance Policy

Attendance of all team members is mandatory and on time for meetings. If a member of the team is unable to attend a scheduled meeting, they must give reasonable notice through GroupMe. All members are expected to be present for the presentations. Attendance will be recorded in all meeting minutes to ensure that members reach no more than 4 unexcused absences per semester. Excused absences include those excused by the FAMU-FSU College of Engineering and meeting which were scheduled in full knowledge of a conflict in schedule. Even excused members are expected to read the meeting minutes to stay updated on project progress. If a team member has 4 unexcused absences the team will then consult with the team advisor for intervention.

Weekly and Biweekly Tasks

Team members will participate in all meetings with the sponsor, adviser and instructor. During said times ideas, project progress, budget, conflicts, timelines and due dates will be discussed. In addition, tasks will be delegated to team members during these meetings. Repeat (>4 per semester) unexcused absences will not be tolerated.

Decision Making

It is conducted by consensus and majority of the team members. Should ethical/moral reasons be cited for dissenting reason, then the ethics/morals shall be evaluated as a group and the majority will decide on the plan of action. Individuals with conflicts of interest should not participate in decision-making processes but do not need to announce said conflict. It is up to each individual to act ethically and for the interests of the group and the goals of the project. Achieving the goal of the project will be the top priority for each group member. Below are the steps to be followed for each decision-making process:

- Problem Definition – Define the problem and understand it. Discuss among the group.
- Tentative Solutions – Brainstorms possible solutions. Discuss among group most plausible.
- Data/History Gathering and Analyses – Gather necessary data required for implementing Tentative Solution. Re-evaluate Tentative Solution for plausibility and effectiveness.
- Design – Design the Tentative Solution product and construct it. Re-evaluate for plausibility and effectiveness.
- Test and Simulation/Observation – Test design for Tentative Solution and gather data. Re-evaluate for plausibility and effectiveness.
- Final Evaluation – Evaluate the testing phase and determine its level of success. Decide if design can be improved and if time/budget allows for it.

Conflict Resolution

In the event of discord amongst team members the following steps shall be respectfully employed:

- Communication of points of interest from both parties which may include demonstration of active listening by both parties through paraphrasing or other tool acknowledging clear understanding.
- Administration of a vote, if needed, favoring majority rule.
- Team Leader intervention.
- Instructor will facilitate the resolution of conflicts.

Statement of Understanding

By signing this document, the members of Team No. 515 agree to all of the above and will abide by the code of conduct set forth by the group. Code of conduct is subject to change with a 4/5ths majority vote.

Name:	**Signature:**	**Date:**
Jasmine Gay	Jasmine Gay	09/12/18
Anjani Good	Anjani Good	09/12/18
Isaac Guettler	Isaac Guettler	09/12/18

Christian Morales		09/12/18
Taylor Shelby		09/12/18

Appendix B: Work Breakdown Structure

Table 12

Fall 2018 Work Breakdown Structure

Task	Assigned Team Member
1. Project Initialization	Taylor Shelby
1.1. Create project scope	Anjani Good
1.1.1. Contact sponsor	Isaac Guettler
1.1.2. Meet with sponsor	Taylor Shelby
1.1.3. Use information from sponsor to write scope	Jasmine Gay
1.2. Create code of conduct	Christian Morales
1.2.1. Meet with team	Isaac Guettler
1.2.1.1. Exchange contact information	Anjani Good
1.2.1.2. Establish schedule	Taylor Shelby
1.2.1.3. Set up meeting times	Christian Morales
1.2.2. Establish attendance expectations	Jasmine Gay
1.2.3. Establish communication expectations	Taylor Shelby
1.2.4. Establish roles	Anjani Good
1.2.4.1. Determine expertise	Christian Morales
1.2.4.2. Assign duties	Isaac Guettler
1.2.5. Establish ethical standards	Jasmine Gay

