Engineering Art

Design Document

sdmay23-04

Client/Adviser: Rachel Shannon

Team Members/Roles:

Ayden Boehme - CprE, Researcher, Frontend Team

Derrick Brandt - SE, Figma Wizard, Frontend Team

Tomas Elias - SE, Note Organizer, Frontend Team

Elizabeth "Liz" Fransen - SE, Communications Guru, Backend Team

Shelby Murray - CprE, Notetaker, Backend Team

Juno "Winter" Robertson - SE, Android Expert, Frontend Team

Cosette Thompson - EE, Electrical Expert, Installation/Backend Team

Nathan "Nate" Underwood - CybE, Security Expert, Backend Team

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Revised: 29 April 2023 / Version 4

Executive Summary

Development Standards & Practices Used

- Standard Practices:
  - Ask questions
  - Only research peer-reviewed sets of publications
  - Develop and use models
  - Obtain, Evaluate, and Communicate information
- Hardware Practices:
  - Document design
  - Adhere to standards
  - Consider design compatibility
  - Test hardware
- Software Practices:
  - Enhance Code Readability
  - Keep Code Efficiency
  - Test often
  - Refactor code
- Engineering Standards:
  - IEEE 1621-2004 - IEEE Standard for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments
  - IEEE 1680.1-2018 - IEEE Standard for Environmental and Social Responsibility Assessment of Computers and Displays
  - IEEE 3079-2020 - IEEE Standard for Head-Mounted Display (HMD)-Based Virtual Reality(VR) Sickness Reduction Technology
  - IEEE 610.2-1987 - IEEE Standard Glossary of Computer Applications Terminology

Summary of Requirements

- The project should be interactive.

- The project should be safe to use.
- The project should be created to inform the public about one of the 21st-century engineering challenges.
- The project should be eye-catching, so someone will come to it without knowing what it is beforehand.
- The project should appeal to all ages and levels of experience with engineering
- The project should be usable with minimal instruction or outside assistance
- The project should use standard power outlets and connections

Applicable Courses from Iowa State University Curriculum

- E E:
  - 201 - Electric Circuits
  - 224 - Signals and Systems I
  - 230 - Electronic Circuits and Systems
  - 321 - Communication Systems I
  - 324 - Signals and Systems II
- CPR E:
  - 310 - Theoretical Foundations of Computer Engineering
  - 329 - Software Project Management
- COM S:
  - 227 - Object-oriented Programming
  - 228 - Introduction to Data Structures
  - 309 - Software Development Practices
  - 311 - Introduction to the Design and Analysis of Algorithms
- CYB E:
  - 234 - Legal, Professional, and Ethical Issues in Cyber Systems
- IND D:
  - 593 - Experiential Learning Special Projects

- HON:
  - 321W - Impact Your World: Teaming Together to Research Global Challenges

New Skills/Knowledge Acquired and not Taught in Courses

- Gen Z Culture - memes and slang
- Functionality of the Muse 2 headset
- Locations of museums and interactive exhibits on Iowa State's campus
- Effective use of Miro as a collaborative tool
- Sketchnoting
- The Design Process and principles of industrial design
- Functionality of a DJ board and integration through Arduino and Teensy
- Functionality and dangers of cathode ray tube (CRT) televisions

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List of Figures, Tables, Symbols, and Definitions

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1 Team

1.1 Team Members

- Tomas Elias, SE
- Shelby Murray, CprE
- Cosette Thompson, EE
- Nathan "Nate" Underwood, CybE
- Elizabeth "Liz" Fransen, SE
- Juno "Winter" Robertson, SE
- Ayden Boehme, CprE
- Derrick Brandt, SE

1.1.1 Consultants and Special Thanks

- Parker "Park" Smith - Consulting Industrial Design Student
- Johnny DiBlasi - Consulting Assistant Professor of Art and Visual Culture at the College of Design
- Wei Shen Theh - Graduate Student, Electrical and Computer Engineering
- ECpE Electronics and Technology Group (ETG)
- Muse 2 development team
- KURE radio station

1.2 Required Skill Sets for Your Project

- Experience developing with open source software
  - This skill is required for using an open source SDK to communicate with the Muse 2, an EEG device we will be using.

- Experience with hardware hacking
  - This skill will be required because of the chosen EEG device, the Muse 2. To pull EEG data from the device, an interface will need to be made between the hardware and software. Hardware hacking experience will fast-track the troubleshooting process.

- Experience with signal processing
  - Knowledge of the Fast Fourier Transform will be required
  - This skill would be useful for ensuring the data pulled from the Muse 2 device is translated from raw data into workable data.

- Developing applications for use on both mobile phones and tablets
  - This skill is required because the exhibit will run on a tablet and will have an accompanying mobile application to view data

- Client-server communication
  - This skill is required because we will be sharing results on individual's devices, requiring infrastructure to get that information across.

- Computer Graphics
  - A large part of this project is creating interesting art from abstract values. This art generation will require expertise in the computer graphics world.

- Experience working with UX
  - Another large part of this project is the guided experience, which is required to keep users engaged. Because of the importance of engagement, User Experience (UX) is a highly needed skill.

- Testing
  - Testing will be required to assure that the experience runs smoothly without bugs.

1.3 Skill Sets covered by the Team

- Experience developing with open source software - Everyone
- Experience with hardware hacking - Cosette, Nathan
- Experience with signal processing - Cosette, Liz, Shelby
- Developing applications for use on both mobile phones and tablets - Juno, Shelby, Liz, Tomas, Ayden, Nathan, Derrick
- Client-server communication - Liz, Nathan, Juno
- Computer Graphics - Liz, Cosette, Juno
- Experience with UX - Liz, Juno, Shelby, Ayden, Nathan, Tomas, Derrick
- Testing - Everyone

1.4 Project Management Style Adopted by the Team

For our project, we have adopted a collaborative management style; we create a list/forum of ideas to be discussed extensively before our team makes decisions. The team has agreed that making decisions have to be unanimous. Ultimately, it brings the team closer together, everybody is valued, and most importantly, everybody has a voice on this team.

1.5 Project Management Roles

1.5.1 Initial Project Management Roles

Group Members	Initial Management Roles
Tomas Elias	Researcher
Shelby Murray	Note Taker
Cosette Thompson	Researcher
Nathan Underwood	Researcher
Elizabeth Fransen	Communications Guru
Juno Robertson	Researcher
Ayden Boehme	Researcher
Derrick Brandt	Figma Wizard

Table 1 *Group members and initial roles.*

1.5.2 Revised Project Management Roles and Team Divisions

Group Members	Initial Management Roles
Tomas Elias	Note Organizer; Frontend
Shelby Murray	Note Taker; Backend
Cosette Thompson	EE Expert; Backend/Installation
Nathan Underwood	Security Expert; Backend
Elizabeth Fransen	Communications Guru; Backend
Juno Robertson	Android Expert; Frontend
Ayden Boehme	Researcher; Frontend
Derrick Brandt	Figma Wizard; Frontend

Table 2 *Group members and revised roles.*

2 Introduction

2.1 Problem Statement

Reverse engineering the brain is one of the National Academy of Engineers' 21st Century Challenges—a list of complex problems that are tightly intertwined with engineering and the future. Medical and technical personnel around the world are working towards solutions that will have applications in artificial intelligence, medical treatments, and prosthetics. The knowledge of this challenge is crucial to garnering public support and increased funding. Our goal is to inform and gain the interest of the general public and potential engineers through an interactive art exhibit that converts brain wave activity from listening to music into art.

