SIMPLE
instruments

February 7th, 2019

Dr. Craig Scratchley
School of Engineering Science
Simon Fraser University
Burnaby, BC, Canada
V5A 1S6

Re: Requirement/Functional Specifications for Luminotes

Dear Dr. Scratchley,

The enclosed document provides requirement specifications for our Capstone project, Luminotes. The goal is to create a projection device which would be mounted over a piano that takes sheet music and illuminates the piano keys for the users to follow along. It will also provide accuracy feedback for the user's performance. Luminotes looks to provide a solution to users who wish to learn piano but struggle to read sheet music or prefer to play songs immediately. This device can also be a cost-effective introduction to learning piano and more powerful to use compared to equivalent learning methods, like YouTube videos.

This document looks to present the requirements and functionality of Luminotes through multiple stages of design. It will delve into the high level requirements before examining individually the software, hardware, firmware, and structural requirements. Finally, the Engineering, and Sustainability & Safety standards of our device will be discussed.
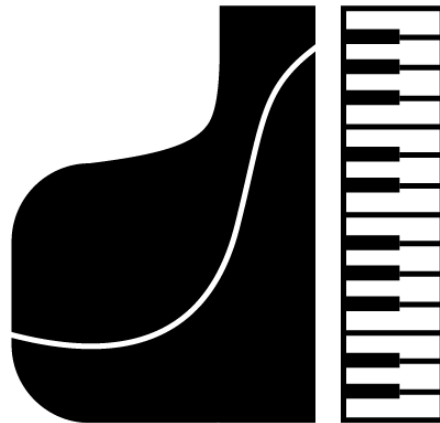
Simple Instruments is a company composed of six undergraduate engineering science students: Shahira A. Azhar, Caitlin Finnigan, Hsiao Chen Eldon Lin, Dayton Pukanich, Adnan Syed, and (Mike) Wei Hao Xu. This diverse group of students looks to utilize their skills in computer, electronics, and systems engineering to construct the piano keys illumination device.

Thank you for your time in reviewing the enclosed requirements documentation. Please feel free to contact us through our email (S.Instrument.Inc@gmail.com) regarding any questions and concerns.

Sincerely,

(Mike) Wei Hao Xu
Chief Communications Officer
Simple Instruments

Requirements and Functional Specifications

ENSC 405W

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Abstract

Luminotes serves as a tool for casual hobbyists and beginners to quickly learn how to play new songs on the piano. It does away with the need for a large monetary and time commitment, that comes with having to learn how to read sheet music. Luminotes achieves this by simply projecting lasers onto the individual keys that the user will follow to play the chosen song. Songs are chosen using a mobile application, which connects to the projector device via bluetooth. The projector device is small, and lightweight enough to be easily mounted to the piano without distraction to the pianist. An embedded microphone records the pianist and that recording is used to determine performance accuracy. This feedback is presented to the user on a mobile application, and serves as an indicator of their learning progress.

This document provides in-depth detail about Luminotes through a system overview and a listing of all functional and structural requirements. It serves as a guide for the design and development of Luminotes. It also offers a guide for meeting or exceeding standards for Engineering, Environmental, Sustainability & Safety.

Table of Contents

List of Figures and Tables

Glossary

ADC	Analog to Digital Converter
App	Luminotes mobile application
Chassis	Structural framework of Luminotes device
Device	Luminotes device
DSP	Digital Signal Processing
Flash	An electronic non-volatile computer storage medium
ISO	International Organization for Standardization
LED	Light Emitting Diode
MCB	Microcontroller Board
Microcontroller	Small computer on a single integrated circuit
MIDI	Musical Instrument Digital Interface; a protocol for digital music recording and playback
RAM	Random Access Memory; a volatile computer storage medium

1 Introduction

Formally learning how to read sheet music in order to play specific songs on the piano can often be a barrier for casual musicians, as it is unintuitive and time consuming. The monetary and time commitment involved with doing so is much too steep for someone who simply wants to learn their favourite song to show off to friends. This road bump is often enough to discourage many hopeful pianists from learning more.