1.2.6. Establish decision making process	Isaac Guettler
1.2.7. Establish conflict resolution procedures	Anjani Good
1.2.8. Establish cultural standards (dress code etc.)	Christian Morales
1.2.9. Create statement of understanding	Taylor Shelby
2. Project Definition	Jasmine Gay
2.1. Create work break down structure	Taylor Shelby
2.1.1. Discuss tasks with team	Isaac Guettler
2.1.1.1. Assign tasks to team members	Isaac Guettler
2.2. Identify customer needs	Christian Morales
2.2.1. Formulate questions for sponsor	Anjani Good
2.2.2. Meet with sponsor	Taylor Shelby
2.2.3. Meet with team	Jasmine Gay
2.2.4. Interpret sponsors responses	Christian Morales
2.3. Create functional decomposition	Taylor Shelby
2.3.1. Research similar projects	Christian Morales
2.3.2. Identify common design steps between researched projects	Jasmine Gay
2.3.3. Divide project into manageable steps	Anjani Good
2.3.4. Order steps and predict deadlines for these steps	Christian Morales
2.4. Identify project targets	Jasmine Gay
2.4.1. Create a list of all functions in the functional decomposition	Taylor Shelby
2.4.2. Create a target that need to be achieved for each function	Isaac Guettler

2.4.2.1. Make each target quantifiable	Jasmine Gay
2.4.2.2. Create a target matrix with target values	Anjani Good
3. Concepts	Isaac Guettler
3.1. Concept generation	Anjani Good
3.1.1. Brainstorm individually	Jasmine Gay
3.1.2. Brainstorming as a team	Taylor Shelby
3.1.3. Research similar projects	Christian Morales
3.1.4. Make a list of all 100 concepts	Isaac Guettler
3.2. Concept selection	Jasmine Gay
3.2.1. Finalize song choices	Anjani Good
3.2.2. Use a decision matrix to cut down number of concepts to 15	Christian Morales
3.2.3. Create Pugh Chart for the 15 concepts	Isaac Guettler
3.2.3.1. Determine level of interactivity	Christian Morales
3.2.3.2. Select a final design	Jasmine Gay
3.2.4. Meet with sponsor	Taylor Shelby
3.2.5. Meet with advisor	Isaac Guettler
4. Fall Closing	Anjani Good
4.1. Bill of materials	Jasmine Gay
4.1.1. Assemble list of necessary components	Taylor Shelby
4.1.2. Identify each component’s priority	Anjani Good
4.1.3. Order list by priority	Christian Morales

4.1.4. Create a planned budget with fail-safes	Christian Morales
4.2. Risk assessment	Isaac Guettler
4.2.1. Identify the hazards	Anjani Good
4.2.2. Decide what/who might be harmed and how	Isaac Guettler
4.2.3. Evaluate the risk and decide on control measures	Jasmine Gay
4.2.4. Record findings and implement them	Taylor Shelby
4.2.5. Review your assessment and update if necessary	Christian Morales
4.3. Spring Project Plan	Taylor Shelby
4.3.1. Determine milestones for spring semester	Jasmine Gay
4.3.2. Create functional decomposition for spring	Anjani Good
4.3.3. Create Gantt Chart	Isaac Guettler