2.2 Intended Users and Uses

User	Key Characteristics (Persona)	Related Needs (POV / Needs statement)	Usage / Benefits
Iowa State University Personnel	Chrystal the curator - Works at Iowa State - Manages art that is put up - Wants to put up art that will bring people to their museum - Enjoys art - Enjoys engineering - Likes Iowa State	- Needs to be easy to set up and maintain the art exhibit	- Exhibit should bring people to their business - Setup and maintain exhibit
Youth	Yvonne the Youth	- Needs to be entertained	- They are the future and are

User	Key Characteristics (Persona)	Related Needs (POV / Needs statement)	Usage / Benefits
	- Doesn't have as much experience - Has a bunch of energy - Is chaotic - Wants to play with something fun - Is easily impressionable	and highly engaged	easily impressionable at a young age
Adults	Adrianne the Adult - Lowkey - Likes cool things - Tech literate - Some call them a "hipster" - Thinks that SIC is just so neat - Ames local	- Needs something that is interesting but won't be too dumbed down	- Interact with the art exhibit for something interesting - Will want to learn more about the exhibit in-depth
Students	Sally the Student - Open option freshman - Unsure what field they want to go into - Technology savvy	- Needs it to be engaging and informative - Needs something that shows the potential of engineering - Needs it to be straightforward enough to understand	- Interacts with the art exhibit for fun or as part of an exploration of different majors - May be encouraged to pursue an engineering major
Professors	Perry the Professor - Knowledgeable about the	- Needs exhibit to be a faithful representation	- May refer their students to check out the exhibit

User	Key Characteristics (Persona)	Related Needs (POV / Needs statement)	Usage / Benefits
	exhibit's subject matter - Experienced professional - High expectations for the display		

Table 3 *Intended users and uses.*

2.3 Requirements & Constraints

- Functional
  - The exhibit should be interactive
  - The exhibit should be safe to use
- User (Specifications)
  - An exhibit should be constructed to inform the public about one of the 21st-century engineering challenges
- Aesthetic
  - The exhibit should be eye-catching, so someone will come to it without knowing what it is beforehand
- User Experience
  - The exhibit should appeal to all ages and levels of experience with engineering
  - The exhibit should be usable with minimal instruction or outside assistance
- Economic
  - $500 (constraint)
- Environmental
  - Likely to have limited space for the exhibit (constraint)
  - Should use standard power outlets and connections (constraint)

2.4 Engineering Standards

- IEEE 1621-2004
  IEEE Standard for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments
  - Power control elements should be properly identified and protected to prevent injuries to the user and persons responsible for set-up and maintenance.

- IEEE 1680.1-2018
  IEEE Standard for Environmental and Social Responsibility Assessment of Computers and Displays
  - Because our exhibit will be interactive and likely use some sort of display, we will want to ensure that we use the computers and displays responsibly.

- IEEE 3079-2020
  IEEE Standard for Head-Mounted Display (HMD)-Based Virtual Reality(VR) Sickness Reduction Technology
  - We are strongly considering using VR. This standard outlines Content design for VR sickness reduction and how to assess sickness related to the VR content.

- IEEE 610.2-1987
  IEEE Standard Glossary of Computer Applications Terminology
  - Because we will probably be talking about AI and other applications related to reverse engineering the brain, we will want to make sure our terms relate to the standard glossary.

3 Project Plan

3.1 Project Management/Tracking Procedures

We have been practicing Agile methodology because our project focuses on the user and industrial design process. Agile project management style provides greater flexibility and feedback from our client as this is a consistently adapting project.

To track our progress, we record and cross off general to-do items in our meeting minutes in a separate section of the shared document. For immediate actions we need to take, we have a special channel in our Discord server reserved for to-do items. We will also use a Git repository (GitHub/GitLab) for software development, which includes an issues list for tasks exclusive to software.

3.2 Task Decomposition

1. **Discover**
    a. Primary Research: Interview with experts in the fields related to our research
    b. Secondary Research: Use of academic and online resources

2. **Define**
    a. Insights: Track behaviors and patterns related to the topic
    b. Themes: Identify overarching themes
    c. Opportunity Areas: Where there are possibilities to fill users' needs

3. **Develop**
    a. Ideation: Brainstorm solutions with a focus on quantity
    b. Evaluation: Select possible solutions with a focus on quality

4. **Implementation**
    a. Build: Integrate components
    b. Test: Conduct team and user testing
    c. Iterate: Make design changes based on user testing

3.3 Proposed Milestones, Metrics, and Evaluation Criteria

1. **Discover (1st semester focus)**
    a. Complete two, four, and six total expert interviews in weekly increments, with additional ones as needed
        i. Focus on artificial intelligence, brain science, and interactive exhibits
    b. Complete secondary research with at least two dozen academic or reliable sources

2. **Define (1st semester focus)**
    a. Identify at least three themes for reverse engineering the brain
    b. Research six areas of opportunity within the field
    c. Define our problem in more detail and select a focus area of opportunity

3. **Develop (1st and 2nd semester focus)**
    a. Brainstorm a dozen possible ‘solutions’ to educating about reverse engineering the brain
    b. Select an idea to implement based on at least a dozen defined criteria

4. **Implementation (2nd semester focus)**
    a. Create a functional prototype and test-run with a dozen expected users
    b. Make changes and repeat the above at least three times
    c. In the final public display, reach a total of 50 users over the course of two hours

3.4 Project Timeline/Schedule

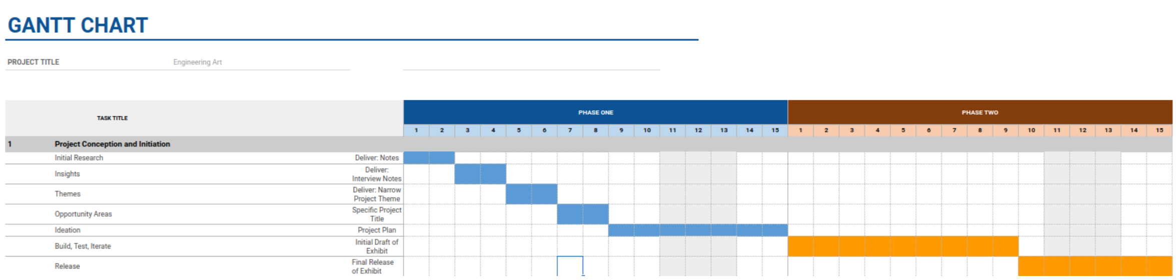


Fig. 1 *Gantt chart timeline of project.*

3.5 Risks And Risk Management/Mitigation

Security Risks with AI and Cybersecurity

Risk	Probability (estimate)	Risk Mitigation Plan (if needed)
AI becomes self-aware and takes over the world	0.000000001	Be nice to AI

Users could find a way to install other software (possibly malicious)	0.3	Digital signing code ensures that only Signed Firmware updates are completed, preventing activities like Debug over USB from being installed.
Users change settings and/or configurations that result in an insatiable installation	0.4	PageVisibilityList policy can be reset to restrict the pages seen within the Settings app.
If the project is to be held in a place for the public to experience it, the hardware may be stolen or broken	0.2	Have the project be accessible to the public only when it is being watched over and/or our team is there to host the project experience for users.

Table 4 *Security risks of AI and cybersecurity.*

3.6 Personnel Effort Requirements

Projected Tasks	Time Period Projection	Team Members in Charge of Tasks	# of Hours Projected to Accomplish Tasks	Projected Cost of Each Task
Secondary Research	ongoing	Team effort	N/A	no cost
Primary Research	10/31/2022	Team assigned groups	10 hours	no cost
Museum visits	10/04/2022-10/05/2022	2 teams	2 hours	no cost
Discover and define phase (deep dive research)	10/28/2022	Team effort	N/A	N/A
Lightning talk 1	10/20/2022	Team Effort	5 hours	N/A

Prepare for group presentation	Presentation by dead week	Team Effort	50 hours	N/A
Develop phase starts	First day of second semester	Team Effort	Be ready	N/A
Start building code for our interactive user experience	ongoing	SE Team	N/A	N/A
Configure security policies	ongoing	Security team	N/A	N/A
Final Presentation of Project	Accumulated hours until now	Team Effort	All hours until now	LOTS of money gone

Table 5 *Personnel effort requirements.*

3.7 Other Resource Requirements

Resources:

- Hardware
    - Required devices, such as Muse 2 - elaboration below
    - Tablet to run user experience app
    - Web server through ETG
- Willing participants
- Experts and their contact information for related fields
- Space for final interactive display/exhibit

4 Design

4.1 Design Context

4.1.1 Broader Context

Our selected 21st Century National Academy of Engineering challenge is reverse engineering the brain. Medical and technical personnel around the world are working towards solutions that will have applications in artificial intelligence, medical treatments, and prosthetics. The knowledge of this challenge is crucial to garnering public support and increased funding. Our goal is to inform and gain the interest of the general public and potential engineers through an interactive art exhibit to display on Iowa State University's campus. That art exhibit is an interactive display of brain wave activity getting converted into AI-generated art.

