Violin Note-teaching Robotic Arm (Ro-BACH-tic Symphony)

ECE3011 Junior Design Project

The Master
Team C02
Dr. Benjamin Yang

Sangeon Jeon EE sjeon84@gatech.edu
Victor Alfaro EE valfaro3@gatech.edu
Christian Santiago EE csantiago38@gatech.edu
Christian Semali CompE csemali6@gatech.edu

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Executive Summary

The design project for the term that needs to be solved is to create a method of teaching kids to make a visual and audible connection to music. As true for any instrument, teaching musical instruments to children requires connecting instrumental motions to physical movements so they can see what is happening. While learning the movements necessary for making music, children must also understand how to compose their music to make the movements produce their very own compositions. We aim for children to compose simple sheet music using a chosen sequence of musical notes they write. This creation will then be translated to a musical keyboard, highlighting their composition through the robotic arm's motions, simulating the act of conducting and having LED lights react and flash based on the intensity of the notes played. Additionally, sixteen light columns (LEDs) will illuminate to show the child the corresponding location of where a note would be on the actual violin. The compositions created will be played through a speaker.

The robotic arm mechanism will function in a way that represents the range of motion corresponding to a specific musical instrument and a musical keyboard that can make music. In this project, a Violin will be used as the primary instrument of instruction. The musical keyboard will accept input from the user. It will directly connect to the robotic arm that will move/pivot circularly and linearly to demonstrate the motion needed to play the musical instrument note the child composed with their own devised sheet music.

The technical problems that may arise for the development of the robot, as the musical keyboard is less technically challenging, will be the feedback correction if the robot needs to be doing the correct range of motion while hitting the correct note. Another technical problem possibility is getting the correct mass and force calculations to allow the robot to hold the violin bow with a certain mass corresponding to it, so if it is too heavy, it will not be able to support it. Calculations will be used to ensure this does not happen. Lastly, the electrical subsystem must have the correct currents and voltages going into each designated part of the mechanisms. To ensure maximum efficiency, voltages will be dealt with by using voltage regulators added onto the PCB, and currents will be dealt with by making sure the indicated chip or section can tolerate a certain specified current.

A specifically crafted model of the overall mechanism has been made through Solidwork, including the arm and the musical board. The size of the violin will not be human-sized but instead scaled down so the PCB can fit well. The robot's design focuses on a movable arm moving around and pivoting to hit specific notes. The robotic arm has three pivot points controlled by three separate servo motors: a shoulder for note selection, an elbow for linear note playing, and a wrist that will correct itself based on its location on the violin. With a robotic arm, rather than a whole robot, the objective of teaching a child the positioning needed for different notes is emphasized dramatically. The child can connect a mechanical arm with their own and try to mimic it. To effectively approach these technical problems and ensure quality, an agile work schedule has been used weekly to make sufficient progress toward a finished product.

As part of the critical design review process and the final document for the robot, with the Bill of Materials established, it is a good record indicator of what we have working with during the semester. The estimated total is currently $74.26. This cost was finite, and we did not need to go over this value and kept it intact.

Lastly, with the project finally coming to close, we have been able to follow the master schedule in section 5 and we only had to write shift a few times. Other than these right shifts, we did meet every deadline and never missed one.

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Violin note-teaching robot arm

1. Introduction

Our team's objective is to create a robotic arm capable of playing the violin in response to piano keyboard input. We have christened our innovation "RoBACHtic Arm," paying homage to the renowned musician Johann Sebastian Bach. We anticipate that the final product will serve as a valuable tool for educators, aiding them in meeting various educational standards outlined in the Georgia Standards of Excellence. To develop the RoBACHtic Arm, we have projected a budget of $100 and an estimated time of two months.

1.1 Motivation

The design problem at hand revolves around creating a solution that addresses two primary motivations. First, the challenge is to make learning the violin more accessible to children. According to the Georgia Standards of Excellence (GSE) for music education, students are encouraged to explore a variety of musical instruments (ESGM5.PR.2.a). However, certain instruments, such as the violin, pose significant difficulties for beginners. Learning to produce the correct sound on a violin requires maintaining precise control over the bow, a skill that can be challenging for novices. This problem hinders the fulfillment of educational standards. The RoBACHtic Arm project aims to be a bridge between the piano and the violin by simplifying the control method, akin to playing the piano, while retaining the musical characteristics of the violin. This innovation also allows students to learn how to play the violin by mimicking the arm's movements, which are designed to resemble those of skilled human violin performers.

Secondly, in today's educational landscape, nurturing well-rounded children who can excel across various disciplines is paramount. The GSE for Music emphasizes the importance of connecting music to other fields of study (ESGM5.CN.1). With the RoBACHtic Arm, one can instruct children about the relationship between music and computer science. By explaining how this machine operates to produce sound, educators can seamlessly integrate music into computer science education, offering a cross-disciplinary learning experience.

1.2. Objective

The project's primary goal is to enhance the educational experience in 5th-grade STEAM (Science, Technology, Engineering, Arts, and Mathematics) classrooms by fostering versatility among students. The product is designed to facilitate cross-disciplinary learning, with a focus on engineering, computer science, and music. It is intended for use in a classroom setting and aims to engage and educate students in a hands-on and interactive manner.

Intended Use and Product Description

The product's intended purpose is to support the holistic development of 5th-grade students by offering a collective learning experience that spans multiple disciplines. Here is a breakdown of its intended uses:

- Engineering: The product will serve as a tool for hands-on engineering activities, allowing students to assemble and interact with the components, gaining practical experience in the field.
- Computer Science: Through carefully crafted lessons, students will learn basic computer science concepts, specifically how the machine processes audio files.
- Music: Once assembled, the product transforms into a musical instrument. Students can have music lessons and use the product to perform music. This bridges the gap between technology and the arts, enriching their education.

Product Features

The key features of this product have been meticulously crafted to replicate the movements of a human violin performer, offering a lifelike musical experience. These features include:

- Sound Length Control: The product restricts the duration of sound produced based on the remaining bow length. This replicates the way a violinist controls the sound by bowing technique.
- Volume Control: The volume of the produced sound is directly proportional to the pressure applied to the keyboard. This feature allows students to understand the dynamics of sound production and control.

- Bow Movement: The speed of the bow's movement is influenced by user input. This dynamic aspect of the product emulates the nuances of a violinist's bowing technique, adding to the realism of the experience.
- Pitch-Dependent Bow Angle: The angle of the bow is modulated in accordance with the pitch of the notes played. This feature provides a visual and tactile representation of how different strings on a violin correspond to various pitch levels.

With these features, students can observe and comprehend the fundamental techniques involved in playing an actual violin by interacting with the product. They gain insights into bowing control, dynamics, and pitch modulation, which are essential skills for any aspiring violinist.

Value Statement

The product offers several benefits to various stakeholders:

- Science Teachers: The product sparks students' interest in engineering, making classroom learning engaging and relevant.
- Students: They gain a unique educational experience that bridges the gap between music and engineering, broadening their skill set and knowledge base.
- Educational Community: This product differentiates itself from existing STEM kits by integrating music and engineering, offering a more comprehensive learning experience.
- Music Teachers: Students can learn to play the violin with the interface of a simpler instrument (piano), making it easier for them to grasp the fundamentals of music.
- Society: By promoting versatility and multidisciplinary learning, the product contributes to developing adaptable human resources, crucial in the modern interconnected world.

Technical Challenges and Safety Considerations

The project acknowledges that creating a product that mimics human performers' movements is a complex task. Technical challenges include servo control, mechanical design, and fine-tuning to achieve a balance between mechanical plausibility and resemblance to human performers.

Safety is a paramount concern, particularly since the target users are children. The project will address potential hazards such as electrical safety and sharp edges, ensuring a safe learning environment.

1.3 Background

We live in an era marked by rapid technological advancements, particularly in the domains of artificial intelligence and robotics. Such advancements necessitate a corresponding evolution in the skills and knowledge base of the workforce. The U.S. Department of Labor forecasts a notable increase in STEM (Science, Technology, Engineering, and Mathematics) occupations, anticipating a rise of about 11% by 2031. This trajectory underscores the importance of early STEM education.[1]

Within this framework, Educational Robotics (ER) emerges as a pivotal tool. ER, which encompasses STEM kits, has been demonstrated to be a highly effective pedagogical method. A comprehensive meta-analysis in the ER field reveals that students, when engaged with educational robots, not only acquire enhanced knowledge but also develop a positive disposition towards science, engineering, and robotics. Furthermore, these students are more inclined to select engineering and related disciplines as their major fields of study, and they tend to actively participate in iterative design processes.[2] Given these benefits, we are confident that our project will serve as a valuable resource, fostering a more knowledgeable and skilled future generation, ultimately contributing to the nation's technological and economic growth.

Given the context provided, our report will be structured as follows:

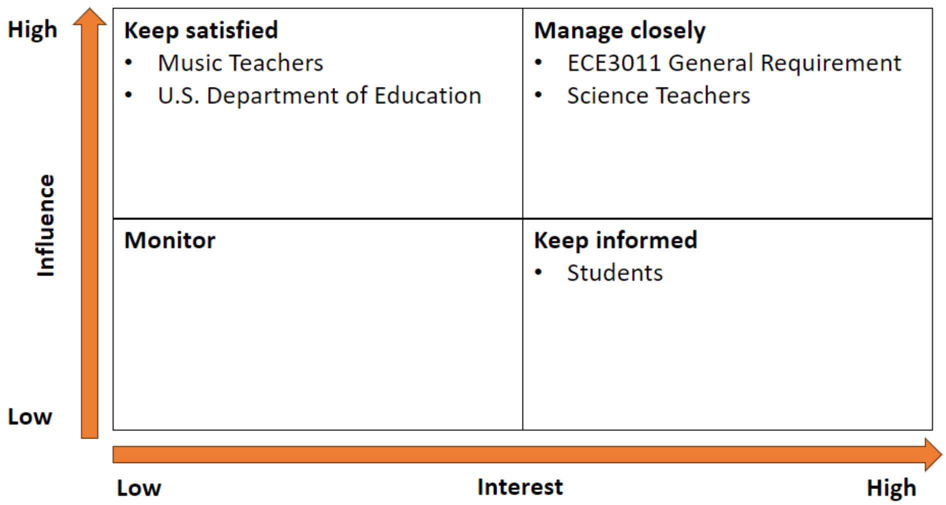
- Section 2: We will commence by delineating the project requirements, followed by an in-depth analysis of how these align with the technical specifications. This ensures clarity in understanding the foundational needs of the RoBACHtic Arm project.
- Section 3: We will break down the entire system into its constituent sub-systems. Each of these will be examined individually, highlighting implementation strategies and noting any potential areas of caution. This modular approach ensures thoroughness and allows us to address specific nuances of each segment.
- Section 5: Armed with a comprehensive view of the project's structure and requirements, we will draft a detailed timeline, outlining key milestones and target completion dates. This will serve as a roadmap for the project's development trajectory.

[1] https://blog.dol.gov/2022/11/04/stem-day-explore-growing-careers#:~:text=In%202021%2C%20there%20were%20nearly,the%20total%20for%20all%20occupations.
[2] Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A Systematic Review of Studies on Educational Robotics.
Journal of Pre-College Engineering Education Research (J-PEER), 9(2), Article 2.
https://doi.org/10.7771/2157-9288.1223

In summation, our objective is to present a compelling argument for the RoBACHtic Arm project. We are confident that, by the end of this report, you will recognize its feasibility, the potential for profitability, and its broader societal benefits.

2. Project Description, Customer Requirements, and Goals

Stakeholders Analysis



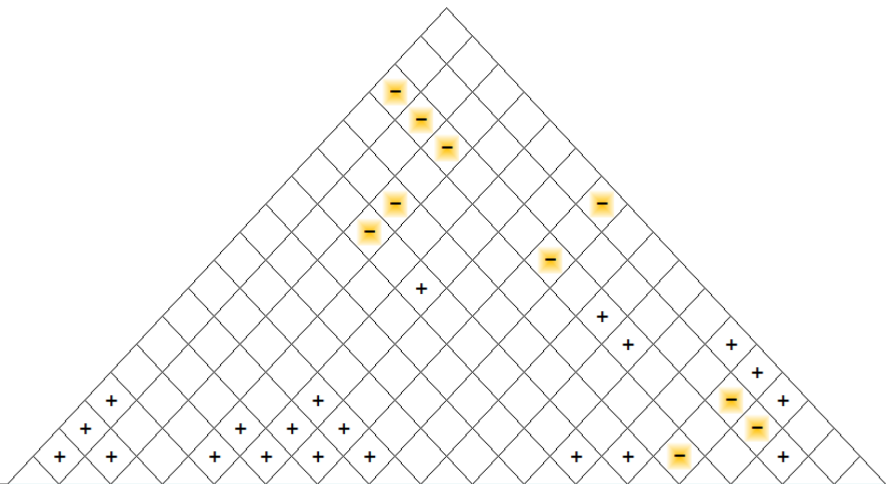
- <u>ECE3011 General Requirement:</u> The project's success hinges on its alignment with the ECE3011 course criteria, as it serves as the primary metric for evaluation.
- <u>Students:</u> Aged 12, these students show keen interest in enjoyable toys. They would be inclined to purchase the product if it meets their expectations for entertainment. However, their limited financial capabilities, owing to their young age, restrict them from buying the product.
- *<u>Science Teachers:</u>* With the rise in popularity of Educational Robotics, many science teachers are on the lookout for high-quality kits to enhance their classes. Their endorsement of a product is pivotal. If they choose to incorporate the product into their curriculum, it becomes a requisite for all students in their class to purchase it.
- *<u>Music Teachers:</u>* Despite the product's fusion of music and STEM, music teachers might not be particularly drawn to our STEM kits. This hesitancy arises from the kit's limited song repertoire and the overarching goal of music education – to enable students to play real instruments like the violin. Still, like science teachers, their decision on classroom materials carries significant weight.
- *<u>U.S. Department of Education:</u>* While the Department of Education may not exhibit distinct interest in the product due to the abundance of STEM kits already available, their influence cannot be understated. Should they express interest in the kit, it could sway educators nationwide towards its adoption.

Customer Requirement, Required functions and QFD Chart

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
9 = Strong	●
3 = Moderate	○
1 = Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Category	Weight	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
		Direction of Improvement	▼	▼	▼	▼	◇	◇	▼	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇
Category	Weight	Customer Requirements (Explicit and Implicit) / Engineering Requirements	Weigh less than 20 lbs	Power-down state kit within WxLxH=35cm x 35cm x 35cm	All movement within WxLxH=75cm x 75cm x 75cm	Case temperature under 80°C	Power fused or short-circuit protected	No exposed 120VAC conductors	Operate from 120 VAC and consume no more than 60 W	Common input power connector	No sharp edges or corners	Band-pass filter that passes only the sound within audible frequency range	Connect non-PCB parts to PCB with connectors and cables assemblies	Three servos that represent wrist, elbow and shoulder	Feedback system that always keeps the bow perpendicular to the violin	Limit the length of sound proportionally to the remaing bow length	Piano keyboard that take inputs from students	Capacitive keypads that senses the pressure applied on keyboard	IMU sensor to sense the position of the arm
ECE3011 General Requirements		Input: sensor input																	●
		Output: Audio, Lights, Motion												●					
		Portability	●	●	●														
		Operate with the standard power in USA							●										
		Mechanical safety for kids				●					●								
		Electrical safety for kids					●	●		●			○						
		Easy to assemble	○							○	○		○						
		Intuitively usable															●		
		Graceful Output: Motion, Audio, Lights										●							
Music Teachers		Resemble the movement of actual violin performers												●	●	○			●
		Mimic the musical properties of real violins														●		●	○

We have omitted the other stakeholders in the QFD chart since ECE3011 General Requirements already encompass the requirements of others well.