Appendix C: Functional Decomposition

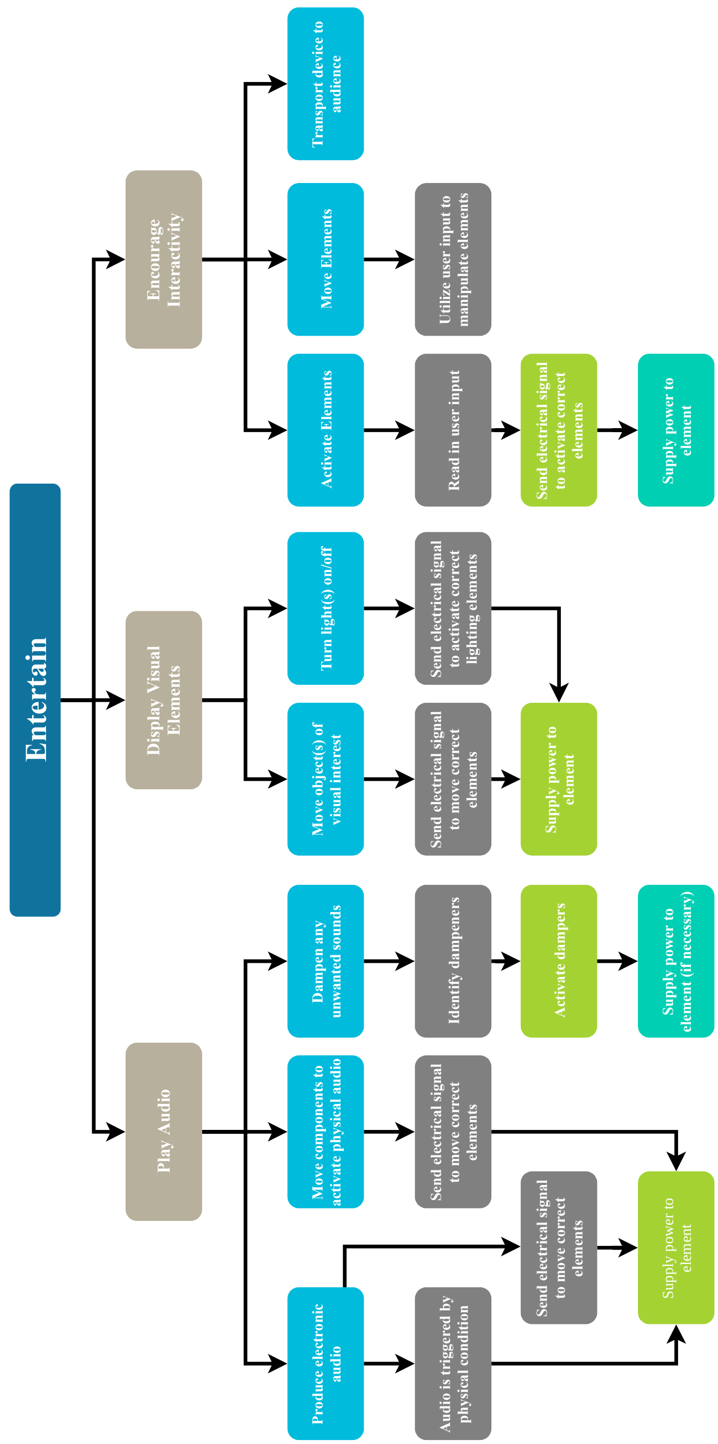


Figure 11. Functional decomposition of the outcomes of the music machine.

Appendix D: Target Catalog

Category	Need	Target	Number
Audio	Produce electronic audio	Audible volume	40-110 dB
		Audible range	5 m^2
	Move physical components to produce audio	Audible volume	40-110 dB
		Audible range	5 m^2
	Recognizable song	Number of songs	1 song
	Dampen unwanted sound	Attenuation percentage	80%
		Sense sound	20-110 dB
Power source	Supply power	Max	120 V
		Corded/battery	12 V
		Min	5 V
Visual	Move objects of visual interest	Mass of objects	Max 11 kg
		Size of objects	3.25ft X 1ft

	Lights On/Off	Number of lights	>=1 lights
		Customizable (RGB?)	>=3 colors
		Power required	60 W
Encourage Interactivity	Complexity	Number of moving elements	>=1 moving parts (not individual parts that make up one moving piece)
		Number of electrical systems	>=1 microprocessors and systems
		Number of electronic instruments	>=1 individual electronic elements
Portability	Size	Volume	2.5 m^3
		Weight	22 kg
		Max length/width	1.98m X 0.61m
	Ease to move	Force required to start motion	220 N

		Force required to maintain motion	130 N
Control	Switch	Power through components (On/Off)	1800 W
	Sensors	Number of motion sensors (Max, min)	1-70 sensors
		Number of audio sensors (max, min)	1-70 sensors

Appendix E: Concept Generation

How will it start

1. Use a hand crank to generate power.
2. Turn on the device with a switch.
3. The music starts by releasing an object, like a domino effect.
4. Turn on the machine with a button.
5. Use a string to trigger the start of the device.
6. Make the wheels of the box work as a crank to power the device so when it is pulled it creates power.

Audio

1. Make a marble roll down an electric contact plate, changing the pitch produced along the way.
2. Theremin don’t require physical contact to operate, so it could provide an option for both audience interaction and audio production.
3. Have mechanical components trigger a mallet to hit a xylophone.
4. Castanets or Kuaiban are both percussion instruments which are operated using similar motions, so they could be used for timing/beat purposes.
5. A Bell tree is vaguely ramp shaped, so it would be ideal for use in conjunction with other rolling elements. However, it is round so it would be too easy for elements to roll off of it.
6. Ratchets are percussive instruments which are operated with rotation, so they could be paired with other rotating elements to create sound.