While alternatives exist in the form of electronic keyboards with fairly easy to follow tutorials using light up keys, they are just not the same as a traditional piano. The lack of string resonance in these keyboards produces a lacklustre tune when compared to a piano. Moreover, having to buy this sort of electronic keyboard is still quite the monetary commitment; especially for the casual hobbyist who already has free access to a piano through friends, family or school.

With all this in mind we offer Luminotes as a solution. Our device acts as a low-cost, and small form factor accessory that makes learning new music easy. One just mounts it to their piano, selects a song from the mobile application that is connected via bluetooth, and follows along to the keys lit up by the device projector. A microphone embedded in the device records the user playing, and they are compared against the expected output. Feedback on performance is then provided to the user through the mobile app. *Figure 1.1* outlines this functionality with a high-level behavioural diagram. Achieving this functionality demands a detailed specificification of requirements, which this document aims to provide.
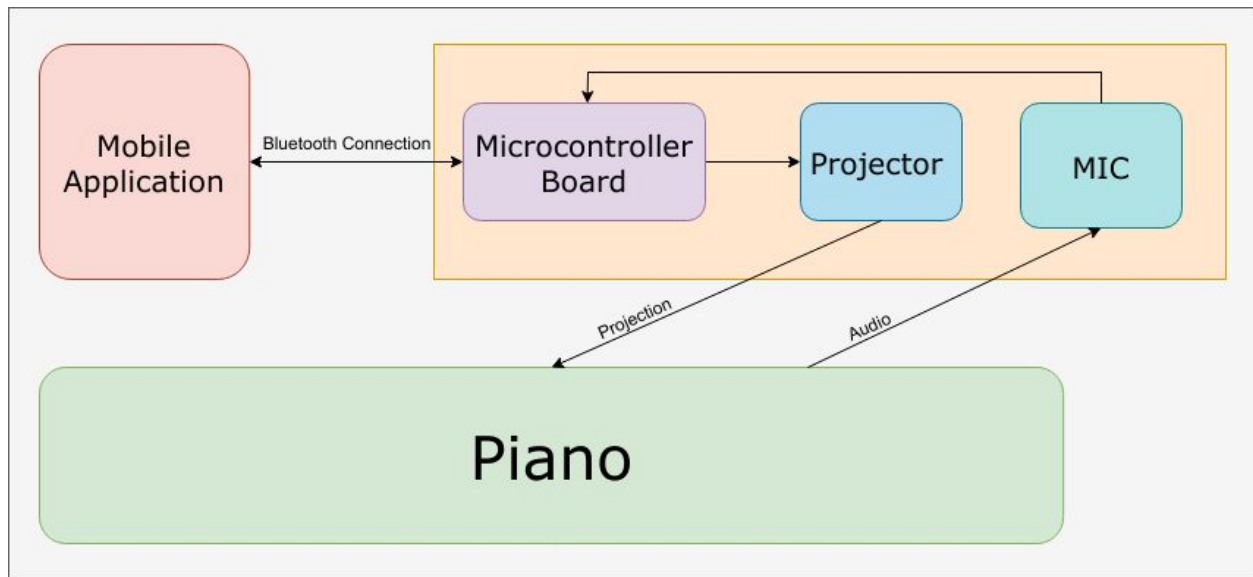

Figure 1.1: *High Level Diagram*

1.1 Scope

This document provides requirement specifications, as well as a system overview of the Luminotes application and device. The requirements are categorized as High Level, Software, Hardware, Firmware, Structural, Engineering Standards, and Safety & Sustainability. These categories are further broken down into subcategories according to the specific functionalities and components involved.

1.2 Intended Audience

This document acts as the main point of reference for specifications of Luminotes functional and structural requirements. Use of this document is targeted towards Simple Instruments Inc. engineers, testers and project managers. This document will be used as a baseline for future revisions of Luminotes. Furthermore, this document is also intended for potential partners, Dr. William Craig Scratchley, Dr. Andrew Rawicz, and teaching assistants.