- Detailed Requirements in respect of musical effects
    a. Bow movement
        i. Up-Bow, Down-Bow: When a new note starts, the bow's direction should change accordingly.
        ii. Return to rest: After an extended silence, the bow should revert to its initial down-bow position.
        iii. Duration of the notes: The sound's length should match the time the user presses the keyboard, but also be limited based on the remaining bow length.

iv. Sound Volume:
Adjust the bow movement's speed based on the pressure exerted on the keyboard to regulate volume.

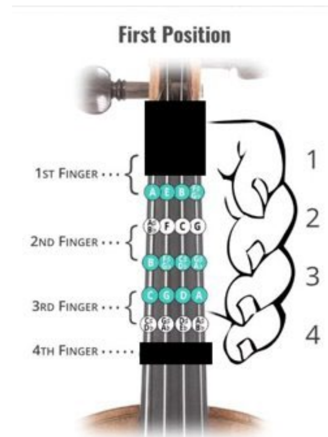
v. Dual String Play (Optional):
When the pitch differences permit, two notes can be played on separate strings at the same time. It's essential to understand the conditions allowing for simultaneous note playing.

b. String Changes

i. Silent Transitic
No sound or linear bow movement should occur duri string transitions.

ii. String Transition Spee
For widely spaced consecutive notes, the robot a needs to adjust the bow's angle quickly. For instance a note is played on the far-left string followed by a nc on the far-right string, the robot arm should transiti rapidly to prevent any jarring sound gaps.

iii. First position limitatic
While various strings can produce the same note, c primary focus is modeling a basic version of the viol Thus, we will limit the finger placements to the fi position when choosing a string to play a specific note



- Other Miscellaneous Requirements
1. Labels on the product:
    a. Must have a visible label on front or top panel that shows:
        i. Product name
        ii. Names of all group members
        iii. Class section and group number
        iv. Georgia Tech/ECE Logo

    b. Must have PCB silkscreen that shows:
        i. Class section and group number
2. PCB (Printed Circuit Board) Constrains
    a. Dimension < WxL=15cm x 15cm
    b. 2-layer design, 1 oz. Copper (36 um thick), fabricated on 1.6mm thick FR-4 material
    c. No glue

Goals

In summary, we outline the following primary objectives for the RoBACHtic Arm:

- Safety: Ensure the RoBACHtic Arm operates safely at all times.
- Function: The RoBACHtic Arm should produce sound and move based on keyboard input.
- STEM Education: The design should be straightforward enough for a 12-year-old to assemble.
- Music Education: The RoBACHtic Arm's movements should mimic those of real violinists.

3. Technical Specifications & Verification

- Functionality Verification

Requirement	O/ X	Description
Bow reaching all four strings	O	
Play all notes within the first position	Δ	14 notes available except for G and A on the E-string
Bow movement requirements	Δ	
1. Up/down bow movement	O	
2. Recato/ Staccato bow movement	X	Only basic bow movement available
Sound length requirements	X	The sound lasts until the next input
1. matches with user pressing time	X	
2. limited by the length of remained bow length	X	
LED requirements	Δ	
1. 16 LEDs array to show the fingering for the note	X	MicroBit is in the box, not on the violin
2. 4 LEDs indicating which string is being played	Δ	Only 2 LEDs working
Sensor input requirements	Δ	

1. IMU facilitating robot to correct its position	Δ	Mounted IMU is not working

- **Quantitative Specification & Verification**

Description	Expectation	Measured Value
Weight	< 10 kg	6 kg
Size at power-down state	< 35 cm x 35 cm x 35 cm	34 cm x 26 cm x 38 cm
Size when powered	< 75 cm x 75 cm x 75 cm	45 cm x 51 cm x 38 cm
PCB Dimension	< 15 cm x 15 cm	8 cm x 10 cm
Case temperature	< 80 °C	20.1 °C (Room Temperature)
Current from 120 VAC outlet	< 5 A	1.5 A
Power	< 60 W	~ 8.52 W
Smooth transition time between strings	< 0.5 sec	3 - 7 sec
Shoulder Servo's angular range	0 – 180 deg	0 – 180 deg
Elbow Servo's angular range	0 - 180 deg	0 - 60 deg
Bow Servo's angular range	0 - 180 deg	0 - 180 deg

- **Qualitative Specification & Verification**

Requirement	O/ X	Description
Mechanical Requirements		
Silent movement	X	Noise made by the mechanical components disturbs the music
No glue	Δ	Mostly assembled by fastener with some exceptions
Portability	Δ	Should carry main box and keyboard separately
No sharp edges	O	
Electrical Requirements		
No exposed 120 VAC conductors	O	
Input power connecter used	O	
Neat Wiring	O	
Fused or Short-circuit protected	X	
Aesthetic and Design Requirements		
Smooth audio	Δ	Use beep sound instead of recording file
Intuitively usable	O	Have conventional keyboard as interface

Product label requirements	O	
1. Product name	O	
2. Names of all group members	O	
3. Class section and Group number	O	
4. Gatech/ECE Logo	Δ	No ECE mark present
PCB label requirements	O	
1. Class section	O	
2. Group Number	O	

4. Design Approach and Details

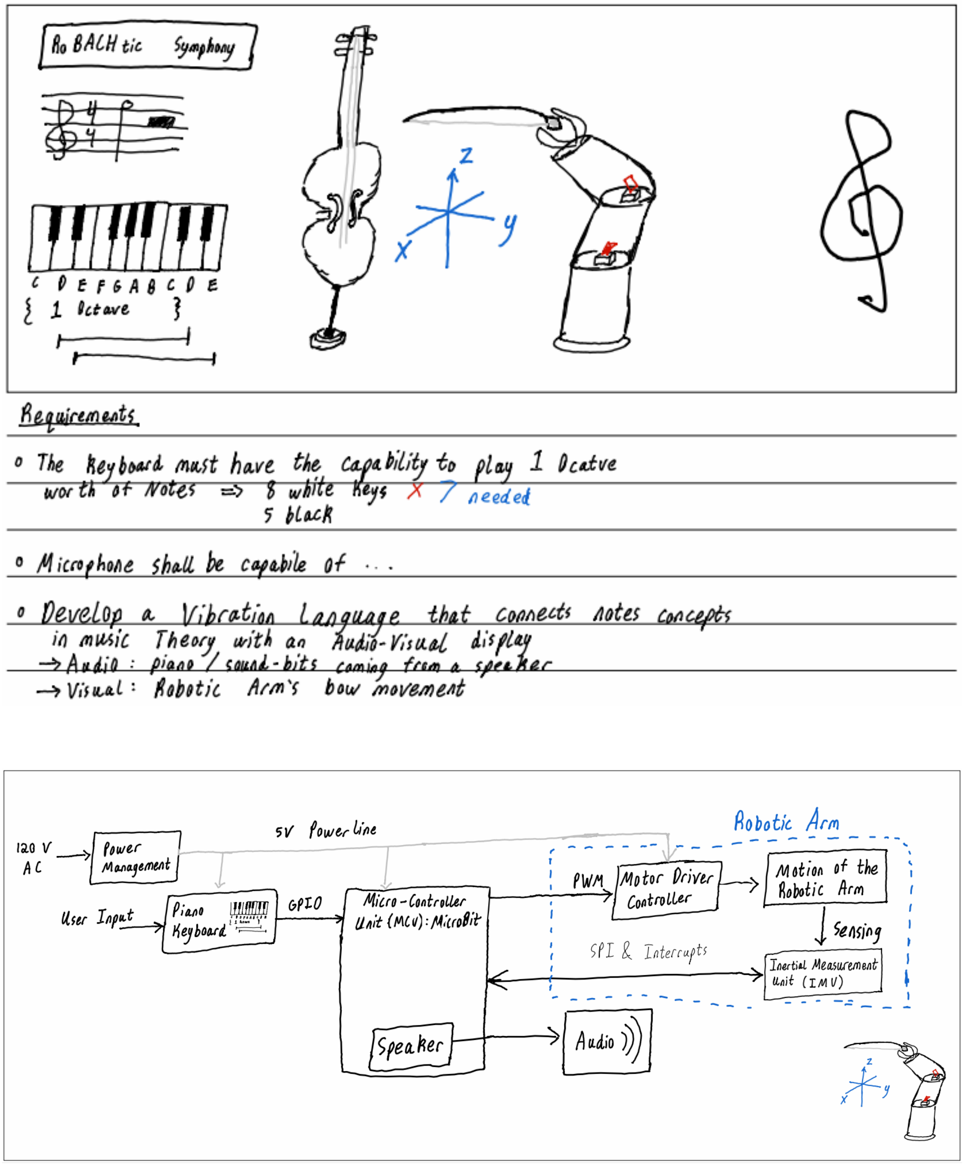


Figure 1: Initial concept sketch of system's features and rough draft list of requirements.

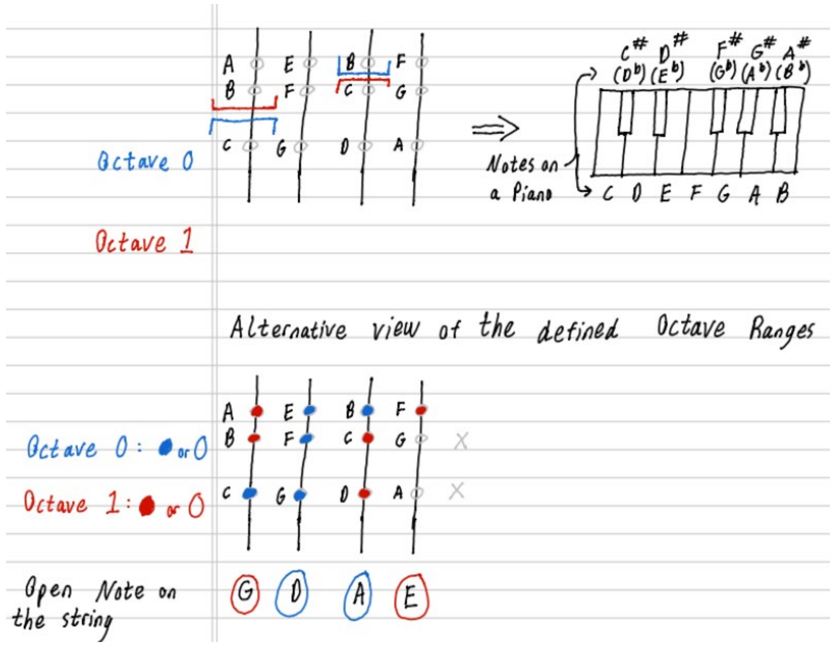


Figure 2: Image highlighting the defined octave ranges of violin notes that will be mapped to the piano keyboard.

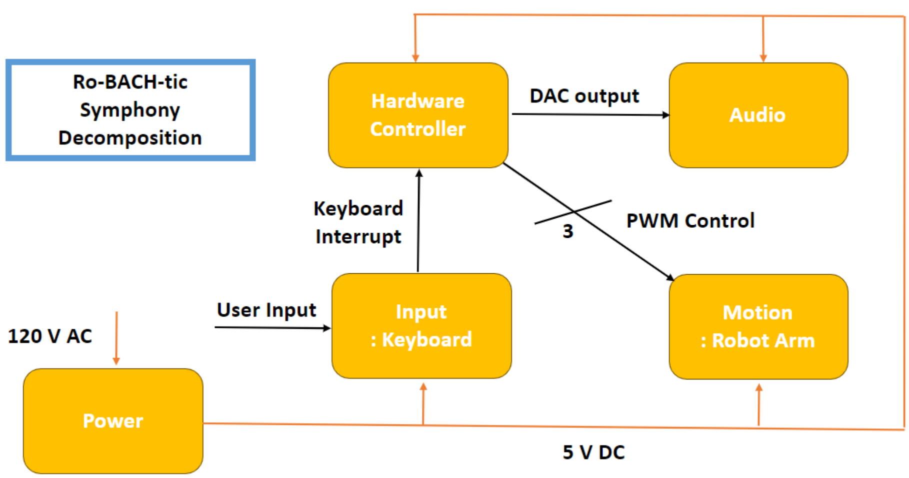


Figure 3: Top-level System Diagram

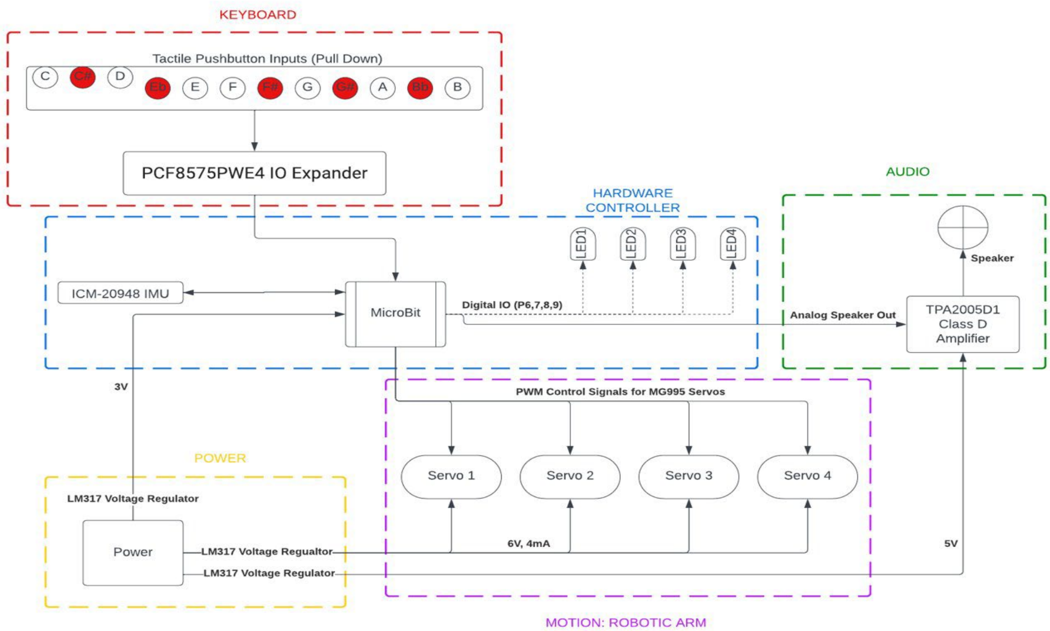


Figure 4*:* Subsystem Breakdown and technical components.