7. Have a music wheel trigger a mallet to hit a lamellophone, it could be electric with amplification or strictly mechanical.
8. Tongue drum is played percussively, but has notes, so it can play melodic elements as well. However, it is not really well known, so it would be an odd sound.
9. Use an air gun and sliding mechanism to produce sound from a slide whistle.
10. Guitaret uses tines like a music box, but it is rather rare so it's unlikely we could find one for our device or learn how to play it easily.
11. Make a mallet or stick hit a gock block for tempo.
12. Although rather large, timpani are classic percussion instruments and could provide a solid bass sound.
13. Make a marble fall only a "snare drum" with a sound produced by rice in a plate.
14. Have a mallet hit a bass drum.
15. Have the music roll trigger a series of mallets to produce sound from a drum set.
16. Put a tambourine on a moving platform and hit it with a mallet in different locations to produce different sounds.
17. Add a triangle to start and end the song.
18. Use pressurized air to produce a whistle noise.
19. Add cymbals and make them crash and/ or scrape.
20. Use wind chimes, hang them from the ceiling and hit them with mallets attached to the music roll.
21. Have a cowbell mounted in the machine, then have a mallet strike it.
22. Use a vibrating or sliding mechanism to move a maraca or shaker.

23. Put bells on pool noodle then attach it to a motor that rotates to produce sound.
24. Have elements hitting guitar strings.
25. Use boomwhackers as mallets to produce two sounds at once, or make an element hit the boomwhackers.
26. Use classic music box tines as a musica component.
27. Have air going across a bottle top.
28. Small speakers for specific sounds (wind/brass/large string instruments)
29. Use an electronic library of MIDI sounds to play a variety of songs.
30. Use an air pump and a pressing mechanism to play bagpipes.
31. Add an accordion to the box attached to something that can contract and expand it as well as play its keys.
32. The Güiro is played by scraping a stick across it, so it could be an interesting percussive element to include in combination with other motion.
33. The Den-den daiko is a drum which can be played with rotational motion, so it is a good option to use with motors or servos.
34. Use waves on the beach as an electronic sound that may play when no other songs are playing.
35. Use trumpeting sounds, such as those of an elephant, to draw attention to the device.
36. Mimic the sound of cricket legs.
37. Have a chirping sound play in the background when the device is not in use.
38. Use a box with a recorded voice on it/ allow people to leave voice recordings.
39. Add a rooster call to the beginning of the song.

40. Create an instrument that mimics the way that a turkey creates a gobbling sound.

41. Create rain sounds electronically.

42. Have wind sounds playing in the background or whenever the device is not in use.

43. Make an instrument that mimics the buzzing sound from a bee.

44. Make a thunder sound electronically to emphasize certain moments in the song.

45. Add a mechanical woodpecker as a way to keep tempo.

46. Create a hooting sound electronically.

47. Add a coughing sound for a comedic effect, maybe play when the device isn't in use.

48. Have applause go off once the song is done.

49. Could program a lullaby as a song choice.

50. Should pick a good song maybe the alma mater or fight songs of both universities.

51. Should add a squeaky nose on the front that makes noise that children can play with.

Visual

1. Have the lights in time with the music.
2. Add an LED cube which changes in time with the music.
3. Lights act like music roll, indicating notes as well as timing.
4. Show cool looking gears throughout the machine.
5. Making mallets look like tools (wrenches, screwdrivers, etc.).
6. Making logos out of metal.
7. Create a marble hill, several ramps zig zagging with a marble rolling down it.
8. Add Newton's cradle on the machine.
9. Build the device out of wood.

10. Have a LED frequency spectrum.
11. There could be themed sections around different engineering types.
12. Have an LCD screen with interchangeable phrases.
13. The device could be painted in FAMU and FSU colors.
14. Add a conveyor belt to transport elements.
15. Add feathers to appeal to younger users.
16. Add colors and unique visuals in a way that mimics a peacock's wings.
17. Make the device resemble a beaver dam.
18. Build the device to look like a tree.
19. Make the machine move like a tree waving in the wind.
20. Add "lightning" by flashing strobe lights during intense moments in a song.
21. Add flames to the top to attract a crowd.
22. Add protein spirals to represent chemical engineering.
23. Create spinning DNA shapes as an educational tool.
24. Paint on a build farm animal for the device to attract younger users.
25. Paint the device with fun colors to attract the audience.
26. Different sections themed to the various categories of engineering.

Interaction

1. Audience could clap to set the tempo of the song.
2. Breaking light beams for non-contact interaction of the audience.
3. Waving from audience could trigger musical elements.
4. Breaking light beams for motion/audio triggers within the machine.