List relevant considerations related to your project in each of the following areas:

Area	Description	Examples
Public health, safety, and welfare	Our project could lead or be improved upon in areas that can help map the human brain. Or assist with reading brain activity to certain situations. And also help people become aware of the possibilities of engineering art.	Increasing exposure to Engineering Art. Can be used as a stepping ladder for other similar fields, like mapping the brain or different forms of art.
Global, cultural, and social	Our project should educate the general public about why reverse engineering the brain is an important topic.	The development of our project is supposed to target groups that are interested in engineering. And both positively and negatively affect the global, cultural, and social areas we live in.
Environmental	Our environmental impact is centered around energy and material requirements for manufacturing our used	Most of our pieces needed to engineer our product use silicone.

	devices. We will also have energy required for use.	
Economic	With our project and the idea we are going with reverse engineering the brain using the Muse 2, it will be difficult to find the perfect product within the $500 budget. We also require an additional tablet purchase because the university does not have one with our necessary components.	There are different options for the Muse 2 ranging from values in the mid $100- $1000. Tablets range in price depending on brand, quality, and year/version.

Table 6 *Broader concepts related to project.*

4.1.2 Prior Work/Solutions

Note: We're not following any previous work as we are building a new interactive exhibit, but we are not the first people to build an interactive exhibit. There are specific benefits that interactive exhibits give, such as the ability to gain more interest and keep users engaged, but with drawbacks, such as complexity. These pros and cons were balanced before we started the project and decided as part of the requirements given to us.

Interactive Exhibits on Campus:

Fig. 2 *Multimedia Wall in Coover Hall.*

Fig. 3 *Hope and anxiety display in Design Building.*

Interactive Exhibit Examples

Mitchell, Bea. "The World's Top 12 Immersive Art Experiences." *Blooloop*, 13 July 2022, https://blooloop.com/technology/in-depth/immersive-art-experiences/.

Museum Web Design by Landslide Creative. "Immersive." *Des Moines Art Center*, 20 Apr. 2022, https://desmoinesartcenter.org/art/exhibitions/immersive/.

Steens, Camille. "The Best Interactive Museum Experiences around the World." *Tiqets.com*, 19 July 2021, https://www.tiqets.com/blog/interactive-museum/.

Muse 2 Headband

"The Brain Sensing Headband." Muse, https://choosemuse.force.com/s/article/How-do-I-get-good-sensor-signal-quality-with-Muse?language=en_US.

"The Brain Sensing Headband." Muse, https://choosemuse.force.com/s/article/Muse-Software-Development-Kit-SDK?language=en_US.

Clutterbuck, James. Mind Monitor, https://mind-monitor.com/Technical_Manual.php#help_graph_raw.

Krigolson, Olave E, et al. "Choosing Muse: Validation of a Low-Cost, Portable EEG System for ERP Research." Frontiers in Neuroscience, U.S. National Library of Medicine, 10 Mar. 2017, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5344886/.

Mutyala, Anush. "Muse 101 - How to Start Developing with the Muse 2 Right Now." Medium, Medium, 22 Aug. 2021, https://anushmutyala.medium.com/muse-101-how-to-start-developing-with-the-muse-2-right-now-a1b87119be5c.

4.1.3 Technical Complexity

1. Assuming our project makes use of the **multimedia wall** in Coover, we will have to do some reverse engineering of our own and figure out how it operates, what type of software it runs, and how to deploy it.

2. Our project **analyzes users' actions** and **makes predictions based on this**; we will need to implement a decently robust prediction algorithm or neural network.

3. So many **assumptions**--this is because our project was given to us in an extremely **open-ended** form. We have many important decisions about how best to represent our chosen engineering challenge, many of which will have far-reaching effects on the rest of our project.

4. Our project will be **installed somewhere** and must be able to function without an expert on hand, possibly without any supervision whatsoever.

5. Requires a sufficient understanding of **reverse-engineering the brain/AI** and their inherent challenges to present the challenge accurately.

6. Our project must strike a **balance**. While it does need to be well-researched, well-informed, and accurate to the engineering challenge it represents, it also should not be too technical. The average person should be able to understand it and learn something.

4.2 Design Exploration

4.2.1 Design Decisions

1st Semester Decisions:

1. **Focusing on 21st-Century Challenges:** To begin our project, we had the options of innovations in the ECpE department at Iowa State and the 21st-Century Engineering Challenges proposed by the National Academy of Engineering. Selecting the 21st-Century Challenges has narrowed our deeper topics down to the fourteen listed rather than the full history of ECpE developments at Iowa State. It also highlighted the importance of outside research and expert opinions--examining the ECpE department would involve almost entirely on-campus outreach.
2. **Focusing on Reverse Engineering the Brain:** Of the fourteen challenges, reverse engineering the brain had the strongest interest from our team and the greatest potential for an interactive exhibit. Again, this influences the future of our project greatly--we know that we should continue research and expert interviews with a focus on neuroscience and biology, in addition to engineering in the field.
3. **Focusing on Applications in Artificial Intelligence:** To further narrow our focus, we decided to focus on the applications of reverse engineering the brain in artificial intelligence. We know to ask questions in upcoming interviews related specifically to artificial intelligence--this will help us make the most efficient use of our time with experts and prevent our topic from growing outside the scope of the project and timeline.
4. **Muse 2 for Brainwave Monitoring:** We examined several electroencephalogram (EEG) devices that can measure electrical activity in a brain, including the Muse and Neurosky Mindwave. We also considered the advantages and challenges of manufacturing our own device. The Muse 2 headset was ultimately selected because it has existing support and troubleshooting options. In addition, we could jump into the implementation of our project quicker and leverage the ability to start on other phases of the project that depend on the data collected through Agile methodology.

2nd Semester Decisions:

1. **Location of the Installation:** To determine the location of our user testing installation, we needed to consider the limitations of the physical space and ability to interact with users. Indoor would be best to prevent poor weather and general wear-and-tear. The university

requires a reservation for most rooms and areas on campus, so the availability of location affected our choice. We needed enough space to set up and access electricity. Internet connectivity would be an advantage, but we could still work without it. Our preferred locations were the Coover and Student Innovation Center atriums. We decided to reserve SIC because we had a greater chance of reaching users outside of the engineering field, and there is a greater throughput of students and tours on a regular basis.

4.2.2 Ideation

Deciding our Project Topic

When we first gathered our team to decide on our project's topic from one of the 14 Engineering Grand Challenges, we all came to our meeting with our own individual thoughts and eventually took votes and narrowed down the topics. Our chosen method for this decision was to draw a mindmap on a whiteboard with each suggested topic challenge as their own center node to their personal mini-mind map. The five challenges that we decided between after completing the first draft of our mind map are: "Enhance Virtual Reality," "Reverse Engineer the Brain," "Restore and Improve Urban Infrastructure," "Secure CyberSpace," and "Provide Access to Clean Water."

From these topic nodes, we connected project ideas to them that related to each given topic node. We then voted out certain topics from the decision pool based on how difficult it was to come up with an art installation for that topic. The first topics to go were "Secure CyberSpace" and "Provide Access to Clean Water '' because we couldn't come up with very many ideas for them, and our whole group seemed to be more enthusiastic about the other remaining topics. By comparing the ideas that we had generated, it had become very clear that our group was interested in VR, but ultimately we decided that we could use VR as a potential platform for our installation without us having to make our topic become "Enhance Virtual Reality." Thus, we took that challenge out of the decision pool as well. This left us between "Reverse Engineer the Brain" and "Provide Access to Clean Water," and our group chose "Reverse Engineer the Brain '' by majority vote. Ultimately we feel that we strongly enjoyed multiple project ideas that we had come up with for "Reverse Engineer the Brain '' and we thought that it could lead to a very interesting VR experience if we decided to still use VR as our platform.