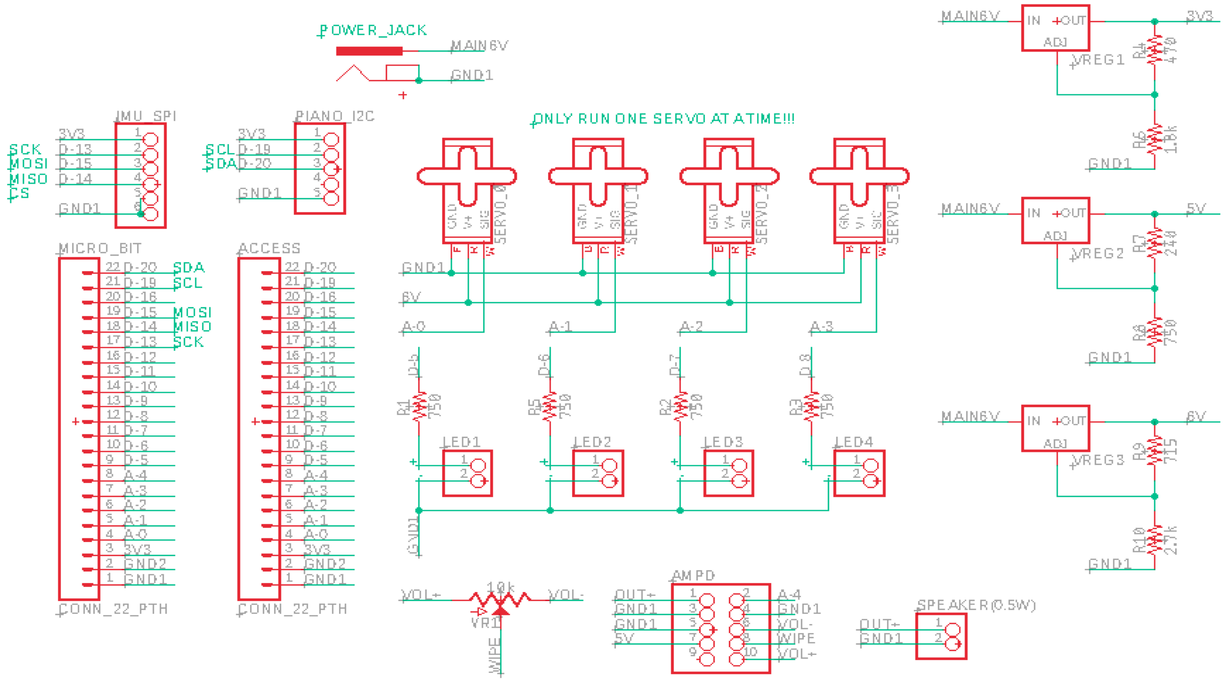


Figure 5: Schematic diagram of the hardware components that will interface directly with the MicroBit Microcontroller. This hardware component consists of three low-dropout (LDO) voltage regulators, four servos, inertial measurement unit (IMU), potentiometer, GPIO expander (connected to the Piano PCB), barrel jack, class D audio amplifier, speaker, and MicroBit breakout.

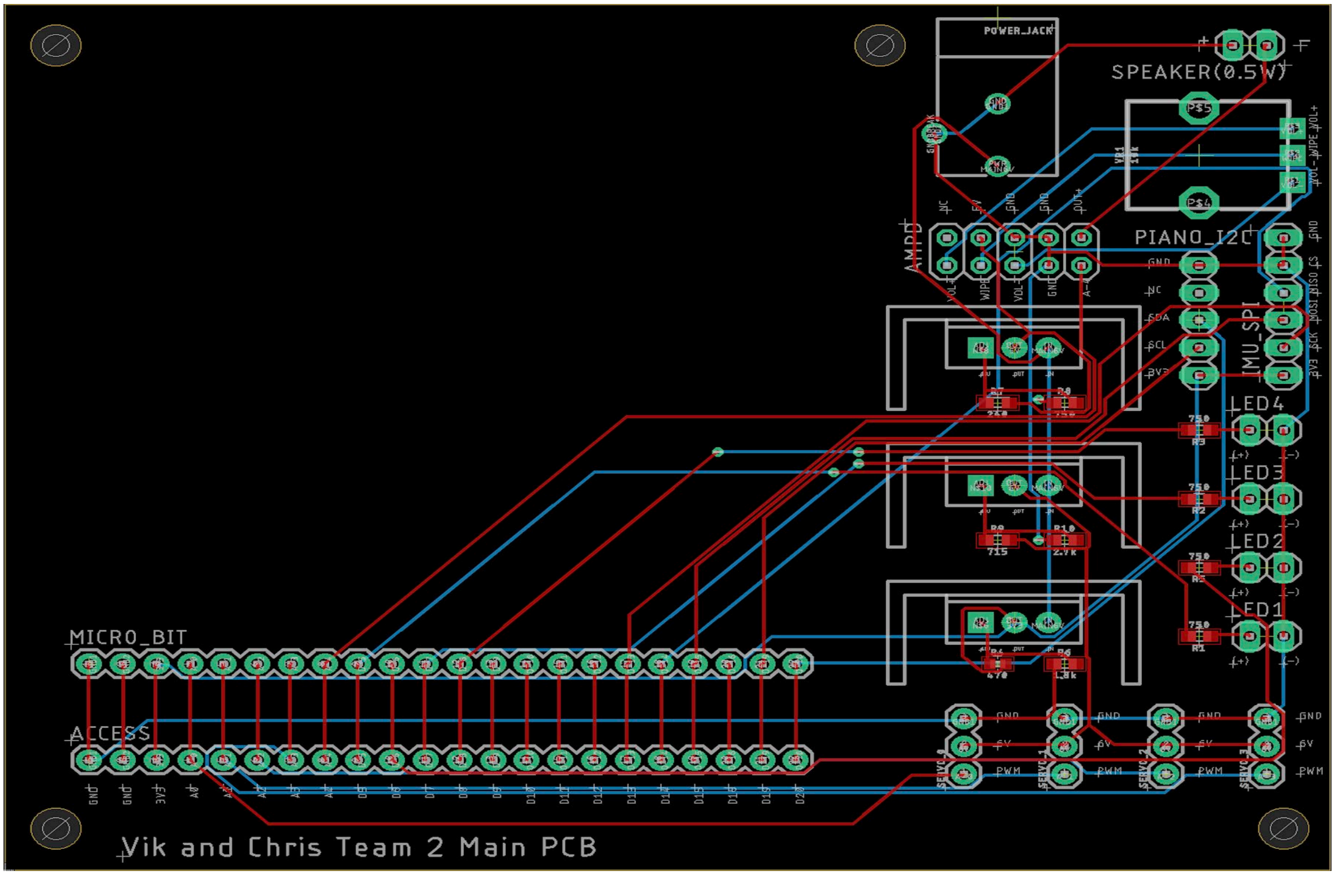


Figure 6: Image of the Main PCB Layout in Eagle. This hardware component consists of three low-dropout (LDO) voltage regulators, four servos, inertial measurement unit (IMU), potentiometer, GPIO expander breakout (connected to the Piano PCB), barrel jack, class D audio amplifier, speaker, and MicroBit breakout.

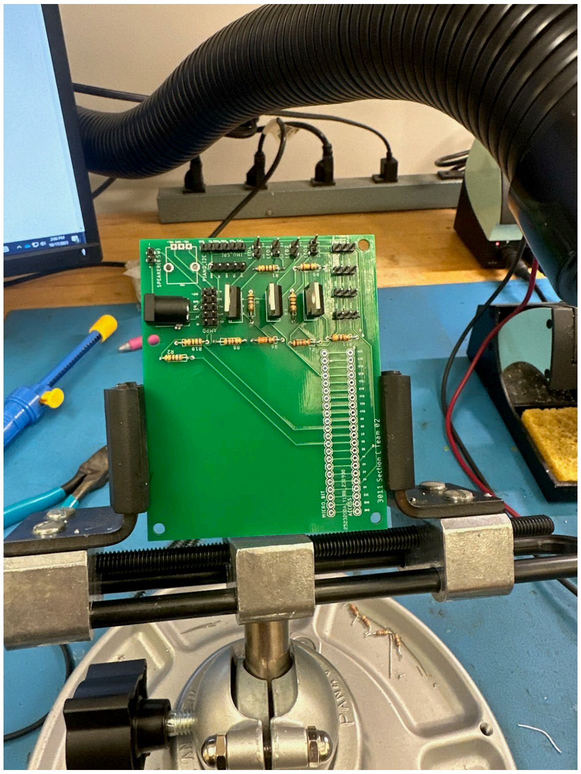


Figure 7: Image of the soldered Main PCB with male breakout pins.

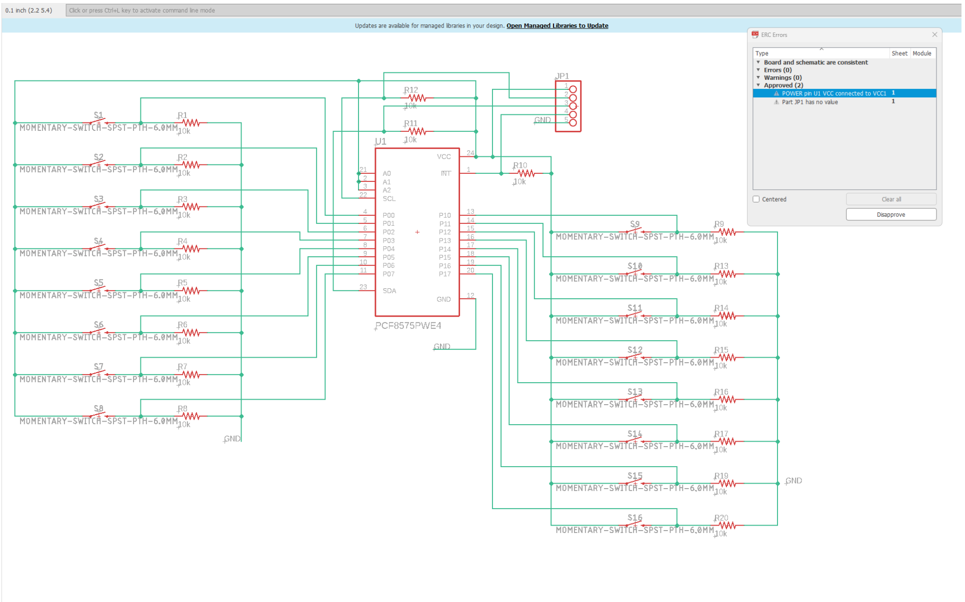


Figure 8: Schematic diagram of the MIDI Piano keyboard. The hardware components of this device consist of 16 pushbuttons, a GPIO expander, and breakout pins of the GPIO expander's communication lines.

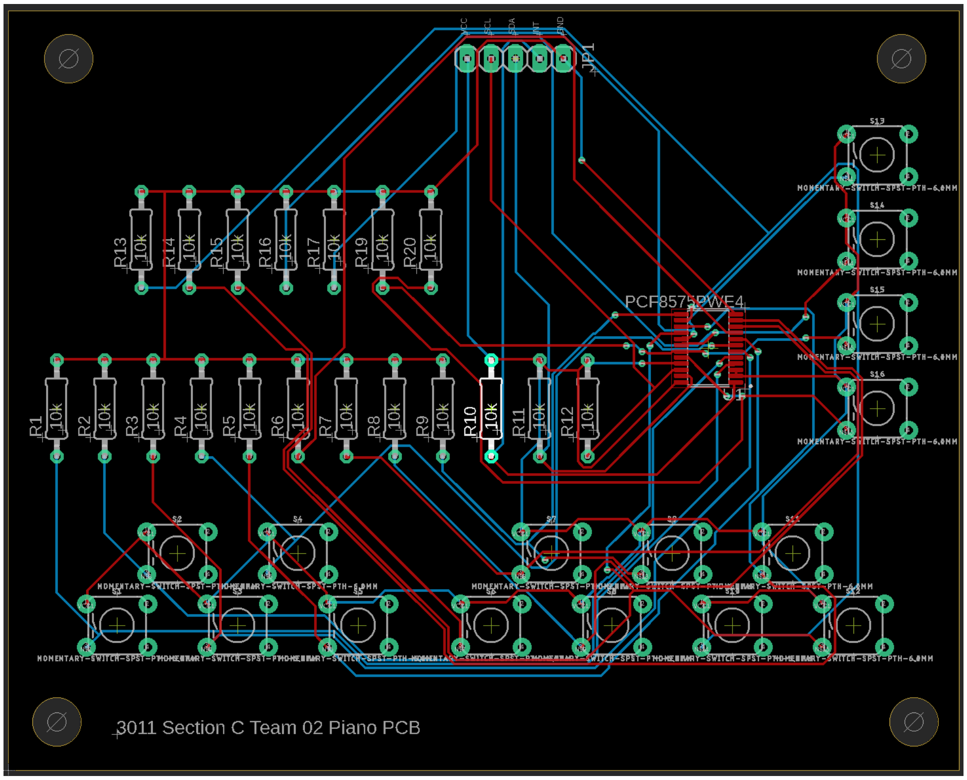


Figure : Image of the Piano PCB in Eagle layout in Eagle. The hardware components of this device consist of 16 pushbuttons, a GPIO expander, and breakout pins of the GPIO expander's communication lines.

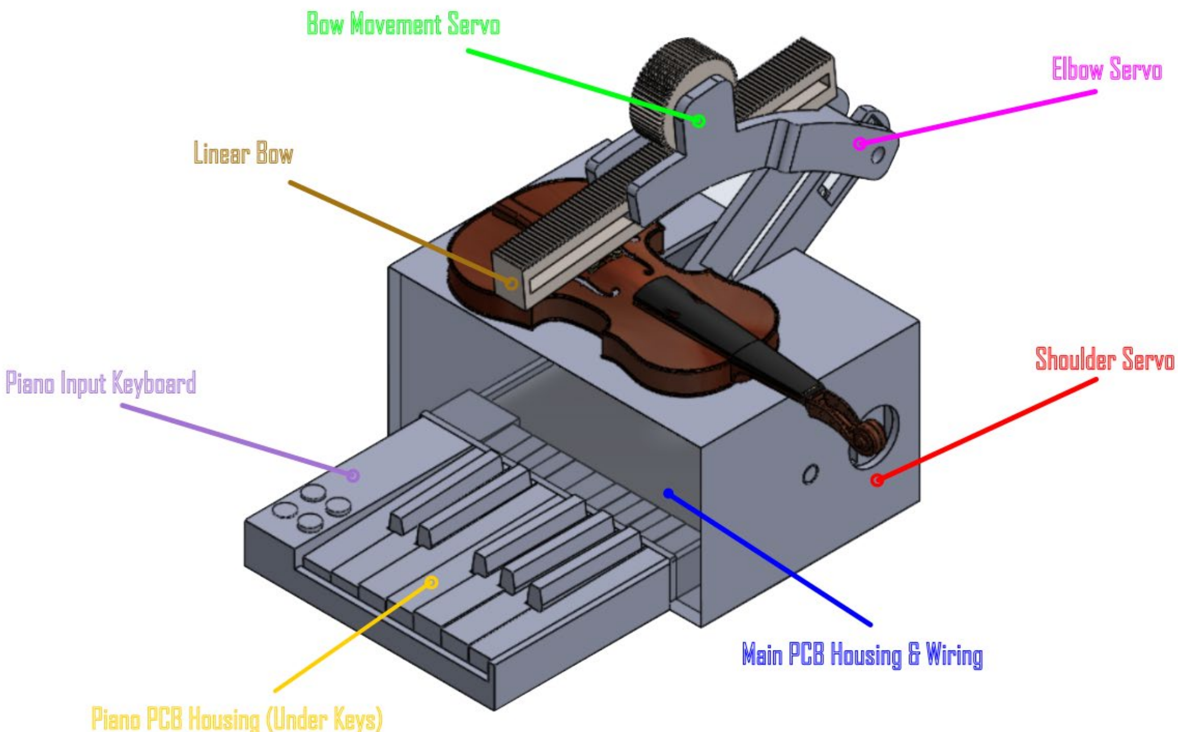


Figure 10: Mechanical Overview of CAD model.