1.3 Requirement Classification

The requirements of this document each have a unique ID, with the format:

[Section number][Sub-section number][Number] - [Design Stage ID]

Design Stage ID	Design Stage
a	Proof-of-concept
b	Engineering Prototype
c	Production Version

Table 1.3*: Requirement Classification*

1.4 Background

Musical Instrument Digital Interface (MIDI) is a file format created in the 1980's, which is used to encode musical information. The file consists of parallel tracks of note sequences as well as timing information. Since MIDI is digital, its file size is significantly smaller than an audio file, which allows for quicker information transfer. Because of MIDI's simplicity, it is easy to integrate into many systems. MIDI files of copyright-free music are widely available; these can be found on websites such as the Petrucci Music Library.

2 System Overview

Luminotes consists of two main components; a mobile application and a projection device. The application is the primary point of user interface with the device. Through it the user can access various settings such as adjusting the metronome, and selecting what music to play. The other point of user interface is on the actual device; a button to power it on and a set of dials to calibrate the projector. Bluetooth is used to connect the app to the projector device. Selected music is a MIDI file that is transmitted wirelessly to the microcontroller board. The board processes the file and forwards it to the Projector unit which then projects it onto the piano keys for the user to follow along to, while the speaker outputs the metronome. The embedded microphone records the user playing and transmits that audio in real-time to the computing unit. There it is processed and compared against the original MIDI to calculate an accuracy value. This value is then sent to the app to serve as performance feedback for the user.
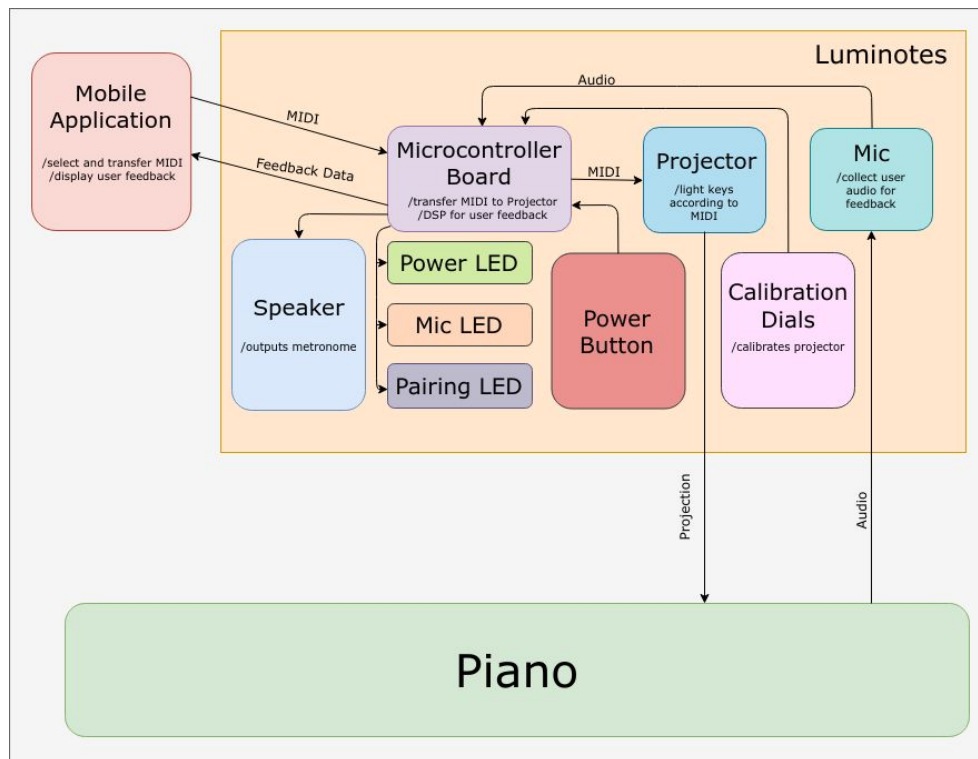

Figure 2.1: *System Overview*

3 High level Requirements

The piano projector is meant to reduce the time needed for a beginner musician to learn to play a song on the piano, by guiding the player's finger placements using light. The Luminotes Microcontroller Board (MCB) will be able to take a song as input from the Luminotes app, in the form of a MIDI file, and use a laser projector to project markings on the keys of a piano where the user should place their fingers. The MCB must be able to record and process the notes played on the piano and determine how accurate the user's playing was. The MBC will then give the user statistics on their performance.