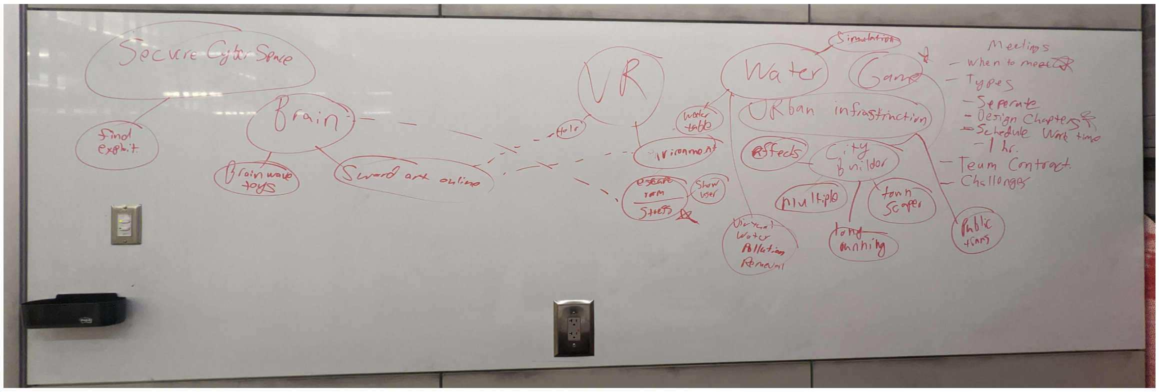


Fig. 4 *Mind Map ideation on a Parks Library whiteboard.*

4.2.3 Decision-Making and Trade-Off

Each option is rated on a scale from 1 to 5; 5 is considered the 'best' for each category. Each category is given a weight to match its importance to the project as a whole. To calculate the total score, the weight and rating are multiplied.

Options:

1. Restore and Improve Urban Infrastructure - City builder
2. Reverse Engineering the Brain - Brainwave toy
3. Secure CyberSpace - Find and show local wireless communications
4. Provide Access to Clean Water - VR Water Pollution Removal
5. Reverse Engineering the Brain - VR Decision-Based Game (ex. Escape Room)

Criteria	Weight	Opt. 1	Opt. 2	Opt. 3	Opt. 4	Opt. 5
Hardware Complexity	4	1	5	4	2	3
Software Complexity	4	5	3	1	2	3
Affordability	5	5	4	3	2	1
Correlation to Challenge	7	1	3	5	4	2
Fun Factor for Users	4	3	5	1	2	4

Team Knowledge of Tools	4	5	3	4	2	1
Relevancy to Prob. State.	8	1	5	2	3	4
(higher is better)	**Total**	**96**	**145**	**106**	**94**	**95**

Table 7 *Weighted decision matrix for engineering challenges.*

For our Engineering Challenge focus, we have chosen Option 2: Reverse Engineering the Brain, a brainwave toy. Using brainwaves is the idea that our team is most excited about. Option 2 scored the highest on hardware complexity, the fun factor for users, and relevance to our problem statement. It had no scores below 3. Every member of our group had some level of interest in the project idea, and it has elements related to each of our majors and areas of expertise. There are enough tasks, applicable previous knowledge, and room for growth and learning to sufficiently fill a year-long project while not being overwhelmed.

4.3 Proposed Design

4.3.1 Overview

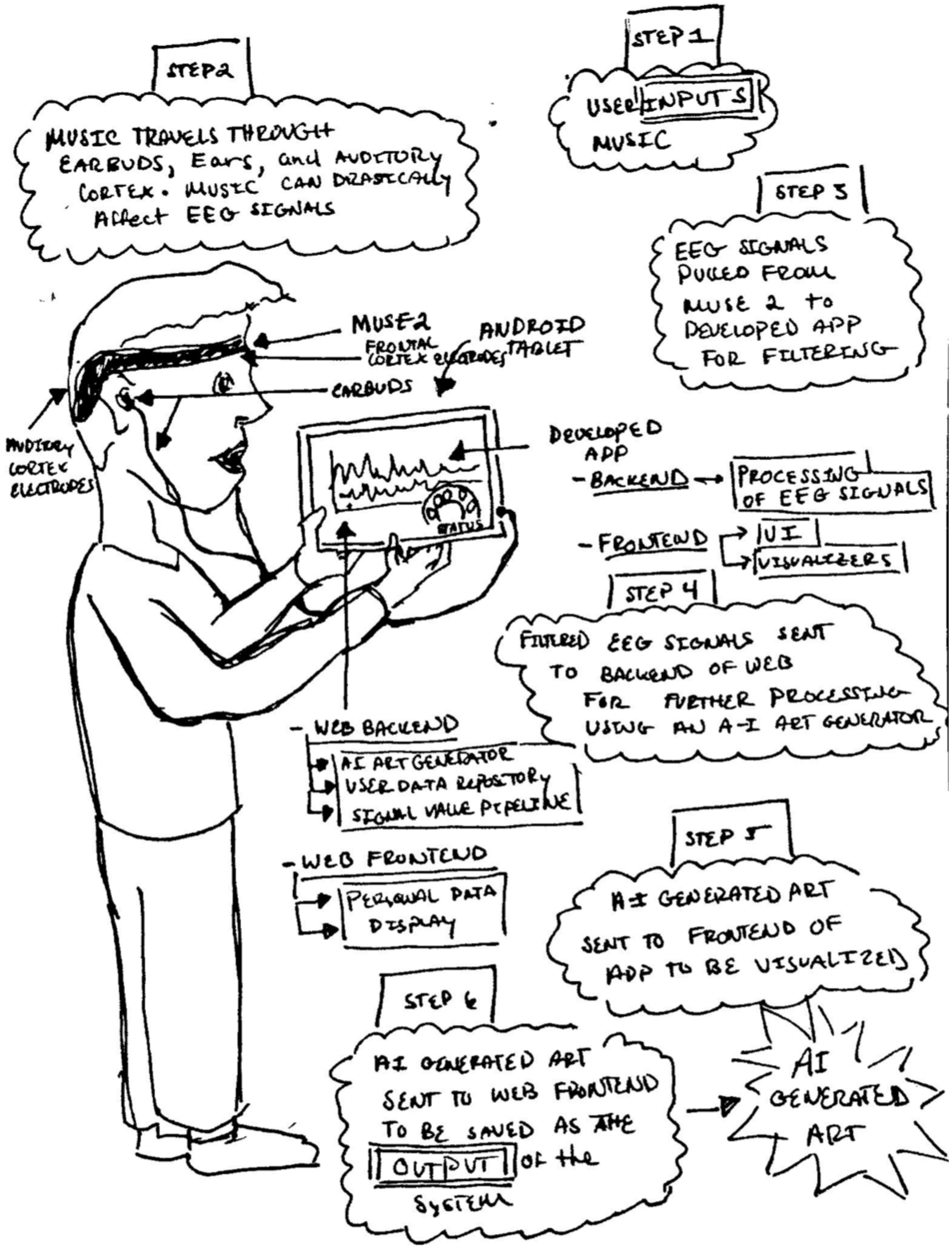


Fig. 5 *System level diagram.*

This interactive experience would inspire and bring awareness about the 21st-century engineering issue of reverse engineering the brain. Our design will accomplish this by having users participate in an interactive experience that monitors their brain waves as they listen to the music of their choice.

There are three main devices needed for this proposed design. The device for monitoring the brain waves will be a compact EEG system. Additionally, a tablet will house the application that users can interact with. Headphones/earbuds will ensure a proper listening experience.

While the user is listening to the music, their brainwaves will be monitored and used to create a personalized, AI-generated art piece in addition to their personal analytics from their experience, both of which can be saved by the user by scanning a QR code displayed in the application upon completion of the experience. The tablet will display prior users generated artforms, highlighting the uniqueness of each individual's experiences. This experience will emphasize how complex and beautiful the brain is while noting the promise reverse engineering the brain has for building empathy through our acknowledgment and appreciation of the unique ways our individual brains process information.