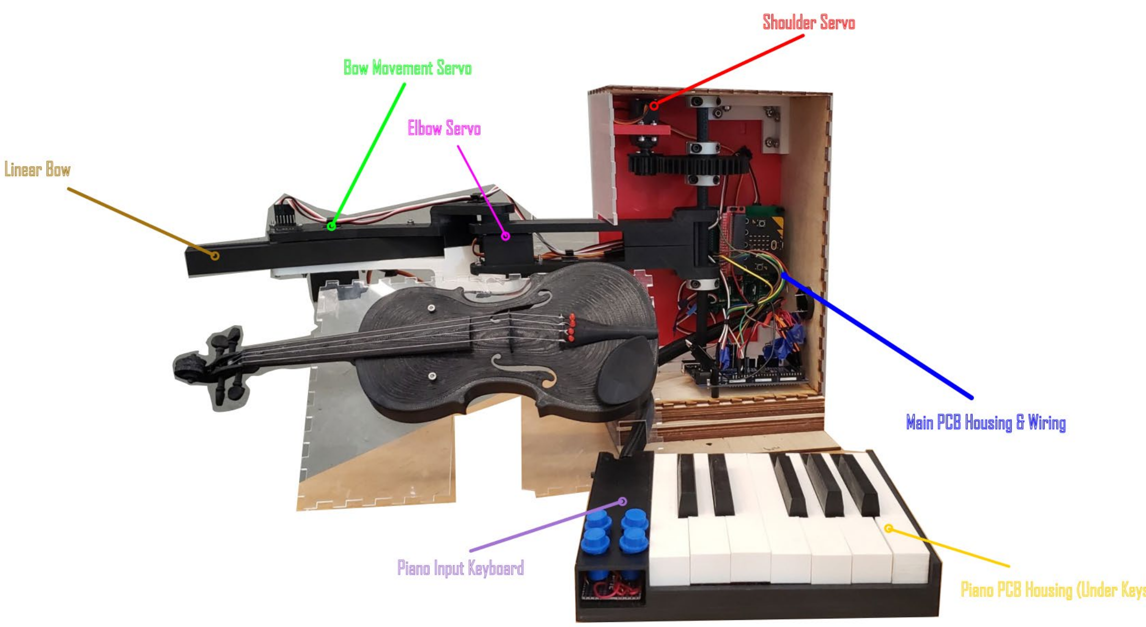


Figure 11: Mechanical Overview of final product.

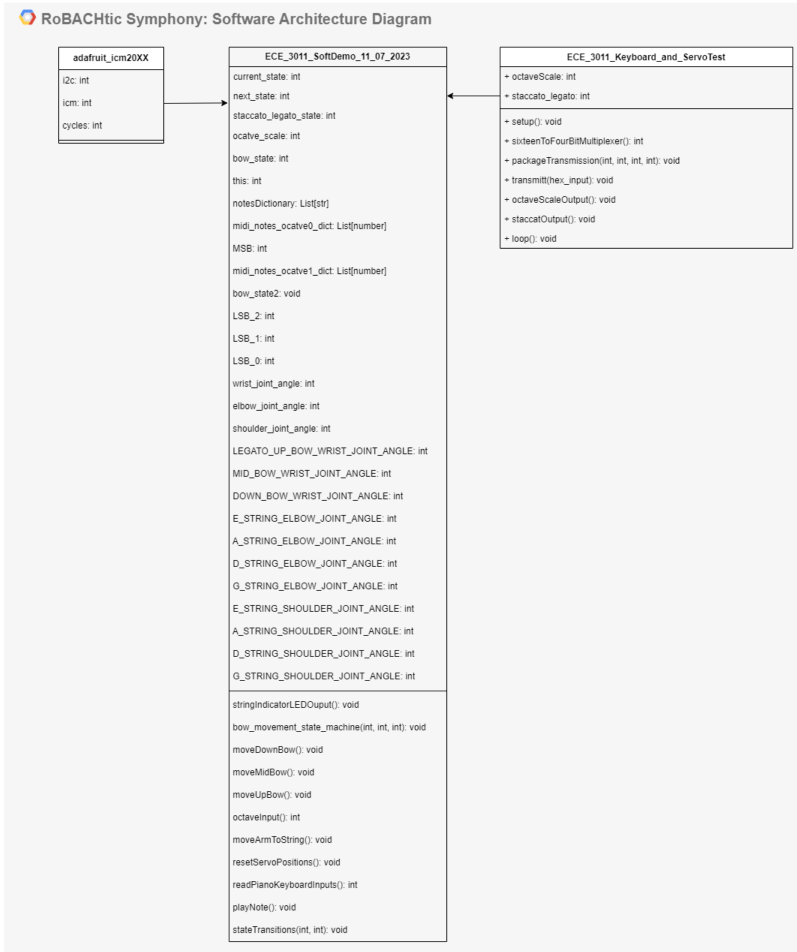


Figure 12: UML Software Architecture Diagram

Decimal	4-Bit Binary	State Note Name	String Name
0	0000	Idle	XX
1	0001	C	G
2	0010	C#/Db	G
3	0011	D	D
4	0100	D# / Eb	D
5	0101	E	D
6	0110	E# / Fb	D
7	0111	F	D
8	1000	F# / Gb	D
9	1001	G	D
10	1010	G# / Ab	D
11	1011	A	A
12	1100	A# / Bb	A
13	1101	B	A
14	1110	XX	XX
15	1111	XX	XX

Decimal	4-Bit Binary	State Note Name	String Name
0	0000	Idle	XX
1	0001	C	A
2	0010	C#/Db	A
3	0011	D	A
4	0100	D# / Eb	A
5	0101	E	E
6	0110	E# / Fb	E
7	0111	F	E
8	1000	F# / Gb	E
9	1001	G	G
10	1010	G# / Ab	G
11	1011	A	G
12	1100	A# / Bb	G
13	1101	B	G
14	1110	XX	XX
15	1111	XX	XX

Figure 13: State Machine Tables which showcase all possible states from the respective first and second octave scales.

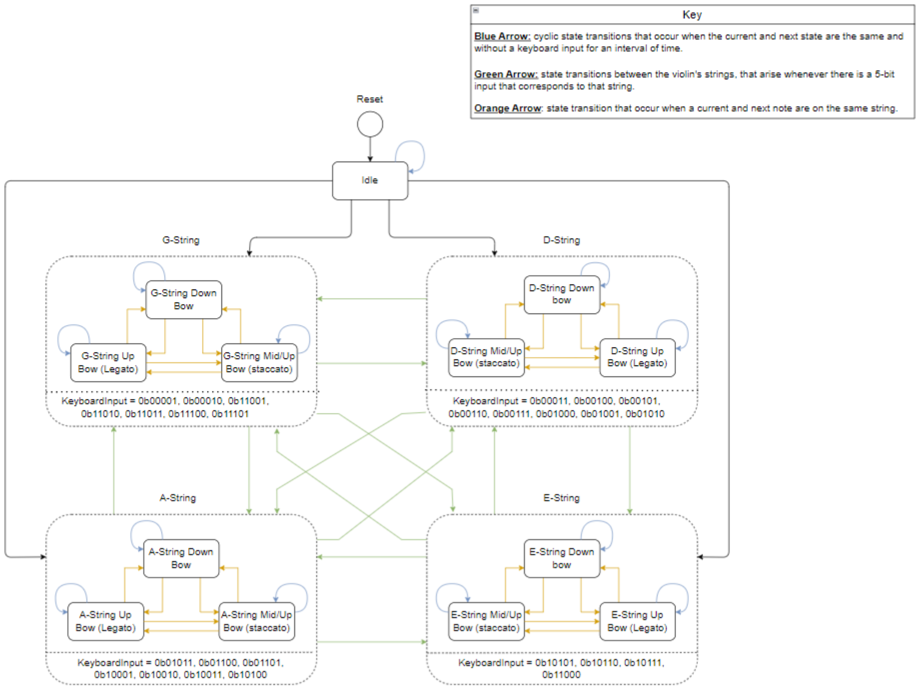


Figure 14: State Machine Diagram showcasing the robotic arm's physical state depending on encoded user input from the piano keyboard.

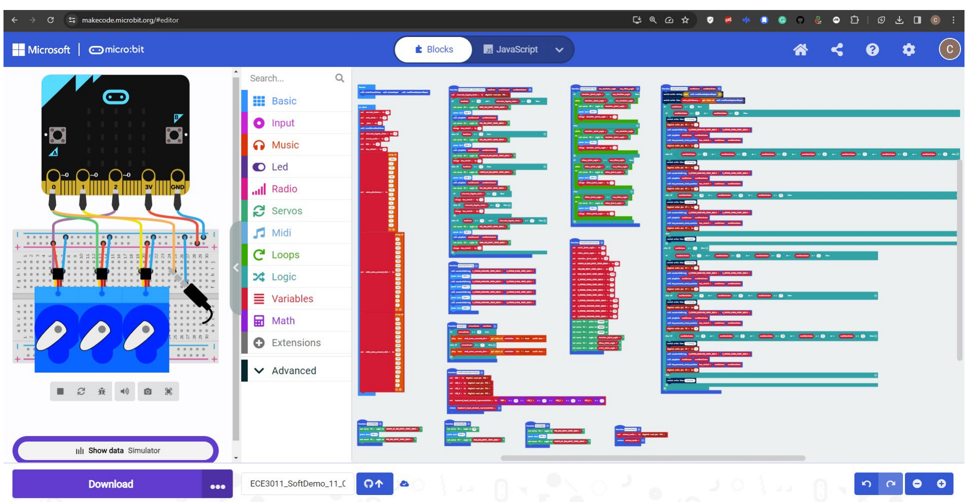


Figure 15: Snippet of the software program uploaded to the MicroBit, shown in block form.

The RoBACHtic Symphony robotic arm uses a piano-like keyboard to receive inputs to show instrumental movements with the arm based on the keys pressed in a sequential manner. It undergoes this by running individual subroutines per key pressed and not only vividly describes what motion a student should make when playing the note, but also which string is bowed and at what intensity. Concurrently it will also play the note and how it should sound when played correctly, overall teaching the student what motions they should be following and how to properly read/play violin notes.

4.1 Design Concept Ideation, Constraints, Alternatives, and Tradeoffs

The RoBACHtic arm currently needs to be able to accept IO input and use it to govern the movements and audible notes played on the arm itself. In its vanilla form the Micro Bit by itself will not be able to achieve the end goal of a musician robotic arm and requires an addition of circuit parts. With this, we can capitalize on using more servos for a large range of motion while communicating with the student the information that can be visually learned from the robot. A major tradeoff we had to make for the sake of not having extreme complexity that boiled down to a critical engineering decision was to scrap having the robot emulate a pure human arm, but rather a simplified model of an arm that still will teach the child how to play the violin.

Hardware Controller

a. The Micro Bit requires a GPIO expansion adapter that can fully release the capabilities of all the available pins that are on-board. We can use this to control all our desired outputs and feedback inputs at a much more organized level in terms of pin control.
b. We will be using the keyboard in a way where it will interrupt any ongoing processes to feel a lot more "responsive" since it would not make sense for a robot to continue its subroutines if the user miss pressed a key.
c. The main controller will take priority on all hardware except it will be overridden by only the keyboard which will send the arm to a "home" state before executing further.
d. As an output, we will incorporate an LED per string on the violin to light up when it is being "bowed" in essence perfectly sequencing the strings played by an LED pattern.

Keyboard

a. The keyboard will be 3D printed to capture the essence of being an "elementary" teaching tool that not only seems more appealing to younger students but allows us to open-source other designs that are used for similar purposes. It will carry internal sensors as each key requires a toggle that will be tactile pushbuttons, this will be utilized through the Micro Bits I2C bus as this allows us to incorporate a IO expander chip to effectively maximize digital input capabilities.
b. This will make it easier for the keyboard and hardware teams to work on their individual portions of the project since they just need a connector between the keyboard and main hardware controller as it will follow digital logic.

c. Mechanically, it will ultimately resemble a keyboard of moderate size that will send digital IO to the main controller board.

Audio

a. We will use an external 0.5W speaker to audibly express the notes being played in our project. This will allow us to have full DSP control over how we want to have the audio sound and at varying intensities since we can control that through software.
b. We strayed from using other options such as piezo speakers since they do not capture the “highs” that we are hoping for as piezo speakers have a more “whiney” noise.
c. Instead, a class D Monoblock amplifier circuit will be utilized that will capture PWM signals from the Micro Bit to output the wanted frequency sounds as we cannot output AC waves from a micro bit.

Power

a. For the overall power supply that will be converting the 120VAC from the wall outlet to 6V at 2 amps through a DC barrel jack power transformer.
b. This will save us from having to constrain ourselves to meet a certain power limit or stay under a certain threshold that is reasonable which allows freedom of creativity when designing and lessens the load on the agile schedule.
c. Instead, the circuit has incorporated step down voltages for all components on the system using LM317 voltage regulators. This feeds proper voltage and current to every part of the circuit.

Robotic Arm

a. After careful consideration for how a violin is played, we decided to have three joints that control the arm's movement to show how a violin should be properly played. The main driving joint will select the string that is to be bowed as it will control the semicircle path of the bow along the strings.
b. The second joint will control whether the bow should be physically touching the string or hovering above it as some note's sequences require successive play.
c. The third joint will be a visual addition that will keep the bow perpendicular to the violin and require a feedback sensor to maintain that perpendicular look. The reason we have gone with this is because to properly play the violin it is a necessity that the bow does not seem to “arc” away from the instrument, so we take priority in making it as realistic as possible.
d. The overall movement of each joint will be controlled using servos as they can have up to 0.5 degrees of accuracy, which is perfect for this application.

e. Gear boxes have been discussed if the need arises per the weight distribution of the arm which can remove the stress and keep the accuracy of the servos.

4.2 Engineering Analyses and Experiment

Design Analysis

a. Hardware controller – Will sum up all the different components towards the middle of the design phase and then incorporate them into a system design for the main controller. Initially we were going to use the IMU to serve as the main controller for feedback and motion but instead have changed that application into a feedback “checker” that just serves as verification of correct general movement with loose thresholds.
b. Keyboard – Open-source a variety of unique designs and bit sending methods to yield the most optimized for our requirements and least time consuming. Initially we were thinking of capacitive touch sensors but decided digital logic was a lot more time saving and reasonable through pushbutton switches.
c. Audio – Pre-filtration of audio notes to maintain clarity pre-processing through the Micro Bit. We have strayed from this since the Micro Bit cannot output DSP modified waves through its analog channel at a sufficient speed or precision so we decided to use a amplifier that take PWM signals from microcontrollers and turns them into audio that can fit our needs.
d. Power – Step down voltage regulators from main source of premade power transformer at a stable 7V 2A.
e. Robotic Arm – we will be using PVC pipes and connectors to simulate the movement that the robot should take and section off what portions of the diorama should be made the modular portions and what requirements we need to follow. We will slowly swap the PVC piece by piece with design joint ideas until we reach a satisfactory design. We have since made laser cut models using acrylic to simulate the movement of the arm which heavily impacted the mechanical design entirely since we learned that the shape of the bow arm must make clearance with the box itself to move the way we want it to.
f. LED lights – We will be using four LEDs to light based on the intensity of the note played. Additionally, sixteen LEDs on the Micro Bit will be used to simulate the finger locations of the notes needed on an actual violin. We have also since been working on a second application of LEDs where we will utilize the micro bit LEDs to display finger placement on the violin strings to play certain notes. It greatly helps with the teaching experience.

Prototype testing

a. Hardware controller – For the hardware controller we will be capitalizing the use serial communication to determine not only what portions of the program are being executed in the hardware controller but also at what length and provide live feedback to help with software development.
b. Keyboard – To test the keyboard we will be directly using it with a logic analyzer or LED's as well as a pull-up configuration to test individual keys post-model.
c. Audio – our DSP team will be focusing on filtering output signals to reach high accuracy of tone and minimal noise for the end user.
d. Power – An oscilloscope and multimeter node testing will provide information as to where problems are occurring post-simulation after different models in PCB and software have been created and tested. We will also breadboard everything and probe test the nodes after a simulation through Multisim.
e. Robotic Arm – A testing program that runs through every subroutine and compares it to a real musician playing that note will be the ultimate test to vividly see the accuracy and changes required within the software to yield the proper mechanical movements.