[Req3.1.1 - a] The app must provide a method for the user to select a MIDI song file from their phone.

[Req3.1.2 - a] The app must be able to send instructions, over Bluetooth, on note timing to the microcontroller based on the user's selection of song and tempo.

[Req3.1.3 - a] The microcontroller must control the laser to light up the correct piano key at the correct time and duration.

[Req3.1.4 - a] The microphone must record the piano audio in a suitable quality and output this to the microcontroller.

[Req3.1.5 - b] The microcontroller must be able to convert the audio data into a score for the user, based on how closely the user's performance matches the expected audio.

4 Software Requirements

The Luminotes mobile application is intended to provide an easy way for the user to control the projector, and see feedback on their accuracy. These requirements were chosen to ensure that the app is intuitive for the user, and requires minimal instructions to learn how to use the functions. These cover any case of user operation.

4.1 Mobile Application Software Requirements

[Req4.1.1 - a] The app will take less than 50 MB of storage space on the mobile device.

[Req4.1.2 - a] The app will support operating systems between Android 5.0 and Android 8.1.

[Req4.1.3 - a] The app will detect that the mobile device is paired with the device.

[Req4.1.4 - a] The app will instruct the user on how to connect to the device if it is not already paired.

[Req4.1.5 - a] The app will send instructions to the device one file at a time.

[Req4.1.6 - a] The app will send the instructions to the device over Bluetooth in less than 10

seconds.

[Req4.1.7 - a] The app will display warnings to the user with less than 1 second of delay.

[Req4.1.7 - a] The app will display errors to the user with less than 2 seconds of delay.

[Req4.1.8 - a] The app will successfully connect to the device 90% of the time.

[Req4.1.10 - a] The app will successfully send the instructions 90% of the time.

[Req4.1.11 - a] The app will notify the user if the instructions fail to send to the device.

[Req4.1.12 - a] The app will notify the user if the pairing to the device fails.

[Req4.1.13 - a] The app will allow the user to play, pause, stop, restart, and repeat the song.

[Req4.1.14 - a] The app will allow the user to enable or disable the metronome on the device.

[Req4.1.15 - a] The app will allow the user to change the tempo of the note projection.

[Req4.1.16 - a] The app will have at least one MIDI file as part of the app.

[Req4.1.17 - b] The app will display accuracy of the user's performance at the end of the song.

[Req4.1.19 - b] The app will have functionality to add MIDI files from the mobile device's storage system.

[Req4.120 - b] The app will allow user to enable and disable feedback, and thus the microphone.

[Req4.1.21 - b] The app will give feedback for monophonic music with a speed of no more than 4 notes per second.

[Req4.1.22 - b] The app will give feedback for up to 3 notes played at a time, with a speed of no more than 8 notes per second.

5 Hardware Requirements

The Microcontroller Board requirements were chosen to support all necessary peripherals for the Luminotes device. These include a microphone, laser projection device, and LEDs.

5.1 Microcontroller Board Requirements

[Req5.1.1 - a] The MCB will support Bluetooth connection.

[Req5.1.2 - a] The power LED will be enabled when in use.

[Req5.1.3 - a] The power LED will blink slowly when on less than 20% of its charge.

[Req5.1.4 - a] The MCB will enabled and disabled by the power button.

[Req5.1.5 - a] The connection LED will be enabled for a successful connection to the app.

[Req5.1.6 - a] The microphone LED will be enabled when the microphone in use.

[Req5.1.7 - a] The MCB will receive input from the microphone.

[Req5.1.8 - a] The MCB will be ADC capable.

[Req5.1.9 - a] The MCB will send instructions to the projector based on the tempo chosen by the user in the app.

[Req5.1.10 - a] The MCB will have enough processing capabilities to support onboard DSP.

[Req5.1.11 - a] The MCB will have a 32-bit MCU architecture.

[Req5.1.12 - a] The MCB will have at least 1 MB of RAM.

[Req5.1.13 - a] The MCB will have at least 2 MB of Flash.

[Req5.1.14 - a] The MCB will have Flash with read-while-write support.

5.2 Laser Requirements

[Req5.2.1 - a] The lasers will be replaceable.