4.3.2 Detailed Design and Visuals

Our high-level design can be broken down into the following main systems:

Device Backend:

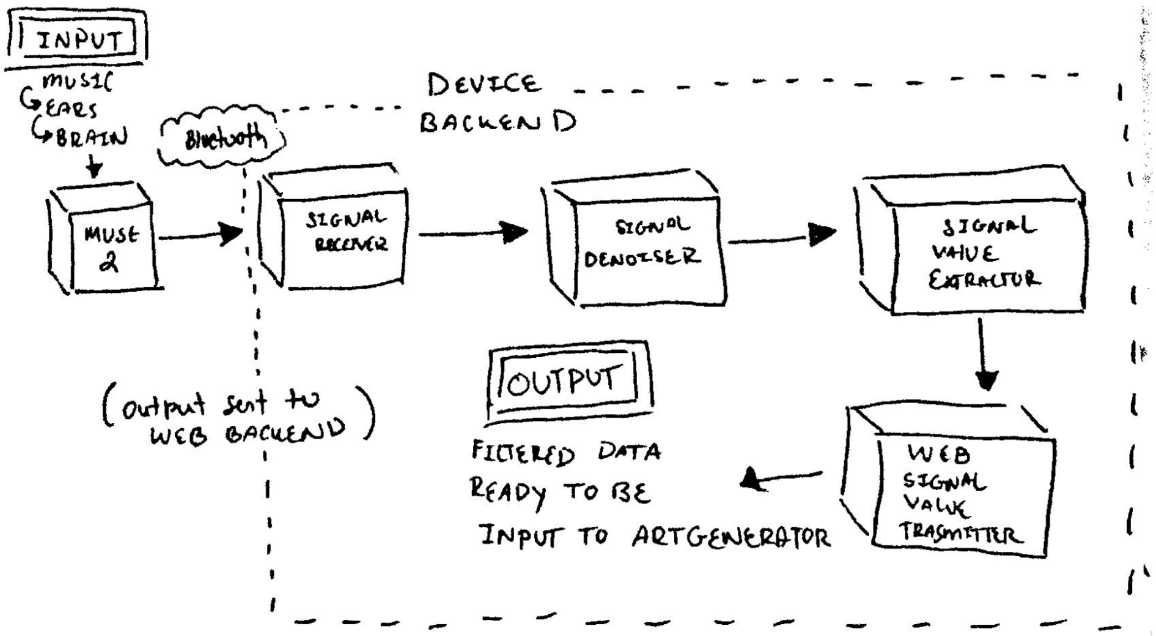


Fig. 6 *Device backend diagram.*

The Muse 2 EEG system has an SDK compatible with ios and Android. In addition, much of the open source software available for the Muse 2 is also IOS and Android. Therefore, the main language we will be using for the extraction and manipulation of the data will be Android. This device backend will be a part of the application made and housed on the Android tablet. The Muse 2 EEG is compatible with 4.2 Bluetooth. Therefore, the EEG system will be connected to the Android tablet via Bluetooth, which will allow raw data from the Muse 2 to be transferred to a signal receiver, included in the backend of the application created. From here, the data needs to be filtered to remove any noise, and the FFT will be utilized to provide finalized processed data that will be sent to other systems for further processing.

Web Backend:

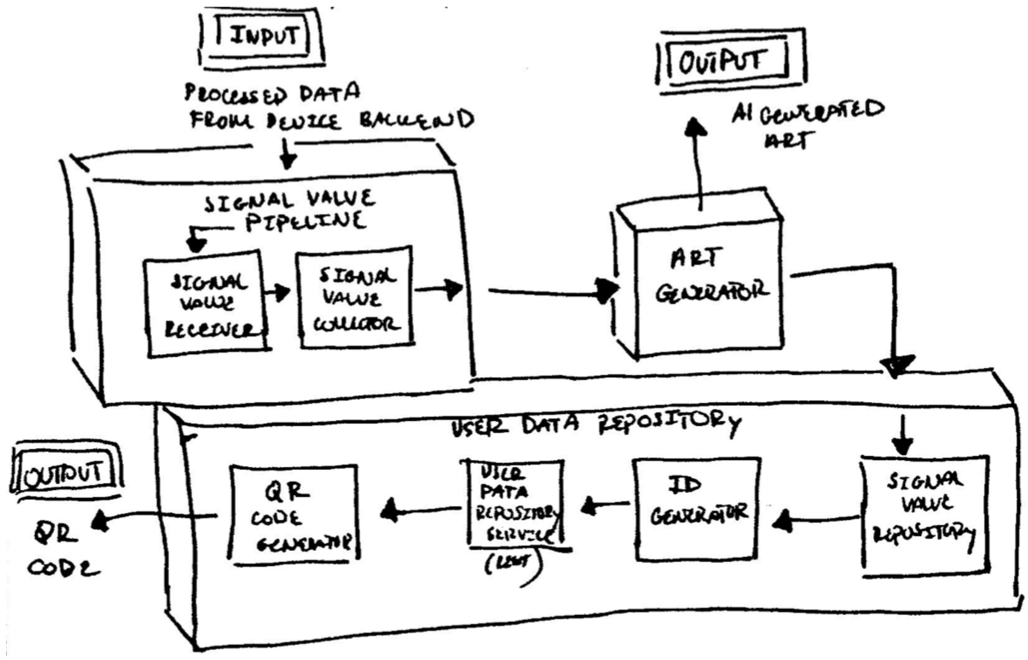


Fig. 7 *Web backend diagram.*

This system is used for further processing of the data into visuals for the user to see in the device frontend. This system consists of a signal pipeline that will receive the data from the device backend. From here, the data will be sent to the art generator, where it will be broken down into gamma, beta, theta, and delta waves. These frequency ranges will be used to determine the generated art in the art generator.

Device Frontend:

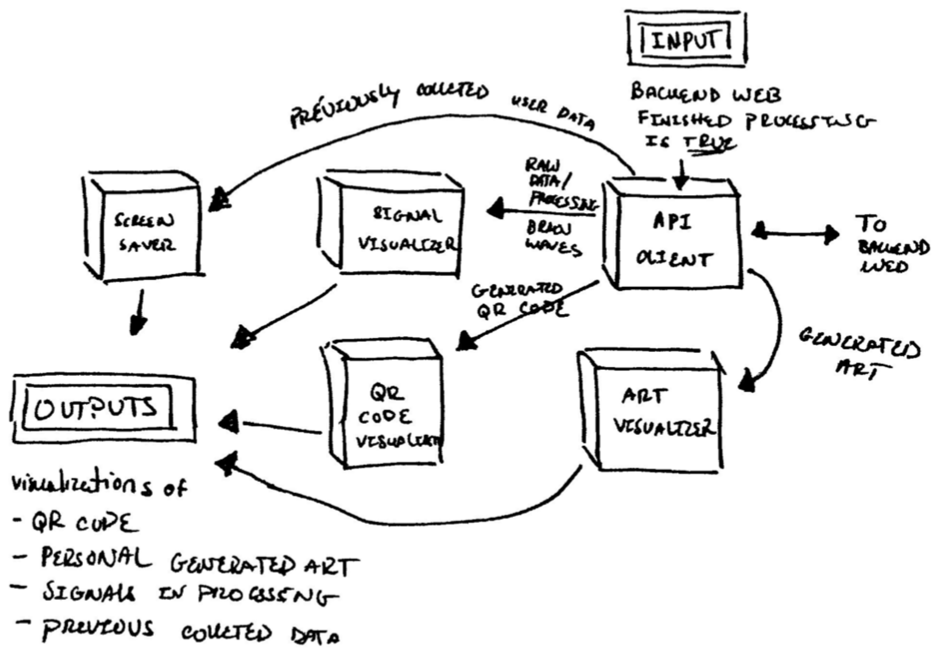


Fig. 8 *Device frontend diagram.*

The application will be housed on an Android tablet. This application will consist of a User Interface with different features to help the users through the experience. The main subsystems of this system are visualizers. These visualizers will allow the users to see the AI-generated art from previous users. Another visualizer will allow users to see the status of their electrode connectivity if adjustments are needed. Additionally, a QR visualizer will allow the user to save the information and AI-generated art. These visualizers will use an API to communicate with the backend of the web, where the signals are further processed.