5. Using voice sensors so the audience could speak to start playing the machine.
6. The audience could crank a wheel to play the machine.
7. Add a "Dance Dance Revolution" mat to the device.
8. Make the speakers say "Play Me" when machine is on but not in use.
9. Add interesting textures to the device is fun to touch.
10. Fitbit tracking to sync music to movement.
11. Encourage crowd to dance along with computerized prompts.
12. Add a Sing along/Karaoke element.
13. Use a "Guitar Hero" type gaming element where users "play" along with the music.

Mechanics

1. Have percussive elements played by sticks/mallets.
2. Sampler (Triggered by mechanical elements?)
3. Add a music roll to trigger several instruments.
4. Use pulleys to reload objects.
5. Add a marble elevator to refill fallen/ used marbles.
6. Attach drumsticks to a stepper motor.
7. Use a pendulum to help with timing or for visual effects.
8. Create a mechanism that resets bowling pins
9. An Archimedes screw could be used to raise marbles.
10. Attach a wheelbarrow to the device for ease of transportation.
11. Add wheels on all four legs of the machine.
12. Use foldable legs to reserve space.

13. Create ramps for marbles to fall into tubes.
14. Use tubes that lead marbles to specific instruments.
15. Have a small air compressor for wind instruments.
16. Use a crank slider mechanics to get objects to slide back and forth.

Power

1. Use a 12V Battery source.
2. Attach a power cord to use power for the walls.
3. Crank to charge the battery and play at the same time.
4. Use a solar powered battery.
5. Have both battery and corded power and use a switch to change the power inputs.

Appendix E: Concept Selection

Table 13

Pairwise comparison

	1	2	3	4	5	6	7	8	9	10	11	12	Total
Keep cost low	X	0	1	1	0	0	0	0	0	0	0	0	2
Play a song	1	X	1	1	1	1	1	1	1	1	1	1	11
Attention grabbing	0	0	X	1	0	0	1	1	1	0	0	0	4
Interesting audio	0	0	0	X	0	0	0	0	0	0	1	0	1
Mechanical components	1	0	1	1	X	1	1	1	1	1	0	0	8
Electrical components	1	0	1	1	0	X	1	1	1	1	0	0	7
Portable	1	0	0	1	0	0	X	1	1	0	0	0	4
Durable	1	0	0	1	0	0	0	X	1	0	0	0	3
Portable power	1	0	0	1	0	0	0	0	X	0	0	0	2
Easy to use	1	0	1	1	0	0	1	1	1	X	0	0	6
Presentable	1	0	1	0	1	1	1	1	1	1	X	1	9
Professional	1	0	1	1	1	1	1	1	1	1	0	X	9
Total	9	0	7	10	3	4	7	8	9	5	2	2	12

Table 14

Analytical Hierarchy Process criteria comparison matrix

Criteria Comparison Matrix [C]					
A↓ B→	Cost	Number of songs	Number of Electronic Instruments	Weight	Number of Moving Elements
Cost	1.00	5.00	1.00	3.00	3.00
Number of songs	0.20	1.00	0.33	3.00	1.00
Number of Electronic Instruments	1.00	3.00	1.00	7.00	1.00
Weight	0.33	0.33	0.14	1.00	0.33
Number of Moving Elements	0.33	1.00	1.00	3.00	1.00
Sum	2.867	10.333	3.476	17.000	6.333

Table 15

Analytical Hierarchy Process normalized criteria comparison matrix

Normalized Criteria Comparison Matrix [NormC]						
	Cost	Number of songs	Number of Electronic Instruments	Weight	Number of Moving Elements	Criteria Weights {W}
Cost	0.349	0.484	0.288	0.176	0.474	0.354
Number of songs	0.070	0.097	0.096	0.176	0.158	0.119
Number of Electronic Instruments	0.349	0.290	0.288	0.412	0.158	0.299
Weight	0.116	0.032	0.041	0.059	0.053	0.060
Number of Moving Elements	0.116	0.097	0.288	0.176	0.158	0.167
Sum	1.000	1.000	1.000	1.000	1.000	1.000