Risk Reduction

a. *Mechanical*
    a. Created many 3D renditions through various SolidWorks physics simulations in order to meet project requirements.
    b. Documentation created over gearbox implementation for smooth servo movement and reinforce weight of the arm not being a risk when moving fully extended weight.
    c. Created a laser-cut acrylic bow movement model with wooden components in order to isolate movement requirements in design. Along with functionality verification that our idea works to hit all strings/notes.
b. *Electrical*
    a. Breadboarded and tested servos that will be used for the final project through microcontroller analog bus. Also taking important note of the full capabilities and limits of our servos such as stress ratings and accuracy.
    b. Multisim simulations for node voltages and proper functionality of segments of circuit.

c. Breadboarding final electrical sub system to individually test functionality of packages that were needed for project.
d. Consulted Kevin from ECE parts shop to discuss PCB design and logic behind components/layout.

c. *Software*
    a. Created a top-level UML diagram of how all parts of program will interface and interact based on project requirements.
    b. Used top-level UML to create an entry draft state machine that was discussed and revised in terms of sensor communication and mechanical output motion timings.
    c. Created a final draft of state machine and Git repository for coding/project that will be able to see the changes between current programs and reasonings behind changing.
    d. Implemented software functionality tests using serial print statements within programs on both microcontrollers (MicroBit and Arduino Mega).

4.3 Codes and Standards

Georgia Standards of Excellence for K-8 Computer science and Music arts were followed such as:

- *Empowered Learner* – Develop and apply keyboarding skills, utilizing current technology.
- *Innovative Designer and Creator* – Modify, remix, or incorporate portions of an existing program into one's own work, to develop something new or add more advanced features.
- *Creative Communicator* – Creating original works or responsibly repurpose or remix digital resources into new creations.
- *Creating* – Create rhythmic and melodic motives to enhance literature. Compose music within an octave scale in simple meter notes, quarter rests, barred eight notes, half notes, dotted half notes, barred sixteenth notes, whole notes, whole rests, dotted quarter notes, single eight notes, eight rests, triplets.
- *Read and Notate Music* – Read, notate, and identify, in various meters, iconic, and standard notation.

U.S. National Electrical Code (NEC): AC power wiring must conform to it.

Engineering Standards

- Since the end user is a child in 5th grade, we have strayed away from mechanisms that could possibly hurt the child being of high speed or considerate force.

- Mechanically, we strayed from linear actuators to improve the building experience in terms of learning and safety as now we are able to control the torque/speed of all moving parts using gearboxes.
- Electronically we want no exposed wires which led to designing the piano to be a part of the box that connects to the main body instead of being a wire-connected device that the user would have to calibrate.

4.4 Broader Impacts & Considerations

a. The top priority of a product being given to younger students would be safety.
b. The overall inclusion of autonomous moving parts could become pragmatic as some questions arise about what precautions are being taken to ensure there is not the possibility that a student can get hurt by the moving parts.
c. The design will incorporate a way to measure if one of the motors is torquing out in case there is some sort of obstruction in the way along with keeping all the teeth of the gears and electrical components covered by non-sharp plates with rounded off corners.
d. The modularity of the product helps with maintaining safety as not only can we minimize the number of parts that can be incorrectly installed but also there is no access to anything that could potentially hurt a student, such as the teeth of gears.

5. Schedule, Tasks, and Milestones:

Name: RoBACHtic Symphony											
Project: STEAM educational kit											
	Week Number										
Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
System Design	ALL										
PDR											
Software Design			Christoph	Christoph	Christopher						
Electrical Design			Christian	Christian	Christian						
			Victor	Victor	Victor						
Mechanical Design			Jeon	Jeon	Jeon						
			Christian	Christian	Christian						
Lesson Plan			Christoph	Christopher							
CDR											
Software Build						Christoph	Christoph	Christopher			
Electrical Build					Victor	Victor	Victor	Victor			
					Christian	Christian	Christian	Christian			
Mechanical Build					Jeon	Jeon	Jeon	Jeon			
					Christian	Christian	Christian	Christian			
Software Test								Christopher			
Electrical Test							Victor	Victor			
							Christian	Christian			
Mechanical Test								Jeon			
ntegration Phase 1: Software & Mechanical								Jeon	Jeon		
Integration Phase 1: Software & Electrical							Christoph	Christoph	Christopher		
ntegration Phase 1: Electrical & Mechanical							Christian	Christian			
							Victor	Victor			
Integration Phase 1 Testing								ALL			
Integration Phase 2: Software & System									Christoph	Christopher	
Integration Phase 2: Electrical & System								Victor	Victor	Victor	
								Christian	Christian	Christian	
Integration Phase 2: Mechanical & System								Jeon	Jeon	Jeon	
								Christian	Christian	Christian	
System Testing										ALL	
Final Inspection and Demonstration											

Figure 16. Master schedule showcasing the timeline of the STEAM educational kit project and the allocated responsibilities of each team member to each sub-system's design, build, test and integration phases. This was the final revision. This schedule was in line with what the team achieved.

<u>Current milestones the group has achieved are as follows:</u>

- We have created multiple PCBs that have been carefully crafted with all of the correctly calculated voltages and currents.
- Created a state diagram that is in the first few revisions that encompass the states the robot will need as well as the transition arcs.
- Devoted multiple days to fabricate a PCB in house with perf boards to hit the exact dimensions that will be needed for the piano box. Eagle PCB dimensions were unrealistic for the end user to do anything meaningful with.
- Robot components have been 3D printed and have been assembled and screwed for an end product.

<u>Tasks for the group:</u>

- Victor and Christian have breadboarded and prototyped everything to make sure we have a good product. We have been working with Jeon to make sure the Mechanical can incorporate well with the electrical to make sure dimensions fit. Everything was integrated well across subsystems.
- Christopher is working on the software side of the project. Has created working code that will incorporate all the needed libraries in Python that will make the end goal achievable.
- As a group, our project updates will need to have more a show tell aspect to them to showcase our newly done progress.
- We have finished all tasks available for the project. A working product was delivered.

6. Marketing and Cost Analysis

6.1 Marketing Analysis[3]

The burgeoning sector of educational robotics kits, as delineated by Fact.MR, is undergoing a dynamic expansion, with the global market poised to burgeon from a valuation of USD 964.1 million in 2023 to an estimated USD 2546.5 million by the end of 2033. This represents a compound annual growth rate (CAGR) of 10.2%. Within this fertile market landscape, the RoBACHtic Arm project emerges as a pioneering venture, uniquely positioned to capitalize on the intersection of science, technology, engineering, and mathematics (STEM) with the artistic nuances of music education.

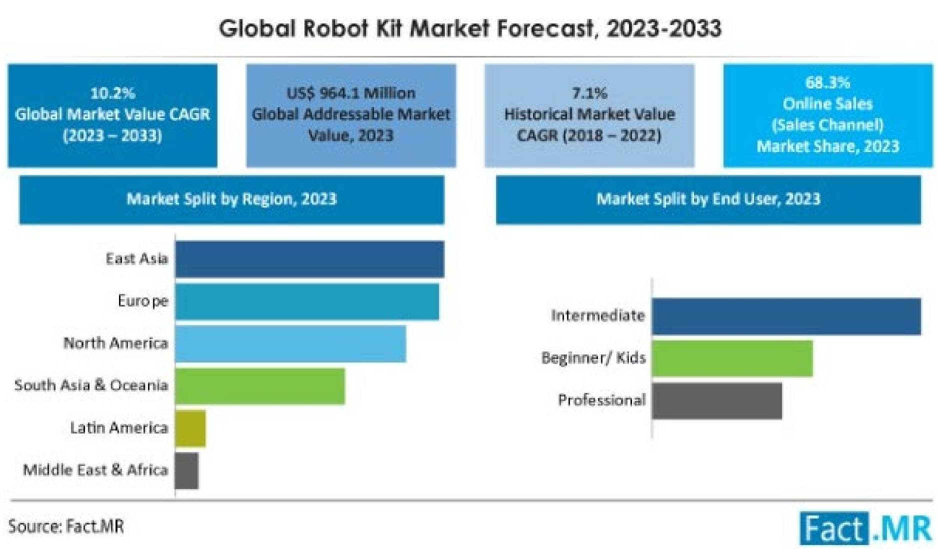


Figure 17. Summary of survey of robot kit market conducted by Fact.MR.

The impetus behind the surging demand for robot kits stems from a digital transformation that pervasively encompasses the educational sector, promoting the infusion of robotics to enhance hands-on student experiences in coding, programming, and engineering. With the expansion of companies on a global scale, there is a parallel increase in the need for a workforce adept in STEM skills. Educational institutions are responding by integrating robotics into their curricula, thereby augmenting the propensity for students to pursue skilled trades aligned with the evolving industrial landscape.

[3] https://www.factmr.com/report/robot-kit-market

The RoBACHtic Arm project is poised to carve out a unique niche by amalgamating the realms of music and science into a cohesive educational experience. This synthesis is a rarity in the current market, as a cursory examination of leading e-commerce platforms such as Amazon reveals a scarcity of STEM kits that concurrently cater to the educational needs of both science and music.

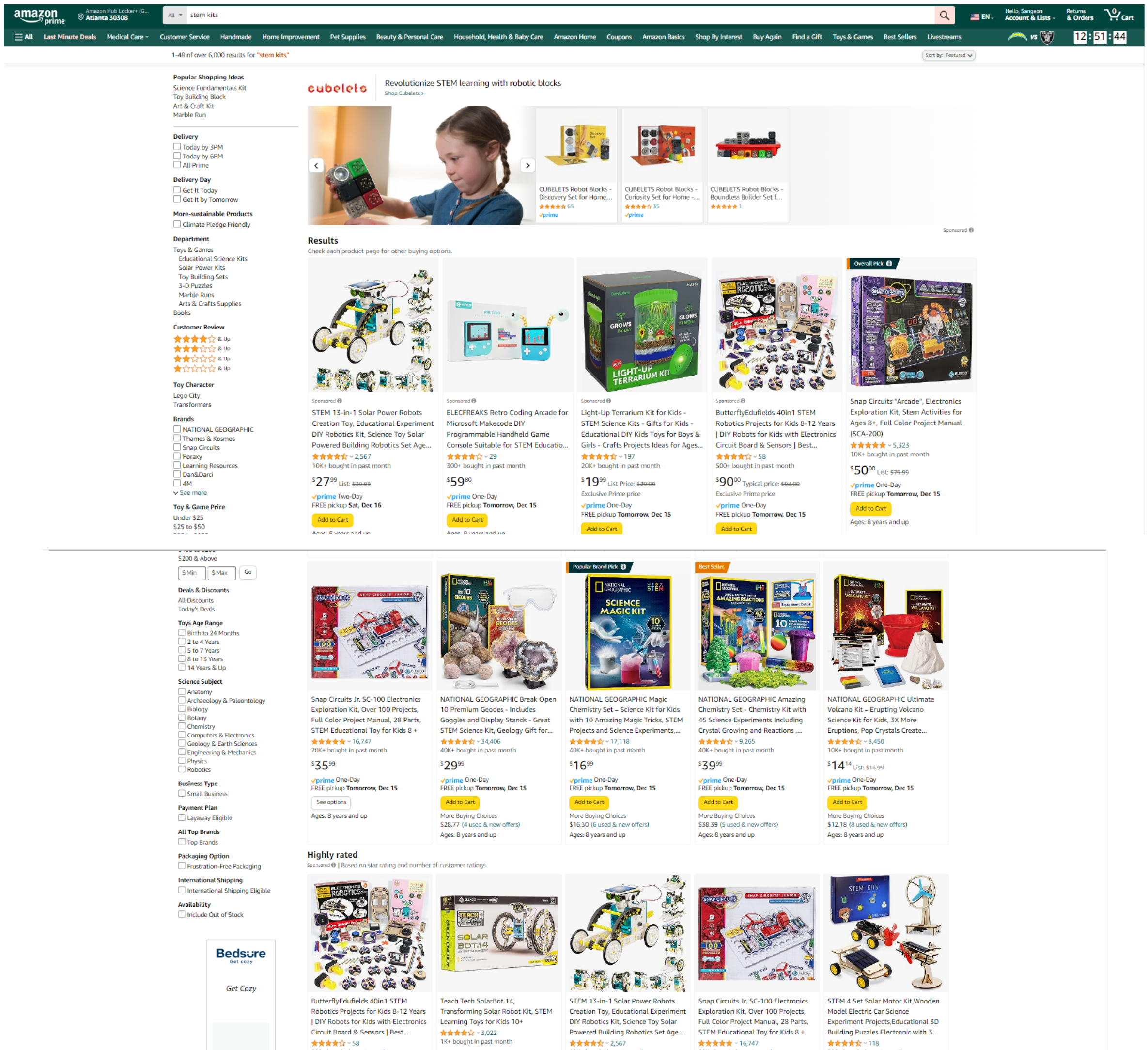


Figure 18: Screenshots of the first page resulting from a search with the keyword 'STEM kits' on Amazon

The existing market for STEM kits, as per the provided Amazon search screenshot, showcases a plethora of kits focusing on various scientific principles and coding exercises. These range from solar-powered robots to terrarium kits, each contributing to a segment of the STEM educational spectrum. However, the integration of music education represents a significant void—a void that the RoBACHtic Arm project is strategically positioned to fill.

Here, the RoBACHtic Arm's differentiation strategy is grounded in its novel approach to education. By enabling students to compose music and engage with the scientific principles underpinning the robotics simultaneously, the kit provides a multifaceted educational tool that is at the forefront of educational innovation. It offers a practical application of science through the creative process of music composition, which can deepen the student's understanding and retention of STEM concepts.

Considering the growth trajectory of the educational robotics kits market, the RoBACHtic Arm stands to not only capture a share of the existing market but also to expand it by attracting a demographic interested in music education. Its market entry strategy should emphasize this dual-educational potential, tapping into both the existing STEM education market and the music education industry.

6.2 Cost Analysis (Budget)

Material Costs

- Servos (4) = 23.99
- PLA Printed Frame + Packaging = 9.99
- Adafruit IMU = 19.95
- IO Decoder = 7.99
- Microbit = 17.95
- Arduino Mega = 48.97 (negligible as final product will work only on MicroBit)
- PCB's = 4.99

Additional Costs

- Cabling = 4.99
- PCB Components = 6.99
- Shaft Collars = $4.99
- DC Power Supply = 4.99

Labor Costs

- Software Engineer = Hours works (65) x Hourly Salary ($45)
- Electrical Engineer (2) = Hours works (65) x Hourly Salary ($54)
- Mechanical Engineering = Hours works (65) x Hourly Salary ($49)

Total Cost: $158.80 + $13,130 = $13,285.80

Selling Price and Explanations

Assuming 500 units sold over 5 years with a need of 20% for testing and assembly of the total material costs.

Assuming 25% for additional expenses

Assuming 30% desired profit for reasonability

Total Development Cost: $13,285.80.
Amortized Development Cost per Unit: $13,285.80 / 500 units = $26.57 per unit.
Material and Labor Cost per Unit: Total material cost ($155.80) plus an additional 20% for assembly and testing. $155.80 * 1.20 = $186.96 per unit.
Total Base Cost per Unit: $26.57 (amortized development cost) + $186.96 = $213.53.
Additional Expenses (Fringe Benefits, Overhead, Sales Expense): 25% of $213.53 = $53.38.
Cost Price per Unit: $213.53 + $53.38 = $266.91.
Desired Profit Margin: 30% of $266.91 = $80.07.
Suggested Selling Price per Unit: $266.91 (cost price) + $80.07 (profit) = $346.98 per unit.