[Req5.2.2 - a] The lasers will be easy to take out and put into the projector.

[Req5.2.3 - b] There will be two sets of lasers with different colours in the scanner: one for the right hand and the other for the left hand.

5.3 Microphone Requirements

[Req5.3.1 - a] The frequency range will be from 120 Hz to 530 Hz. (1)

[Req5.3.2 - a] The SNR will be a minimum of 60 dB.

[Req5.3.3 - a] The microphone will have digital output.

[Req5.3.4 - b] The frequency range will be from 27 Hz to 7910 Hz. (2)

5.4 Projector Requirements

[Req5.4.1 - a] The projector will display lasers on the corresponding keys based on the instructions from the MCB.

[Req5.4.2 - a] The projector will be able to project light onto 2 octaves of keys on the keyboard.

[Req5.4.3 - b] The projector will display preview of the next set of notes to be played.

[Req5.4.4 - b] The projector will be able to project light onto 4 octaves of keys on the keyboard.

[Req5.4.5 - b] The projector will weigh less than 1000 grams.

[Req5.4.6 - c] The projector will display the name of the note to be played.

[Req5.4.7 - c] The projector will display the finger placement of each note.

6 Firmware Requirements

The firmware requirements specify constraints on the MCB's firmware, so that the device can provide feedback efficiently to the mobile application.

6.1 Microcontroller Firmware Requirements

[Req6.2.1 - a] The firmware will process the music within 5 seconds per 1 minute sample.

[Req6.2.2 - b]   The firmware will identify the pitch of a note being played on piano.

[Req6.2.3 - b] The firmware will process the pitches in less than 2 seconds.

[Req6.2.4 - c]   The firmware will identify the pitch of 2 notes being played simultaneously on piano.

7 Structural Requirements

The structural requirements were chosen to allow the hardware to be compactly packaged, into a product that is sturdy and does not interfere with the user's piano playing.

7.1 Mount Requirements

[Req7.1.1 - a] The mount will be long enough to not obscure the user's ability to use the piano.

[Req7.1.2 - a] The mount will remain still regardless of common exterior movement.

[Req7.1.3 - a] The mount will be flexible enough to be moved with a single hand.

[Req7.1.4 - a] The mount will be irremovable from the chassis.

7.2 Chassis Requirements

[Req7.2.1 - a].The chassis will contain the microcontroller board.

[Req7.2.2 - a] The chassis will contain the microphone.

[Req7.2.3 - a] The chassis will contain the projector.

[Req7.2.4 - a] The chassis will contain a speaker acting as a metronome.

[Req7.2.5 - a] The chassis will contain a slot for the power LED.

[Req7.2.6 - a] The chassis will contain a slot for the microphone LED.

[Req7.2.7 - a] The chassis will contain a slot for the pairing LED.

[Req7.2.8 - a] The chassis will contain a way to configure the projector.

[Req7.2.9 - a] The chassis will allow the projector to display the lasers without self-interference.

[Req7.2.10 - b] The chassis will contain the microphone in a location that best records the piano.

[Req7.2.11 - b] The chassis will display labels for the interactable components.

[Req7.2.12 - b] The chassis will contain a slot for batteries with a removable cover.

[Req7.2.13 - b] The chassis will firmly hold its contents in place when assembled and moved.

[Req7.2.14 - b] The chassis will allow the engineer to easily replace contents.

8 Engineering Standards

The Luminotes device and app will adhere to the following standards.

8.1 Laser

ISO 11553-2:2007	Safety of machinery -- Laser processing machines -- Part 2: Safety requirements for hand-held laser processing devices [1]
ISO 11252:2013	Lasers and laser-related equipment -- Laser device -- Minimum requirements for documentation [2]

Table 8.1: *Laser Standards*

8.2 Electrical

CAN/CSA-C22.2 NO. 61508-1:17	Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 1: General requirements [3]
CAN/CSA-C22.2 NO. 0-10	General Requirements - Canadian Electrical Code, Part II
UL 60950-1	Information Technology Equipment - Safety - Part 1: General Requirements
UL 60065	Standard for Audio, Video and Similar Electronic Apparatus - Safety Requirements [3]

IEC 60065:2014	Audio, video and similar electronic apparatus - Safety requirements