Table 16

Analytical Hierarchy Process criteria consistency check

Consistency Check		
Weighted Sum Vector {Ws} = [C] * {W}	Criteria Weights {W}	Consistency Vector Cons = {Ws} / {W}
1.932	0.354	5.456
0.638	0.119	5.342
1.600	0.299	5.346
0.316	0.060	5.255
0.884	0.167	5.295
Average (λ)		5.339

Table 17

Analytical Hierarchy Process criteria consistency comparison

Consistency Comparison	
λ - n	0.339
n - 1	4.000
Consistency Index	0.085
RI (from table)	1.110
Consistency Ratio	0.076

Table 18

Analytical Hierarchy Process cost criteria comparison matrix

Criteria Comparison Matrix [C]			
A↓ B→	Concept 6	Concept 8	Concept 9
Concept 6	1.00	0.20	0.33
Concept 8	5.00	1.00	3.00
Concept 9	3.00	0.33	1.00
Sum	9.000	1.533	4.333

Table 19

Analytical Hierarchy Process normalized cost criteria comparison matrix

Normalized Criteria Comparison Matrix [NormC]				
	Concept 6	Concept 8	Concept 9	Concept Weights {W}
Concept 6	0.111	0.130	0.077	0.106
Concept 8	0.556	0.652	0.692	0.633
Concept 9	0.333	0.217	0.231	0.260
Sum	1.000	1.000	1.000	1.000

Table 20

Analytical Hierarchy Process cost consistency check

Consistency Check		
Weighted Sum Vector {Ws} = [C] * {W}	Criteria Weights {W}	Consistency Vector Cons = {Ws} / {W}
0.320	0.106	3.011
1.946	0.633	3.072
0.790	0.260	3.033
Average (λ)		3.039

Table 21

Analytical Hierarchy Process cost consistency comparison

Consistency Comparison	
λ - n	0.039
n - 1	2.000
Consistency Index	0.019
RI (from table)	0.520
Consistency Ratio	0.037

Table 22

Analytical Hierarchy Process number of songs criteria comparison matrix

Criteria Comparison Matrix [C]			
A↓ B→	Concept 6	Concept 8	Concept 9
Concept 6	1.00	7.00	1.00
Concept 8	0.14	1.00	0.14
Concept 9	1.00	7.00	1.00
Sum	2.143	15.000	2.143

Table 23

Analytical Hierarchy Process number of songs normalized criteria comparison matrix

Normalized Criteria Comparison Matrix [NormC]				
	Concept 6	Concept 8	Concept 9	Concept Weights {W}
Concept 6	0.467	0.467	0.467	0.467
Concept 8	0.067	0.067	0.067	0.067
Concept 9	0.467	0.467	0.467	0.467
Sum	1.000	1.000	1.000	1.000

Table 24

Analytical Hierarchy Process number of songs consistency check

Consistency Check		
Weighted Sum Vector {Ws} = [C] * {W}	Criteria Weights {W}	Consistency Vector Cons = {Ws} / {W}
1.400	0.467	3.000
0.200	0.067	3.000
1.400	0.467	3.000
Average (λ)		3.000

Table 25

Analytical Hierarchy Process number of songs consistency comparison

Consistency Comparison	
λ - n	0.000
n - 1	2.000
Consistency Index	0.000
RI (from table)	0.520
Consistency Ratio	0.000

Table 26

Analytical Hierarchy Process number of electronic instruments criteria comparison matrix

Criteria Comparison Matrix [C]			
A↓ B→	Concept 6	Concept 8	Concept 9
Concept 6	1.00	0.33	0.33
Concept 8	3.00	1.00	0.33
Concept 9	3.00	3.00	1.00
Sum	7.000	4.333	1.667

Table 27

Analytical Hierarchy Process number of electronic instruments normalized criteria comparison matrix

Normalized Criteria Comparison Matrix [NormC]				
	Concept 6	Concept 8	Concept 9	Concept Weights {W}
Concept 6	0.143	0.077	0.200	0.140
Concept 8	0.429	0.231	0.200	0.286
Concept 9	0.429	0.692	0.600	0.574
Sum	1.000	1.000	1.000	1.000

Table 28

Analytical Hierarchy Process number of electronic instruments consistency check

Consistency Check		
Weighted Sum Vector {Ws} = [C] * {W}	Criteria Weights {W}	Consistency Vector Cons = {Ws} / {W}
0.427	0.140	3.049
0.897	0.286	3.133
1.853	0.574	3.230
Average (λ)		3.137

Table 29

Analytical Hierarchy Process number of electronic instruments consistency comparison