Our kit could compare to the current pricing of the VEX robotics systems as our Microbit controller could be able to be used for a wide variety of projects especially since we have a pinout on our PCB. The only main difference between the two would be that fact that VEX has a lot more "sandbox" capability to make more open ended projects.

https://www.vexrobotics.com/exp

7. Project Demonstration

During our presentation of the robot, to best show our working product, we had multiple ways of demonstrating our robot and its abilities to the audience. To demonstrate we …

- Played all 12 piano keys, showcasing their capability of being pressed and outputting unique audio (note frequencies) from the MicroBit's speaker for both octave scales.
- The robotic arm moves to the correct string position depending on the piano keyboard input.
- The octave up and down buttons switch the set of notes that can be played.
- Used the four bottom left buttons to showcase the change in violin playstyle.
- Showed how the PCB from the musical keyboard integrated with the PCB inside the robot box to allow the desired change musical note states.

These forms of showing our robot in action were effective in showing to the class that this robot could capture the attention of a child and show them how the arm would move to different strings and can stay on a string but with a different note that sounds unique to others. There were update to the specifications that was not fully demonstrated would be the staccato and legato commands from the piano keyboard. There were a few features specifications that was not fully demonstrated, such as the staccato & legato button controls due to lack of time, turning on the LED corresponding to the violin string, and configuring the class D audio amplifier & speaker. The latter two features we had spend a great deal of time working on it, but ran into many debug and setup challenges with using the MicroBit. When connecting all four LEDs to the MicroBit, only two were capable of accurately flashing upon a new string movement transition. The class D audio amplifier was difficult to configure with the MicroBit's python library.

Documentation:

- **YouTube Demonstration video:**
    - https://studio.youtube.com/video/xMAuhqyGBg8/edit

- **Github Links:** (access to call software programs developed throughout this project)
  - https://github.com/BellLabsEra/RoBACHtic-Symphony-Microbit-Code
  - https://github.com/BellLabsEra/RoBACHtic-Symphony
- **Google Drive Folder:**
  - https://drive.google.com/drive/folders/1wq_gFr0jehypxX68gxPW9Vy_XzZYNBAQ?usp=drive_link

Mechanical Module:

- Verified that the 3D printed, and laser cut parts were properly size and could interface/be connected to the electrical components.

- Tested all through holes using allen keys as placeholders to ensure that all frame bolt holes were properly positioned and drilled correctly to mount everything.

Electrical Module:

- Created a breadboard prototype of the main and piano schematic.

- Validated that the PCB passed through ERC checks

- Multimeter tested the soldered PCB and perfboard, ensuring that the is electrical connectivity

Software Module:

- Verified the software functionality of the electrical inputs and outputs are correct by using serial print statements from the microbit and Arduino Mega's serial ports.

- Iteratively tested and verified that the robotic arm's servos move in a smooth manner (incremental time steps between setting servo position) to the correct position on each violin string.

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8. Conclusion & Current Status

This final analysis of the term project is a revised version of the CDR document. The aim of this revision of the CDR was to account for all the changes that have occurred since the critical design review. A lesson plan was created for what the project hopes to achieve in allowing a child to connect with music and technology. This objective drives the overall function of the robotic arm and keyboard. To make this objective a reality, as a group, an idea had to be narrowed down for the project, and roles had to be divided, corresponding to what each member believed themselves to be most proficient in. For the past months we have devoted all our time to delivering this robot to be as functionable as possible

The roles for each subsystem were as follows: Christian and Victor were assigned to the Electrical systems, Christopher was software, and Jeon mechanical. We collaborated on specific aspects of the projects, such as the state diagrams, to see if we were all on the same page. Ultimately, Christopher made a state diagram that was feasible for the project. Two sets of eyes are more beneficial than one, as peer reviewing is crucial to the industry. Upon finishing this document and finalizing design parameters, as a group we were always able to hit deadlines and there were never any missed deadlines. Other than the necessary right shifting needed for a project of this size. We would not have done anything differently than what was done because in the end a functioning robot was delivered and was functionable. As the semester ends and with the completion of this paper, we are now able to put this robot project to a close and take away valuable group experience that reflects how we will be in the workforce.

9. Leadership Roles & Contributions of Team Members

9.1 Leadership Roles

- Software Master – Christopher Semali
  - Design software architecture, lead code development, manage GitHub repo, ensure clean code & documentation, serve as the database admin whenever storing experimental sensor and audio data, and create Unit tests, issue tickets in Jira.
- Electrical Mage – Victor Alfaro
  - Takes charge of most aspects of the electrical system. Design electrical components to the system that match with the integration of the overall system.
  - Design the PCB for the system once a working design is established and simulated. A second PCB was needed, then design and create once more.
- Mechanical Wizard – Sangeon Jeon
  - Do a 3D modeling for each part with SolidWorks
  - Simulate the mechanical designs before building
- Integration/testing Squire and Mechanical/Electrical Helper – Christian Santiago
  - Works with all teams to ensure compatibility between all parts of project.
  - Edge-case tester and analyzer ensuring safety for end-user
  - PCB integration in designing and simulations
  - Sensor Inputs and outputs tester

9.2 Contributions of Team Members

For each team member, describe the contributions to the project. The list of contributions should be associated with all aspects of the project including contributions to writing assignments as well as contributions to design, build, and testing of the prototype.

Sangeon Jeon

- Design the mechanical parts
- Build the mechanical parts
- Reflect the feedback from the testing
- Reflect the feedback from the integration processes

- Has put in a tremendous amount of time created and updating SolidWorks designs of the mechanical parts of the overall project.
- Consistently laser cut wood boards to have the correct design and dimensions for the robot.

Christian Santiago

- Works with all team members to provide “flow” between systems when integrated together in a preemptive manner.
- Will provide a helping hand in all categories and document status of all team groups for better end-product integration.
- Communicates any rising needs to software/mechanical/electrical teams.
- Heavily tests edge-cases, overall functionality, and troubleshoot mechanical/electrical/software aspects of final product.
- Spent a few days creating perf boards with Victor Alfaro.

Victor Alfaro

- Design the electrical system.
- Make sure there is a seamless integration between the Mechanical and Electrical systems.
- Will have a design a PCB specific to the system and if there is a need for a second PCB, then this too will be designed.
- Have created two PCBs with Christian Santiago since we are both Electrical wizards.
- Collaborated with other teammates on various other parts of the project such as software to give input, albeit small.
- Spent days with Christian Santiago working on creating perf boards to have all electrical connections correct.

Christopher Semali

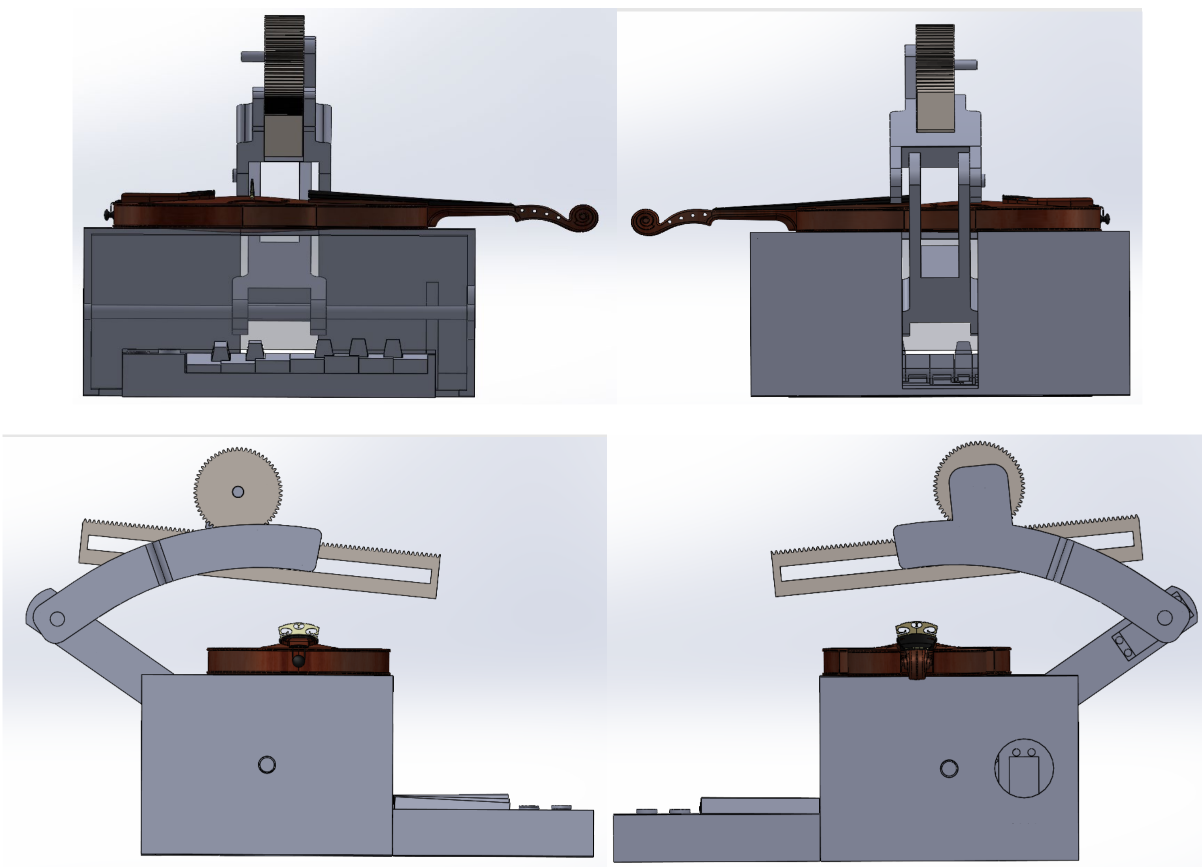
- Design the software architecture and lead the software development process.
- Integrate software into electrical and mechanical subsystems.
- Created a Github that would allow for document files. Created it as a final spot as teams is the primary

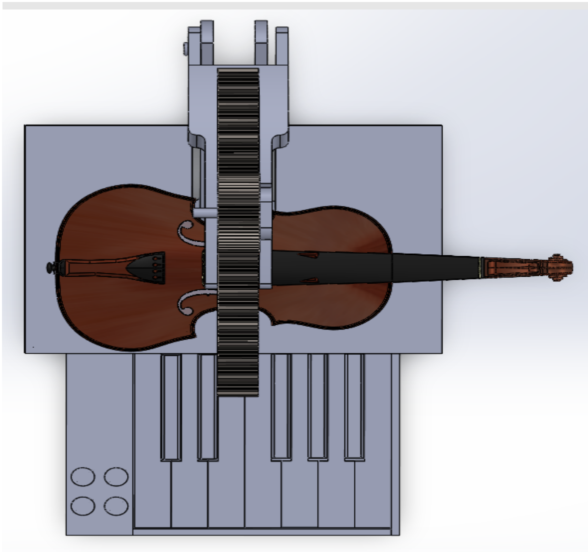
10. References

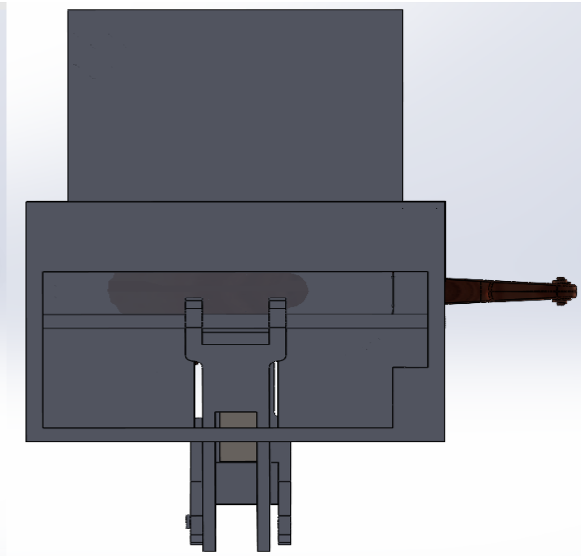
Include a list of references for all items cited in this report. Use IEEE style format. You should include references for background information, similar products or projects, items you purchased, cost information, and any other information that you have found and used for your project. You may have additional items not specifically referenced but which you consulted. If you do, put these in a separate section called "REFERENCES" in the form of an unnumbered list.

Appendices

<u>Mechanical Overview at different angles:</u>



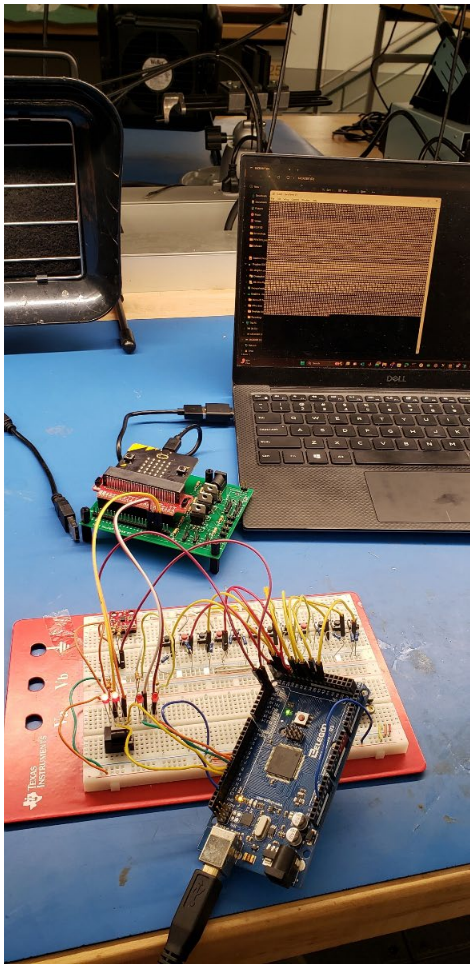


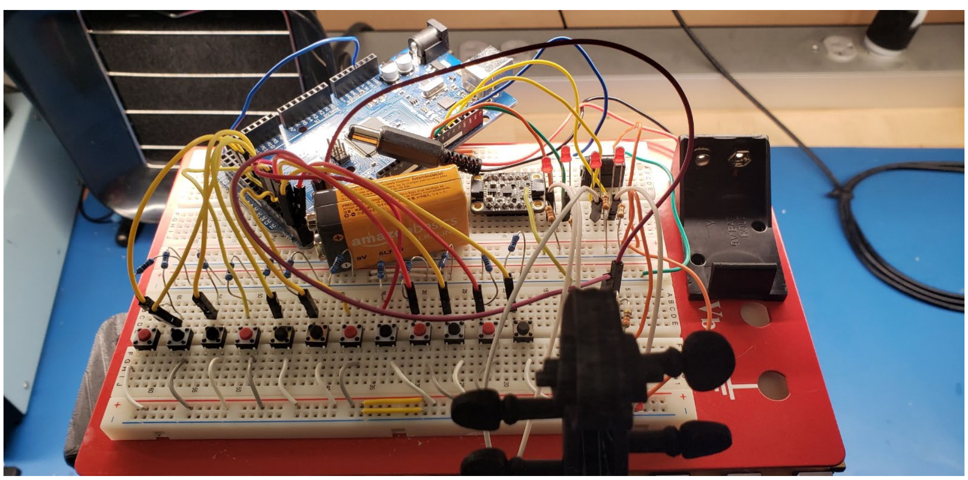


Final Bill of Materials:

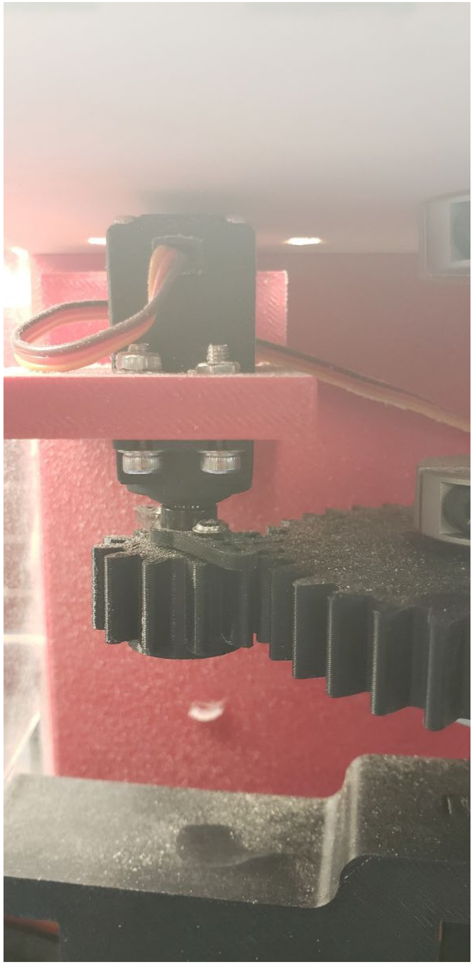
Vendor Part Number	Link to data sheet	Quantity	Unit cost	Total Cost	ECE Stock Y/N	If not in stock, has request to buy parts been sent to Kevin/James Y/N	Obtained Parts Y/N
https://tinyurl.com/mryy78sf	https://www.towerpro.com.tw/product/mg995/	1	19.99	19.99	N	N	Y, obtained
4554	https://learn.adafruit.com/adafruit-tdk-invensense-icm-20948-9-dof-imu	1	14.95	14.95	N	N, ordering post CD	Y, obtained
1597-1770-ND	cpc&utm_campaign=PMax%20Shopping_Product_Low%20ROAS%20Categories&ut	1	6.9	6.9	Y		Y, obtained
BOB-11044	05d1.pdf?_gl=1*r3suf*_ga*NTMyMTc4MDkwLjE2OTI3NTg5NTU.*_ga_T369JS7J9N*	1	9.5	9.5	N	N	Y, obtained
https://tinyurl.com/2p8jt4fr	N/A	1	9.99	9.99	Y		Y, obtained
296-33529-5-ND	l=https%253A%252F%252Fwww.ti.com%252Fgeneral%252Fdocs%252Fsuppproduc	1	3.69	3.69	N	N, ordering post CD	N
497-1575-5-ND	document/datasheet/group1/a0/db/e6/9b/6f/9c/45/7b/CD00000455/files/CD0000	3	0.77	2.31	N	N, ordering post CD	N
1497-XCMDK12D-ND	https://www.sunledusa.com/products/spec/XCMDK12D.pdf	4	0.34	1.36	Y		Y
PRT-10811	pdf?_gl=1*kwm0xb*_ga*NTMyMTc4MDkwLjE2OTI3NTg5NTU.*_ga_T369JS7J9N*MT	1	1.05	1.05	N	N, ordering post CD	Y, obtained
N/A	N/A	1	2	2	N	Y	Y, obtained
2223-TS02-66-60-BK-160-LCR-D-ND	https://www.cuidevices.com/product/resource/ts04.pdf	14	0.18	2.52	N	N, ordering post CD	N
			Total	74.26			

Breadboard Prototype implementing the Piano schematic, excluding the GPIO expander:

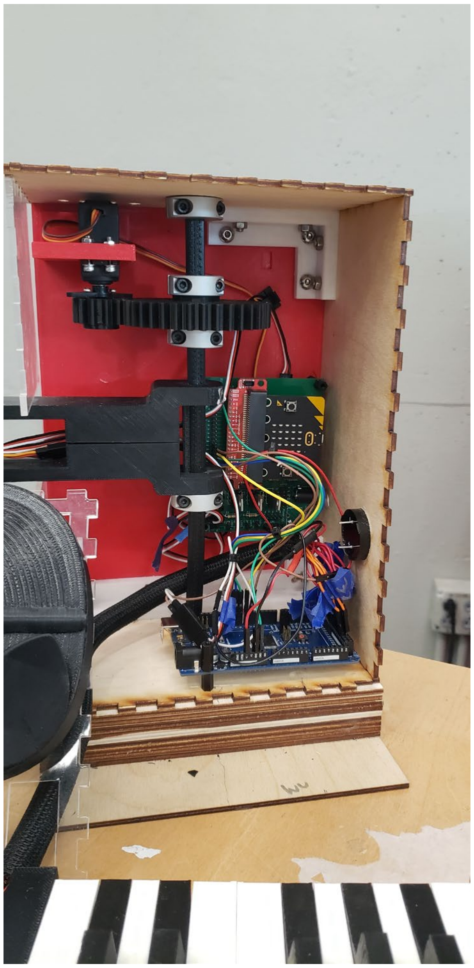


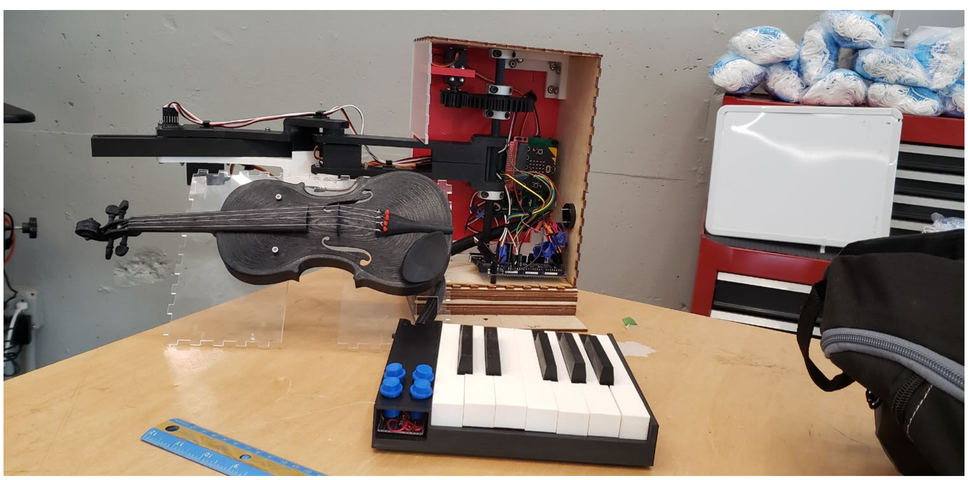


<u>Image of the shoulder gear driving module (</u><u>internal to the electronics box):</u>



<u>Pictures of the final robot product:</u>





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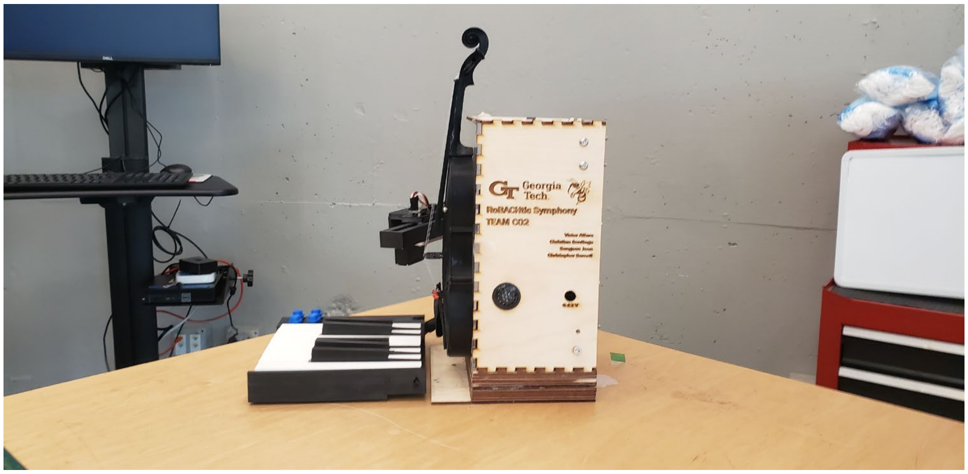
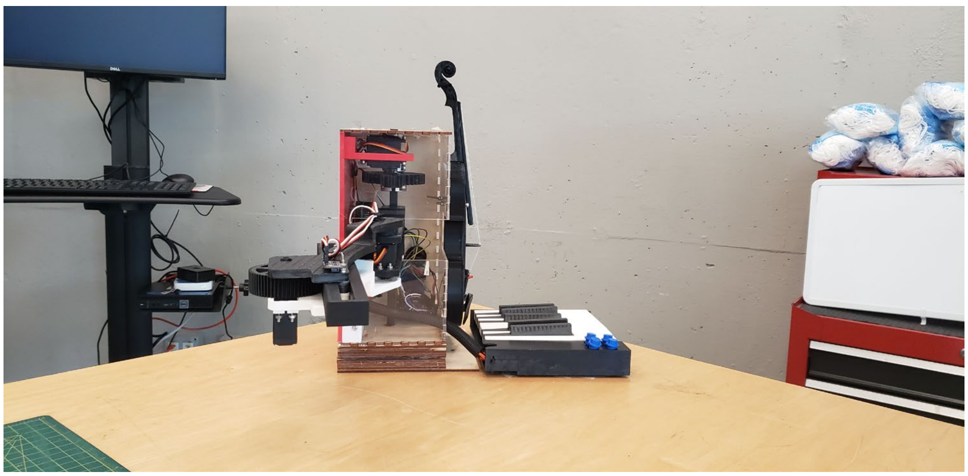
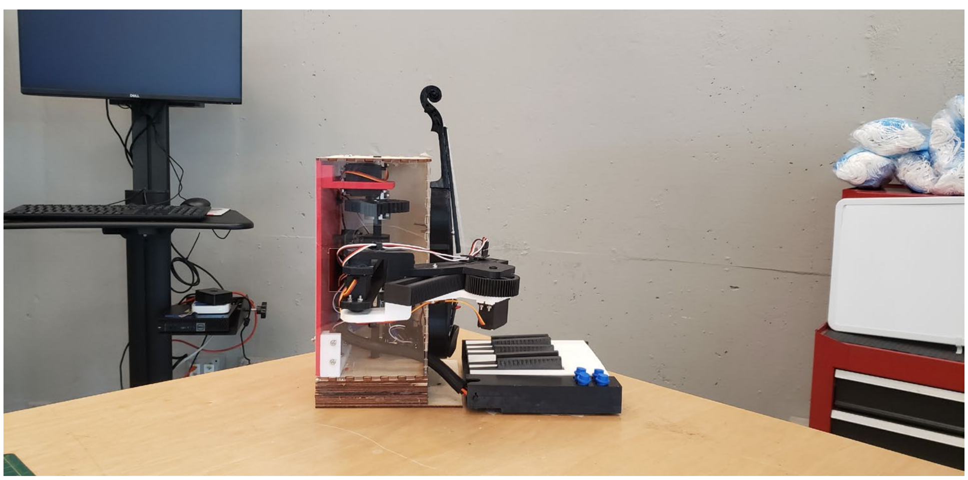
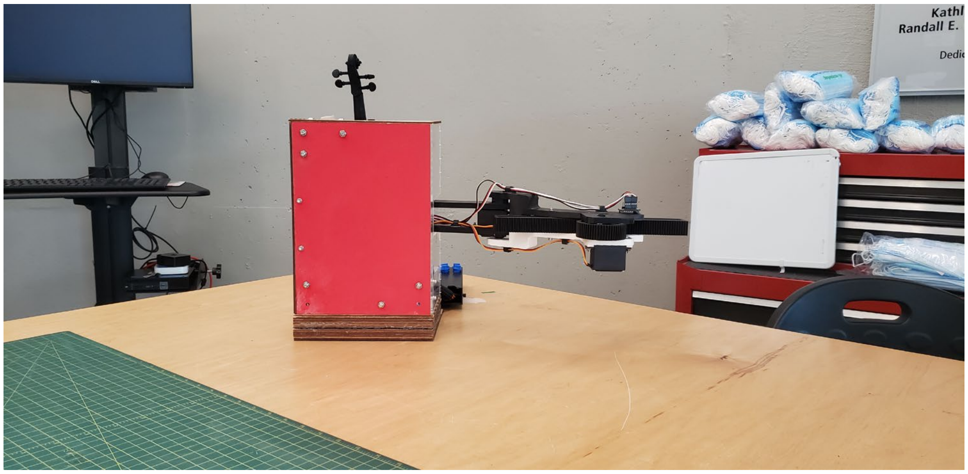
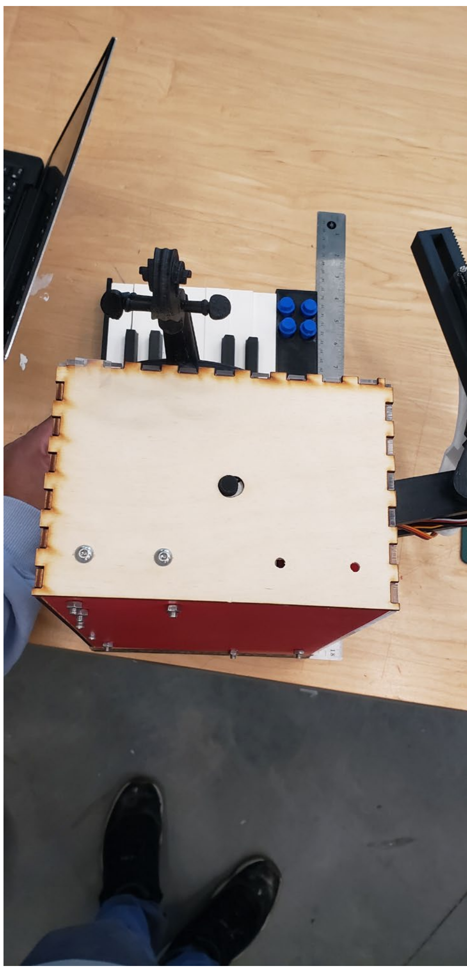

Georgia
Tech
RoBACHtic Symphony
TEAM C02









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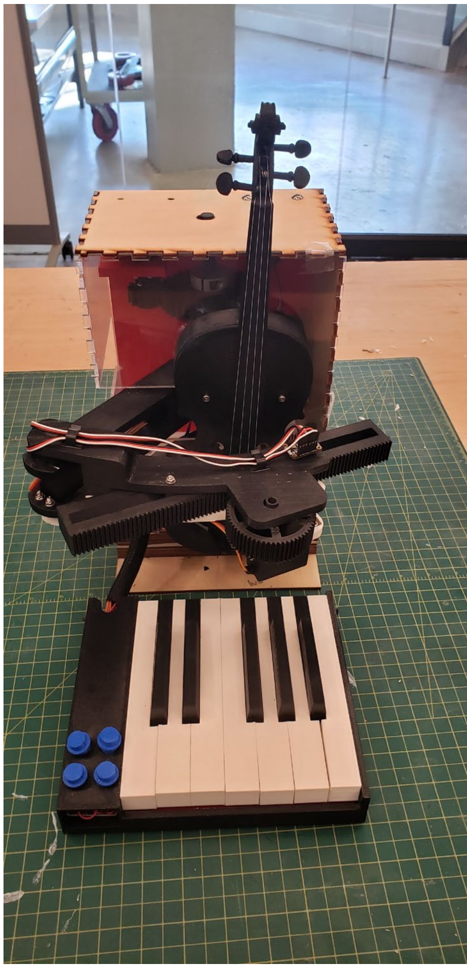


Lesson Plan

Part 1:

Overview

- Title of the unit: **RoBACHtic Symphony**

- Target grade: **5th Grade**

- Problem statement:
  - How do you determine a violin's bow movement, placement, and techniques (bow posture) while playing a musical piece with a variety of notes?
  - How does a computer handle sound without any resonating chamber, strings, and pipes unlike any other traditional instruments: wind, percussion and string instruments

- Learning objective
  - Computer Science
    1) CS1: Students will be able to distinguish between analog and digital and understand that digital data are much easier to process with the electronics.
    2) CS2: Students will be able to realize the given machine is a basic synthesizer.
    3) CS3: Students willl be able to develop the idea that technology could promote the aethestic activities.
  - Music
    1) M1: Students will be able to understand the importance of bow movement, position, and techniques (bow posture).
    2) M2: Students will be able to determine bow movement, position, and techniques (bow posture) when reading sheet music.
    3) M3: Students will be able to interpret bow position notation in sheet music.