Web Frontend:

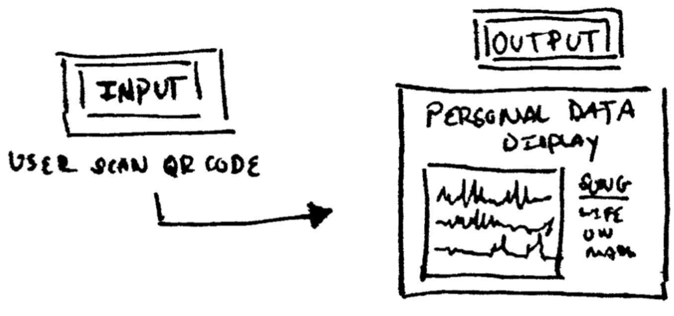


Fig. 9 *Web frontend diagram.*

This system will display the saved user data. The saved user data will be associated with a user ID. This user ID will be included in the QR code provided to the users of the exhibit. Once the QR is scanned, the user will be taken to a webpage containing their data from their experience at the exhibit.

4.3.3 Functionality

This experience will have users wear headphones in addition to the Muse 2 brain monitoring device. The user will also have a phone or tablet that contains a specifically designed app for the interactive experience.

The user will be able to interact with a UI that allows them to see the status of their Muse 2 device in case the electrodes are not properly making contact with their head. In addition, the users will be able to follow a guided experience where they will first have the option to choose music. Following this, music will be played through the headphones, and the user will be instructed to stay as still as possible. The user will then be given information about what is happening in their brain while listening to the music. This will give the user an informative and personalized visual aid during the song's length. Following the song's duration, the UI will let the user know that the experience is complete and show the user a QR code along with the AI-generated art piece that reflects personalized characteristics of the user's experience while listening to the song. If the user would like to save the information, the QR code will allow for downloading the AI-generated art as well.

4.3.4 Areas of Concern and Development

One concern for this potential project is the financial cost of the Muse 2 device and the possibility of damage if the display is a stand-alone stop-and-go exhibit. The Muse 2 is reasonably priced, but it still needs to be cared for appropriately to prevent any damage. Maintenance could be challenging depending on the expertise of whoever is responsible for the physical site of the exhibit. With a large number of users, the risk of accidents increases. In addition, only having one headset or setup would restrict the number of people we can reach simultaneously. If we can only have one person through every ten minutes (a generic estimate), we may struggle to reach people stopping by on campus.

To address this concern, we plan to continue brainstorming solutions and speaking with experts. One interview with a professor with experience in mixed realities and education suggested a walkthrough-focused exhibit rather than a stop-and-go one. We have also visited interactive exhibits on campus and plan to continue exploring options in the local area.

4.4 Technology Considerations

Hardware for EEG Signals: Muse 2

Strengths:

The chosen brain monitoring device we will be using is the Muse 2. The Muse 2 was chosen based on the physical design of the device, the technical specifications, and its current prominence in research fields as a well-regarded, low-cost, non-medical grade EEG device.

The device is easily adjustable for multiple different users with varying head sizes. Additionally, the device utilizes dry electrodes, which alleviates the complexity of using wet electrodes that require significantly more maintenance.

Weaknesses:

The downside of the device is the inaccuracy of the data if the user moves too much. This is something we would like to avoid, so it may be worthwhile to investigate one of the more expensive Muse 2 devices that incorporate a complete headband for better electrode-to-forehead connectivity.

Considerations:
An additional downside could be the sampling rate of the Muse 2. EEGs need to be sampled significantly higher than the nyquist rate in order to receive accurate results that can be used to find meaningful correlations between stimuli and brain activity. As of the present moment, many papers have been published on how the sampling rate of the Muse 2 does not pose a significant problem for the data. However, keeping the sampling rate in mind will be important if we implement AI for the art generation to ensure the AI does not need finer-tuned data to work with.

Software for Tablet App: Android Studio

Strengths:
Our main software will run on a tablet (likely running Android). Android Studio is proven, industry-standard software for developing Android apps. Additionally, the Muse 2 provides an API, which can be used with Android or iOS.

The apps produced with Android Studio can run natively on any Android device (assuming you can target its API level). They can also easily be multithreaded to speed up processing.
We would like to give our app a screensaver, and Android apps are capable of including a system screensaver, which can be set in device settings.

Several of our team members are familiar with Android Studio, and at least one has significant experience.

Weaknesses:
We may instead end up with an iPad. Android Studio will not work at all for this case.

Considerations:
A cross-platform development tool could be more viable if our hardware is unknown.

4.5 Design Analysis

Throughout this semester, we worked through the double-diamond design process. This process takes a team through multiple stages of design analysis.

We spent this first semester working through this design process's first diamond. Therefore, the chosen design discussed in section 4.3 will begin implementation as soon as possible since this is the design we converged on following primary research, secondary research, and deep dives on the included topics relevant to the Engineering Art Project.

Our design may change since we still have some areas of concern. However, for the present moment, this is the design we have chosen to implement because our analysis is that it is both feasible, engaging, and informative of reverse engineering the brain.

5 Testing

Testing in our project involves three main areas: unit testing, integration testing, and system testing.

5.1 Unit Testing

Our project can be divided into the following systems and units:

- Device Backend
  - Muse Signal Receiver
    - This unit receives data from the Muse and sends the signals to other units in the pipeline
  - Signal Denoiser
    - This unit acts as middleware for the signal pipeline which removes noise from signals.
  - Signal Value Extractor
    - This unit acts as a terminal for the signal pipeline, taking signals and using an algorithm--such as FFT--to extract values from a signal.
  - Web Signal Value Transmitter
    - This unit transmits signals from the device to the web server
- Web Backend

    - Signal Value Pipeline
        - Signal Value Receiver
            - This unit acts as a handler for received signals from the device and is sent to the Signal Value Collector and Art Generator
        - Signal Value Collector
            - This unit collects received signal values and stores in the signal repository
    - Art Generator
        - An abstract unit that can take in values generated from the signal pipeline and generate art from them.
    - User Data Repository
        - Signal Value Repository
            - Central repository to store previous user's data
        - ID Generator
            - Used to generate short (6 character) Unique IDs for users
        - User Data Repository Service
            - REST service used to access public user data
        - QR Code Generator
            - Used to generate QR Code images for linking to user data

- Device Frontend
    - Screensaver
        - Screensaver to show previously collected user data
    - Signal Visualizer
        - Visualizer to show raw signals collected from muse
    - API Client
        - Used to communicate with the backend
    - Art Visualizer
        - Used to show visualized artwork generated by backend
    - QR Visualizer
        - Final screen to show QR Code to access personal data

- Web Frontend
    - Personal Data Display
        - Display for personal data

These units will be tested separately, and our project will determine whether a feature is properly implemented. For the backend, units not being tested will be mocked using Mockito, and assertions will be done with both AssertJ and JUnit. For the frontend, we will use React and React Testing Library to test that frontend units are working as expected.

The testing strategy starts with creating a test for the system, then integration tests, then finally, unit tests. We will implement features until all unit tests succeed, then do the same for integration and system tests.

The Art Generator does not belong to a parent set of units because values will simply be transformed using a third-party tool to generate images. The UI does not belong to the parent set of units because the UI for this project is simply a set of screens to display information and does not require a complex state.

5.3 Integration Testing

The high-level unit compositions we are testing are:

- Signal Receiver & Transmitter
    - Primary purpose of the device backend is to receive signals, process them through a pipeline, and then send those values to the web backend.

- Signal Value Pipeline
    - An entry point to the web backend which receives signal values and submits them to the User Data Repository and Art Generator.

These compositions require combining units to make sure testing works successfully. The tools we are using for unit testing can also be leveraged to test these compositions. There are no compositions for the frontends or the Art Generator, as these units belong directly to the systems in which they are implemented.

5.4 System Testing

The systems we need to test include

- Device Backend
  - We must be sure that the device, when receiving signals from the Muse 2 can process them and send them to the web backend

- Web Backend
  - We must be sure that the web backend, when receiving signal values from the device, can process them into art and send that art back to the device frontend.
  - We must also ensure that when receiving signal values, those values persist to a repository that can be retrieved later.
  - We must also ensure that we can access the user data repository using a REST API.

- Device Frontend
  - We must make sure the device frontend can be interacted with appropriately, and when done so send data to the web backend and can visualize the data received.

- Web Frontend
  - We must make sure that the web frontend can view personal data collected by the web backend
  - We must also ensure that when given invalid input, the frontend gives an appropriate error screen.

- Installation
  - DJ Board
    - We must confirm the DJ board can control the volumes of songs safely.

  - CRTs - cathode ray tube box televisions
    - We must verify the CRTs display changes at expected times and remain safe for users and operators.