Table 8.2: Electrical Standards

8.3 Mobile Device and MicroController

IEEE 1003.13-2003	IEEE Standard for Information Technology - Standardized Application Environment Profile (AEP) - POSIX(R) Realtime and Embedded Application Support
IEEE 1625-2008	IEEE Standard for Rechargeable Batteries for Multi-Cell Mobile Computing Devices
IEEE 802.15.1-2002	IEEE Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)

Table 8.3: *Mobile Device and Microcontroller Standards*

8.4 Environmental

CAN/CSA-ISO 14040-06 (R2016)	Environmental Management - Life Cycle Assessment - Principles and Framework

Table 8.4: Environmental Standards

9 Sustainability & Safety

The Cradle to Cradle process in Luminotes device involves that the components are properly manufactured. This will allow the product to be created from production to users homes and back to production for reuse. This will benefit the environment and help push a sustainable message to the audience that Luminotes has a safe and sustainable product.

9.1 Sustainability

[Req10.1.1 - a] The lasers will be recyclable [4].

[Req10.1.2 - b] Scanner recognize if it has been idle for more than five minutes. If so scanner will turn of the laser and turn itself off.

9.2 Safety

[Req10.2.1 - a] The app will not share the user's information with third-party.

[Req10.2.2 - a] The laser will be the color RED as it safest color [5].

[Req10.2.3 - a] The lasers used must be class [6,7].

[Req10.2.4 - a] The chassey must be made sturdy and robust to prevent scanner from falling on the user which can injure them.

10 Conclusion

This requirement specification document has described all the important prerequisites needed for hardware, software, structural, electrical and sustainability and safety. Each of these prerequisites embodies smaller components' requirements that will assist with connecting all the parts together. A summary of the requirements are described below:

Mobile App Requirements
- The user will be able to select a song from the app
- The app will be able to send the song to the controller

Software Requirements
- The controller will be selecting which keys are to light up
- The controller will control the power on/off of the projector
- The controller will process audio to compare to original
- The controller will communicate with app to download songs

Hardware Requirements
- The microcontroller supports bluetooth, laser projector, on board DSP and ADC capable.
- The projector can light up to 4 octaves

Structural Requirements
- The mount will be non-interfering and easy to adjust
- The chassis will contain key components including MCB, projector, and microphone

Sustainability and Safety Requirements
- Lasers are classified as class 2 and have recyclable components and the projector will turn itself and the laser off after being idle for more than 5 minutes
- The Projector will be lightweight and have a chassis that is sturdy to prevent itself from falling. Both of these prevents from damaging the piano and hurt the user.
- The microcontroller board will have a button for power On/Off to save power.
- User information stored on the app must be secure

These requirements will help Simple Instruments progress throughout each phase.

11 References

[1] "Safety of machinery -- Laser processing machines -- Part 2: Safety requirements for hand-held laser processing devices, "ISO 11553-2:2007, *ISO,* 2007 [Accessed 6 Feb. 2019].

[2] "Lasers and laser-related equipment -- Laser device -- Minimum requirements for documentation," ISO 11252:2013, *ISO,* 2013 [Accessed 6 Feb. 2019].

[3] "Functional safety of electrical/electronic/programmable electronic safety related systems — Part 1: General requirements" *Standard Council of Canada.* [Accessed 6 Feb. 2019]

[4] "Quartet 4-Function Executive Laser Pointer, Silver (6447428000)," *Staples,* [Online]. Available

https://www.staples.ca/en/quartet-4-function-executive-laser-pointer-silver-6447428000/product_100137_1-CA_1_20001 [Accessed 6 Feb. 2019].