Part 2: GSE Standards

- **Computer Science:**
  - ***Innovative Designer and Creator: CSS.IDC.3-5.4*** Use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.

    3. Modify, remix, or incorporate portions of an existing program into one's own work, to develop something new or add more advanced features.

Considering the inherent limitations of the machine, like requiring transition time between notes and playing just one string at a time, students are encouraged to develop inventive strategies to work around these restrictions, especially as the complexity of their chosen song escalates. Some viable approaches students might explore include:

1. Collaborating with traditional instruments, assigning the machine the sections that are less demanding.
2. Employing multiple machines simultaneously to circumvent the identified limitations.
3. Adapting the chosen song to accommodate the machine's specific constraints.

➢ ***Creative Communicator: CSS.CC.3-5.6*** Select and use the most appropriate platform, tool, style, format, and digital media to clearly and creatively express thoughts, messages, goals, or positions.

1. Create original works or responsibly repurpose or remix digital resources into new creations.
2. Communicate complex ideas clearly and effectively by creating or using a variety of digital objects.

Students will learn that the machine generates music by synthesizing pre-recorded violin sounds—pre-made digital resources—effectively engaging in a form of remixing. In this sense, they could express their emotions and thoughts by utilizing the digital resources composing the music.

❖ **Music**:

➢ ***Creating: ESGM5.CR.2*** Compose and arrange music within specified guidelines.

a. Create rhythmic and melodic motives to enhance literature.
b. Compose music (with or without text) within an octave scale in simple meter (e.g. quarter notes, quarter rests, barred eighth notes, half notes, half rests, dotted half notes, barred sixteenth notes, whole notes, whole rests, dotted quarter notes, single eighth notes, eighth rests, triplets).
c. Arrange rhythmic patterns to create simple forms, instrumentation, and various styles.

➢ ***Performing: ESGM5.PR.3*** Read and Notate music.

a. Read, notate, and identify, in various meters, iconic, and standard notation (e.g. quarter notes, quarter rests, barred eighth notes, half notes, half rests, dotted half notes, barred sixteenth notes, whole notes, whole rests, dotted quarter notes, single eighth notes, eighth rests, triplets).
b. Read and notate melodic patterns within a treble clef staff.
c. Read, notate, and identify standard symbols (e.g. repeat sign, bar line, double bar line, time signatures, crescendo/decrescendo, 1st and 2nd endings, coda, accent mark, accelerando/ritardando, sharp/flat).

Before the performance segment, students will engage in a brief instructional session where they will acquire basic knowledge on reading sheet music and understanding fundamental principles of music composition. This preparatory phase will empower them with a grasp on the majority of the music vocabulary listed below, with particular emphasis placed on a few crucial concepts. Upon completing practice sessions with the machine using a set of simple, pre-selected songs, participants will be tasked to create a piece of music that effectively complements the functions and features of the assigned machine.

❑ <u>Vocabulary</u>

- **Computer Science:**
  - **Analog** – A defining characteristic of data; analog data are stored in a continuous transmission of a signal. It is often contrasted with digital, which is how computers store and process data as a set of individual symbols.
  - **Event** – An action or occurrence recognized by software, often originating from the external environment, that may be handled by the software.
  - **Remix** – To change a set of code by adding or rearranging smaller code segments to create a different outcome.
  - **Sequence** – An ordered, step-by-step process of an action or event proceeding in a pattern.
- **Music**:

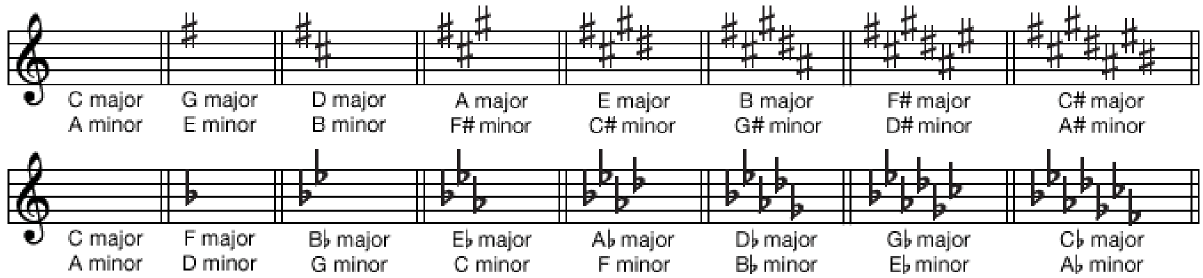
1. **Sheet Music Vocabulary:**
   - **Motive / Phrase / Period / Section** – units consisting a sheet music
   - **Bar line / Double bar line / Bold double bar line –** lines that separate units of a sheet music
   - **Repeat sign** – A sign that indicates a section should be repeated
   - **Note / Rest** – A music notation indicating the length of sound and silence e.g. barred notes, dotted notes, triplets

ITEM	NOTE	REST	VALUE (number of beats)
Whole note/rest	𝅝	𝄻	4
Half note/rest	𝅗𝅥	𝄼	2
Quarter note/rest	♩	𝄽	1
Eighth note/rest	♪	𝄾	1/2
Sixteenth note/rest	𝅘𝅥𝅯	𝄿	1/4

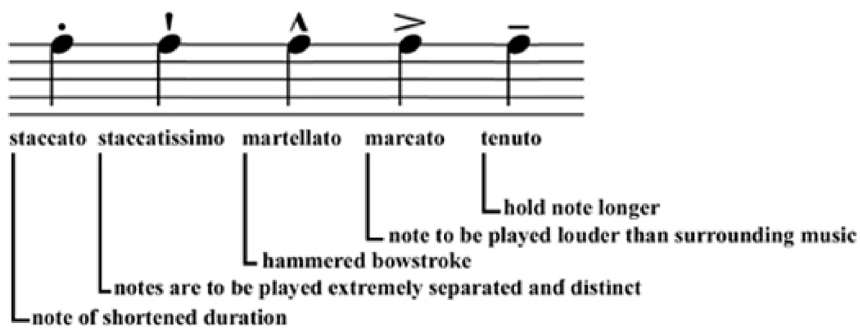
   - **Time signature** – A music notation indicating how many beats are in each measure

	time signature	beat unit	division of the beat
Simple Duple	2/4	♩ ♩	♫ ♫
Compound Duple	6/8	♩. ♩.	♪♪♪ ♪♪♪
Simple Triple	3/4	♩ ♩ ♩	♫ ♫ ♫
Compound Triple	9/8	♩. ♩. ♩.	♪♪♪ ♪♪♪ ♪♪♪
Simple Quadruple	4/4	♩ ♩ ♩ ♩	♫ ♫ ♫ ♫
Compound Quadruple	12/8	♩. ♩. ♩. ♩.	♪♪♪ ♪♪♪ ♪♪♪ ♪♪♪

- **Key signature -** the arrangement of signs on particular lines and spaces of a musical staff to indicate that the corresponding notes, in every octave, are to be consistently raised (by sharps) or lowered (by flats) from their natural pitches. e.g. sharp (♯), flat (♭), natural (♮)



- **Accent** – A music notation indicating a a louder dynamic and a stronger attack to apply to a single note or an articulation mark.



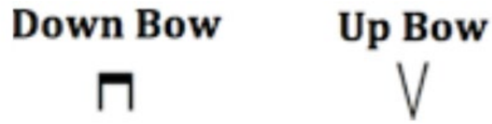
- **Dynamics** - A music notation indicating the variation in loudness between notes e.g. crescendo / decrescendo

Symbol:	*pp*	*p*	*mp*	*mf*	*f*	*ff*
Italian:	Pianissimo	Piano	Mezzo Piano	Mezzo Forte	Forte	Fortissimo

- **Tempo –** A music notation for the speed at which the composer wants a piece of music performed
e.g. accelerando / ritardando

Tempo	Definition	bpm
Largo	slowly and broadly	40-60
Adagio	slowly	66-76
Andante	at a walking pace	76-108
Moderato	moderately	108-120
Allegretto	moderately fast	112-120
Allegro	fast and bright	120-168
Vivace	lively and fast	168-176
Presto	exceptionally fast	168-200

2. **Violin Vocabulary:**
    - **Upbow / Downbow –** Direction of a bow stroke



    - **Legato / Slur –** A music notion indicating that the notes are played continously

Part 3: Lesson Plan

1. Lesson Overview (3-5 minutes):
    a. Brief introduction to the lesson and its objectives.
    b. Introduce the four-stringed Classical Orchestra instruments with a focus on the violin.
    c. Show examples of violin instrumentals in music and movie soundtracks to open their mind and ears to intentional hearing of these instruments in other musical environments
2. Understanding the Violin & Basic Music Theory (7-10 minutes):
    a. Discussion on violin strings and their corresponding open notes on sheet music.
    b. Introduction to the octave scale and essential music theory symbols and concepts: up-bow, down-bow, legato, staccato, etc.
3. Introduction to Sound Synthesis and Digital Music (7-10 minutes):
    a. Brief explanation of analog vs. digital data with a focus on sound.
    b. Introduction to sound synthesis: how digital devices like computers can generate and manipulate sounds without traditional instrument components.
    c. Explanation that the machine they will assemble is a basic synthesizer, showcasing the blend of technology with music.
4. Kit Assembly and Familiarization (10-15 minutes):
    a. Students read the instruction manual and assemble the educational kits.
    b. Explanation and identification of key components, with an emphasis on how each part contributes to sound synthesis and manipulation.
5. Practice & Debugging Session (15-20 minutes):
    a. Lead students in playing "Twinkle-Twinkle Little Star" using their kits.
    b. Support them through any debugging issues, ensuring their machines function correctly.
    c. Play a snippet of a classical piece from a famous movie or a piece that has been frequently reused and have students identify and notate the bow movements.
    d. Repeat the practice session with this piece, guiding students through the process.
6. Creative Composition & Peer Review (20-25 minutes):
    a. Instruct students to compose a short melody on a blank piece of sheet music, adhering to a rubric requiring at least five uses of bow notation, at least three unique notes, and a total of 10-20 notes.
    b. Have students play their composed pieces for a peer, who will provide constructive feedback based on the rubric.

Part 4: Pedagogical notes

Bow	By interactively observing proper bow techniques on a model violin, the student will be able to

Technique	make the connection between theoretical concepts and their application. This will strengthen their understanding and pattern recognition of bow movement, position, and techniques. **Tips for Educators:** Use visuals, demonstrations, and videos to illustrate the concepts effectively. Help train their hearing by engaging students with questions that make them distinguish different sounds based on the bow technique.
Remix	As the students write their sheet music, they will remix a musical progression. This creative process can help further develop the student's ability to determine bow technique when listening to any violin instrumentals. **Tips for Educators:** Use simple pieces to help students grasp the concept then gradually showcase more complex compositions in mainstream productions. Use demonstrations and music samples to help explain the significance of different bow positions on sound production.
Interpret bow notation in sheet music	Learning how to interpret bow notation in sheet music is critical to include a visual demonstration. By controlling the mechatronic arm when playing a sample piece of music, the students will gain a more intuitive audio-visual understanding of bow notation. **Tips for Educators:** Provide memorable sheet music examples with bowing notations (up-bow, down-bow, legato, staccato, etc.).
Understand Digital	Students should develop an understanding of how digital sound synthesis works and how it differs from acoustic sound production. They'll explore the concept of digital versus analog signals, learning how the machine they're working with synthesizes violin sounds digitally. **Tips for Educators:** Incorporate visual aids and sound samples that distinctly demonstrate the differences between digital and analog sounds. Facilitate hands-on activities where students can manipulate digital sound and immediately hear the results.

Item No	Description	Vendor	Vendor Part Number	Link to data sheet	Quantity
1	4PCS MG995 Servo Motors	Amazon	https://tinyurl.com/mryy78sf	https://www.towerpro.com.tw/product/mg995/	1
2	TDK InvenSense ICM-20948 9-	Adafruit	4554	https://learn.adafruit.com/adafruit-tdk-invensense-icm-20948-9-dof-imu	1
3	GPIO Expansion Board	Digikey	1597-1770-ND	n=cpc&utm_campaign=PMax%20Shopping_Product_Low%20ROAS%20Categories&utm	1
4	Sparkfun Mono Audio Amp	Sparkfun	BOB-11044	2005d1.pdf?_gl=1*r3suf*_ga*NTMyMTc4MDkwLjE2OTI3NTg5NTU.*_ga_T369JS7J9N*MT	1
5	Servo 3-Pin Extenders	Amazon	https://tinyurl.com/2p8jt4fr	N/A	1
6	PCB IO Expander	Digikey	296-33529-5-ND	url=https%253A%252F%252Fwww.ti.com%252Fgeneral%252Fdocs%252Fsuppproducti	1
7	PCB LM317T Voltage Regulator	Digikey	497-1575-5-ND	l/document/datasheet/group1/a0/db/e6/9b/6f/9c/45/7b/CD00000455/files/CD000004	3
8	PCB XCMDK12D LEDs	Digikey	1497-XCMDK12D-ND	https://www.sunledusa.com/products/spec/XCMDK12D.pdf	4
9	PCB DC Barrel Jack Adapter	Sparkfun	PRT-10811	2.pdf?_gl=1*kwm0xb*_ga*NTMyMTc4MDkwLjE2OTI3NTg5NTU.*_ga_T369JS7J9N*MTY5N	1
10	Printed Circuit Board	JLPCB	N/A	N/A	1
11	TS02 Pushbutton Switch	Digikey	2223-TS02-66-60-BK-160-LCR-D-ND	https://www.cuidevices.com/product/resource/ts04.pdf	14
12					

Tot

Unit cost	Total Cost	ECE Stock Y/N	If not in stock, has request to buy parts been sent to Kevin/James Y/N	Obtained Parts Y/N
19.99	19.99	N	N	Y, obtained from team parts
14.95	14.95	N	N, ordering post CD	Y, obtained from kevin
6.9	6.9	Y		Y, obtained from parts checkout
9.5	9.5	N	N	Y, obtained from ECE 4180 Lab
9.99	9.99	Y		Y, obtained from kevin
3.69	3.69	N	N, ordering post CD	N
0.77	2.31	N	N, ordering post CD	N
0.34	1.36	Y		Y
1.05	1.05	N	N, ordering post CD	Y, obtained from kevin
2	2	N	Y	Y, obtained from kevin
0.18	2.52	N	N, ordering post CD	N
:al	74.26			