5.5 Regression Testing

Because of the nature of Test Driven Development, every new feature should have a test associated with it. When new functionality is introduced, all tests must pass before being merged into the code base. This will assure that previous functionality is not broken.

5.6 Acceptance Testing

Acceptance will be implemented by properly transforming requirements into tests that are used to implement new functionality using test-driven development. Test names will be verbose so we can easily check what is currently implemented vs. what needs to be implemented.

5.8 Results

Because of test-driven development, the results of our tests can assure us that our units, compositions, and systems are working as defined. This will give us assurance that our applications are fully implemented and working as expected.

5.9 Time Considerations

One of the main difficulties of this project was time. While we wanted to follow all the testing guidelines mentioned above, we knew we also needed a minimum viable product. Because of this, we opted to do manual testing--especially when it came to hardware. We were still able to verify that our project worked when needed and encountered minimal bugs when we performed user testing.

5.10 User Testing

Before our demo, we opted to perform user testing. During this time, we had many users test our project with a variety of input data. Our goal was to see what would attract people and what needed to change, so we created a Google form for people to fill out afterward.

User testing was a massive success, and we learned that our project was eye-catching and got people excited to learn more. We need to improve on guiding the experience while showing users the output, as they weren't always sure what they were looking at.

Fig. 10 *Photos of user testing in SIC.*

5.10.1 Quantitative Results from Google Form

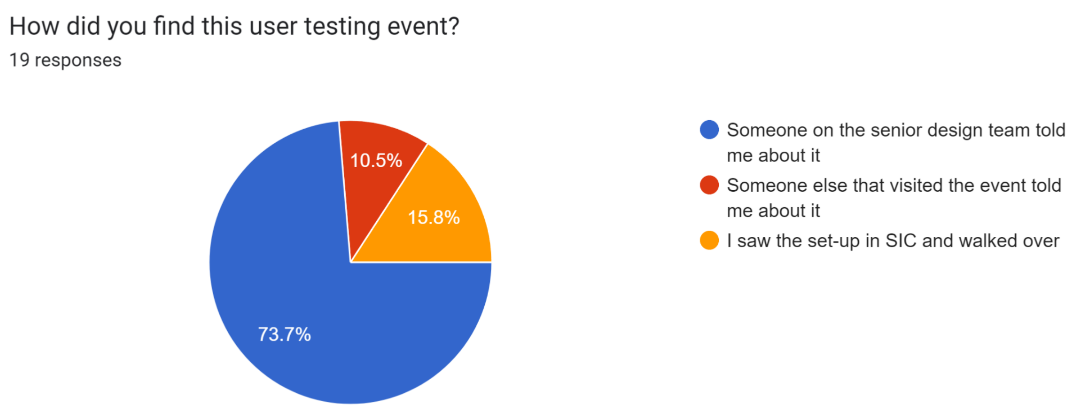


Fig. 11 *User testing Google Form question 1 results.*

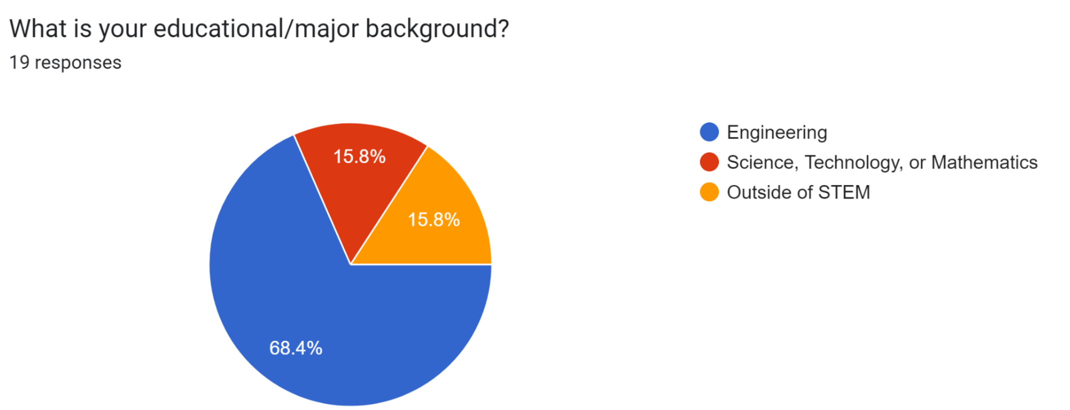
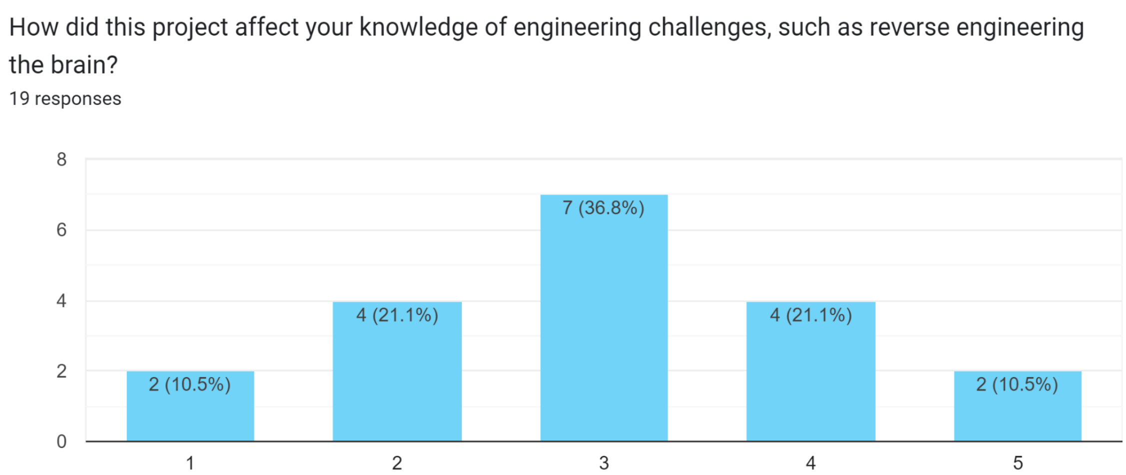
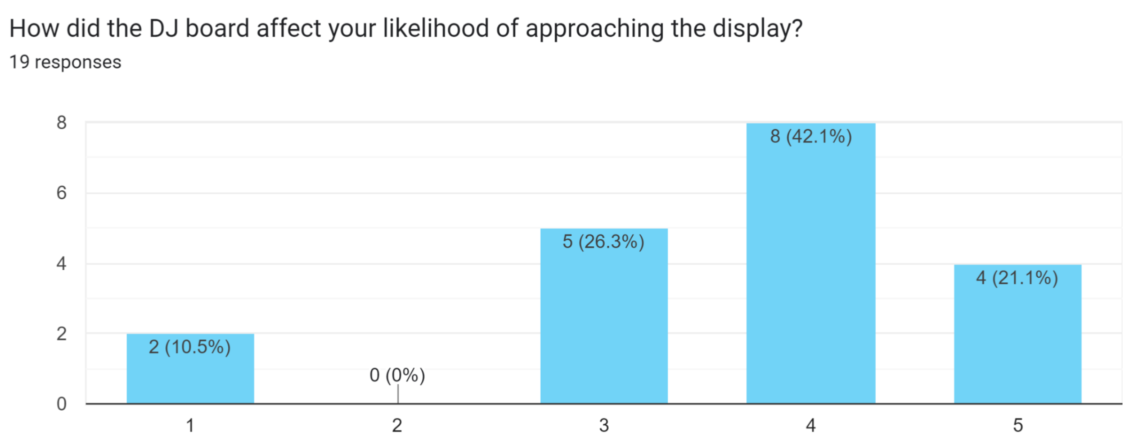


Fig. 12 *User testing Google Form question 2 results.*



Legend: 1 as "unaffected", 5 as "greatly increased"
Fig. 13 *User testing Google Form question 3 results.*



Legend: 1 as "less likely", 5 as "more likely"
Fig. 14 *User testing Google Form question 4 results.*