[5] "How laser pointers are made," *Made How*, [Online].
http://www.madehow.com/Volume-7/Laser-Pointer.html, [Accessed 06-Feb-2019]

[6] "Laser Safety," *Wikipedia,* 2019 https://en.wikipedia.org/wiki/Laser_safety#Class_2 [Accessed 06-Feb-2019]

[7] "What color laser is the least dangerous given the same power rating?," *Quora,* 2016
https://www.quora.com/What-color-laser-is-the-least-dangerous-given-the-same-power-rating [Accessed 07-Feb-2019]

12 Appendix
12.1 Acceptance Test Plant
Team 14: Simple Instruments

Date:

Software	
Mobile App	**Comments:**
1. App takes less than 50MB of storage space on the mobile device ☐ Yes ☐ No	
2. App supports OS between Android 5.0 and Android 8.1 ☐ Yes ☐ No	
3. App able to instruct how to connect to the MCB ☐ Yes ☐ No	
4. App detects mobile device is paired with the MCB ☐ Yes ☐ No	
5. App sends file to MCB over Bluetooth in less than 10 seconds ☐ Yes ☐ No	
6. App able to successfully connect to the MCB 90% of the time ☐ Yes ☐ No	
7. App able to send instructions successfully 90% of the time ☐ Yes ☐ No	

8. App displays warnings with less than 1 second of delay ☐ Yes ☐ No	
9. App displays errors with less than 2 second of delay ☐ Yes ☐ No	
10. App allows user to play, pause, stop, restart, and repeat the song ☐ Yes ☐ No	
11. App can enable or disable metronome on MCB ☐ Yes ☐ No	
12. App able to change the tempo of note projection ☐ Yes ☐ No	
13. App able to send instructions to the MCB one file at a time ☐ Yes ☐ No	
14. App notifies user if instructions failed to send to the MCB ☐ Yes ☐ No	
15. App notifies user if pairing with MCB fails ☐ Yes ☐ No	

Hardware	
Microcontroller Board	**Comments:**
1. MCB supports Bluetooth ☐ Yes ☐ No	
2. Power LED enabled when in use ☐ Yes ☐ No	
3. Power LED blinks slowly when MCB has less than 20% of charge ☐ Yes ☐ No	
4. Connection LED enabled when there is a successful connection to the app ☐ Yes ☐ No	
5. Microphone LED enabled when in use ☐ Yes ☐ No	
6. Power button enables and disables the MCB ☐ Yes ☐ No	
7. MCB receives input from microphone ☐ Yes ☐ No	
8. MCB is ADC capable ☐ Yes ☐ No	

9. MCB able to send instruction to projector with tempo chosen by user ☐ ☐ Yes No	
10. MCB able to support onboard DSP ☐ ☐ Yes No	
11. MCB has flash with read-while-write support ☐ ☐ Yes No	
Laser	**Comments:**
1. Laser is replaceable ☐ ☐ Yes No	
2. Laser is easy to take out and put into the projector ☐ ☐ Yes No	
Microphone	**Comments:**
1. The frequency range is between 120Hz to 530Hz. ☐ ☐ Yes No	
2. SNR is a minimum of 60 dB ☐ ☐ Yes No	
3. Microphone has digital output ☐ ☐ Yes No	

Projector	Comments:
1. Projector displays laser on the corresponding keys based on the instructions from the MCB ☐ Yes ☐ No	
2. Projector is able to project light onto 2 octaves of keys on the keyboard ☐ Yes ☐ No	

Firmware

Microcontroller Firmware	Comments:
1. Firmware processes the music within 5 seconds per 1 minute sample ☐ Yes ☐ No	

Structural

Mount	Comments:
1. Mount does not obscure user's ability to use piano ☐ Yes ☐ No	
2. Mount remains still regardless of common exterior movement ☐ Yes ☐ No	
3. Mount is flexible enough to be moved with a single hand ☐ Yes ☐ No	
4. Mount is irremovable from the chassis ☐ Yes ☐ No	
Chassis	Comments:

1. Chassis contains the MCB ☐ ☐ Yes No	
2. Chassis contains the microphone ☐ ☐ Yes No	
3. Chassis contains the projector ☐ ☐ Yes No	
4. Chassis contains a speaker to act as a metronome ☐ ☐ Yes No	
5. Chassis contains a slot for the power LED ☐ ☐ Yes No	
6. Chassis contains a slot for the microphone LED ☐ ☐ Yes No	
7. Chassis contains a slot for the pairing LED ☐ ☐ Yes No	
8. Chassis contain a way to configure the projector ☐ ☐ Yes No	
9. Chassis allows projector to display the lasers without self-interference ☐ ☐ Yes No	