Consistency Comparison	
λ - n	0.137
n - 1	2.000
Consistency Index	0.069
RI (from table)	0.520
Consistency Ratio	0.132

Table 30

Analytical Hierarchy Process weight criteria comparison matrix

Criteria Comparison Matrix [C]			
A↓ B→	Concept 6	Concept 8	Concept 9
Concept 6	1.00	0.20	1.00
Concept 8	5.00	1.00	5.00
Concept 9	1.00	0.20	1.00
Sum	7.000	1.400	7.000

Table 31

Analytical Hierarchy Process weight normalized criteria comparison matrix

Normalized Criteria Comparison Matrix [NormC]				
	Concept 6	Concept 8	Concept 9	Concept Weights {W}
Concept 6	0.143	0.143	0.143	0.143
Concept 8	0.714	0.714	0.714	0.714
Concept 9	0.143	0.143	0.143	0.143
Sum	1.000	1.000	1.000	1.000

Table 32

Analytical Hierarchy Process weight consistency check

Consistency Check		
Weighted Sum Vector {Ws} = [C] * {W}	Criteria Weights {W}	Consistency Vector Cons = {Ws} / {W}
0.429	0.143	3.000
2.143	0.714	3.000
0.429	0.143	3.000
Average (λ)		3.000

Table 33

Analytical Hierarchy Process weight consistency comparison

Consistency Comparison	
λ - n	0.000
n - 1	2.000
Consistency Index	0.000
RI (from table)	0.520
Consistency Ratio	0.000

Table 34

Analytical Hierarchy Process number of moving elements criteria comparison matrix

Criteria Comparison Matrix [C]			
A↓ B→	Concept 6	Concept 8	Concept 9
Concept 6	1.00	0.20	3.00
Concept 8	5.00	1.00	5.00
Concept 9	0.33	0.20	1.00
Sum	6.333	1.400	9.000

Table 35

Analytical Hierarchy Process number of moving elements normalized criteria comparison matrix

Normalized Criteria Comparison Matrix [NormC]				
	Concept 6	Concept 8	Concept 9	Concept Weights {W}
Concept 6	0.158	0.143	0.333	0.211
Concept 8	0.789	0.714	0.556	0.686
Concept 9	0.053	0.143	0.111	0.102
Sum	1.000	1.000	1.000	1.000

Table 36

Analytical Hierarchy Process number of moving elements consistency check

Consistency Check		
Weighted Sum Vector {Ws} = [C] * {W}	Criteria Weights {W}	Consistency Vector Cons = {Ws} / {W}
0.655	0.211	3.100
2.254	0.686	3.284
0.310	0.102	3.033
Average (λ)		3.139

Table 37

Analytical Hierarchy Process number of moving elements consistency comparison

Consistency Comparison	
λ - n	0.139
n - 1	2.000
Consistency Index	0.069
RI (from table)	0.520
Consistency Ratio	0.134

Table 38

Analytical Hierarchy Process final rating matrix

Final Rating Matrix			
	Concept 6	Concept 8	Concept 9
Cost	0.106	0.633	0.260
Number of	0.467	0.067	0.467
Number of	0.140	0.286	0.574
Weight	0.143	0.714	0.143
Number of	0.211	0.686	0.102

Table 39

Analytical Hierarchy Process criteria weights

Criteria Weights {W}
0.354
0.119
0.299
0.060
0.167

Table 40

Analytical Hierarchy Process final concept ratings

Concept 6	0.179
Concept 8	0.476
Concept 9	0.345

Appendix A: APA Headings (delete)

Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading

Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading

Heading 3 is indented, boldface lowercase paragraph heading ending with a period.

Heading 4 is indented, boldface, italicized, lowercase paragraph heading ending with a period.

Heading 5 is indented, italicized, lowercase paragraph heading ending with a period.

See publication manual of the American Psychological Association page 62

Appendix B Figures and Tables (delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 12 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.

Figure 12. Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table 41

The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase

Level of heading	Format
1	**Centered, Boldface, Uppercase and Lowercase Heading**
2	**Flush Left, Boldface, Uppercase and Lowercase**
3	***Indented, boldface lowercase paragraph heading ending with a period***
4	***Indented, boldface, italicized, lowercase paragraph heading ending with a period.***
5	*Indented, italicized, lowercase paragraph heading ending with a period.*

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