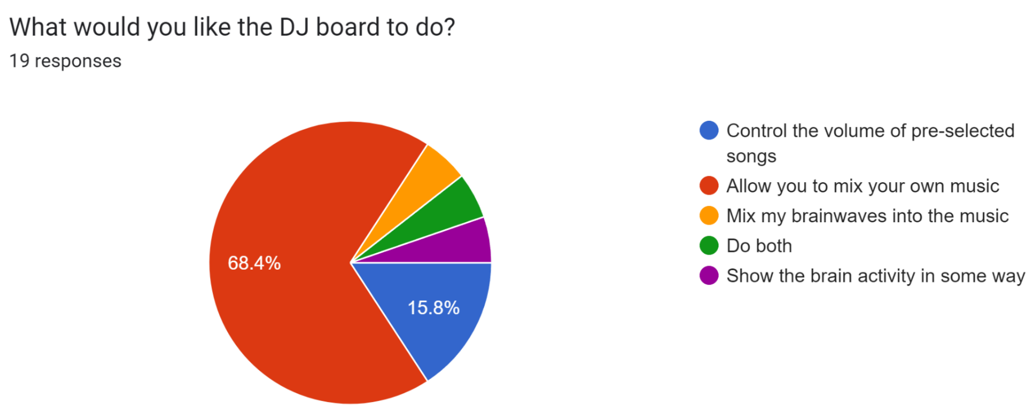


Fig. 15 *User testing Google Form question 5 results.*

6 Implementation

6.1 Required Elements

Muse 2

- Acquire device
- Tinker with, figure out how to get raw data from it

Tablet

- Acquire device
- Ensure tablet's OS version is recent enough and includes all required features

Tablet App

- Basic UI
- Ability to connect to Muse 2
- Ability to pull raw data from Muse 2
- Data denoising
- Ability to connect to web backend
- Ability to exchange data with web backend
- Beef up UI and add guided experience
- Polish UI and experience

Web Backend

- Ability to connect to tablet app
- Ability to exchange data with tablet app
- Art generation
- Ability to store and retrieve results

Web Frontend

- Basic UI for displaying results

Process Book

- Industrial Design practice requested by our advisor and client
- Shows visual elements of design process, such as sketchnoting

6.2 Revising Design for Areas of Concern and Development

One of our areas of concern and development was the state of our design as an "installation" and the level of interactivity we have offered to the users as they are getting their brain's scanned.

To help develop an art installation that would be attractive to users, we brought on a consultant, Professor Johnny DiBlasi, as he has experience in "visual culture specializing in scientific visualization and digital media." Professor DiBlasi was a massive help to help us create an attractive exhibit and give us resources for those who have done similar projects in the field.

Johnny DiBlasi - Assistant Professor of Art and Visual Culture

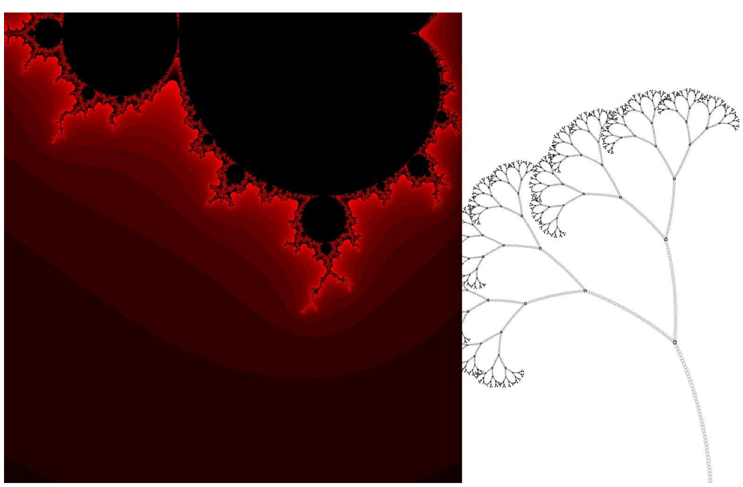


Fig. 16 *P5.JS generated image from Professor DiBlasi.*

Although we had the help of Professor DiBlasi, we wanted to develop a new team to better approach the concept of an art “installation” as well as incorporate more clear interaction from the users. We decided to add on an “installation” team whose main focus was to create installable hardware components that could be used by the users as well as visual the brain wave data in a unique way. We reached out to an Industrial Design student our team was familiar with as a consultant:

Parker Smith - Industrial Design student brought on as consultant

The main focus of the team was to develop ideas that could add additional functionality to the design and improve the level of interactivity. The installation team, in communication with other members of the team, performed research on what brings people to art exhibits, how art exhibits can incorporate hardware, and how reverse engineering can be a focal point of the installation through the integration of older technologies. One of the specific artists that influenced the design of the installation team’s additions was Nam June Paik.

Fig. 17 *Nam June Paik’s Piece “Electric Highway”.*

The following sketch shows the initial design considerations for the installation team. It added to the overall design as a hardware interface installation that would be used in tandem with the rest of the software components mentioned beforehand.

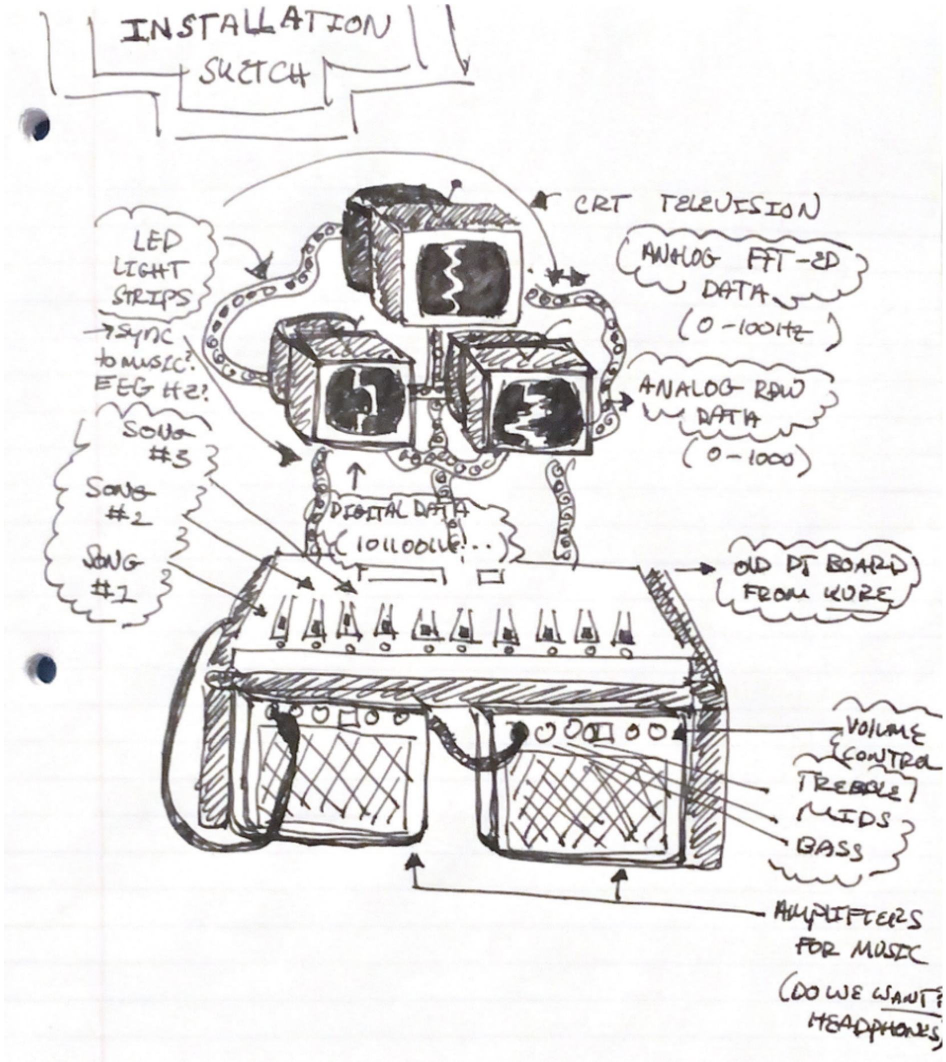


Fig. 18 *Initial Installation Design Ideas.*

EEG Signal Visualizers made from CRT TVs: CRT TVs that are converted into Oscilloscopes by modifying coil wiring to visualize EEG data .

DJ Board: Interactive User Interface for changing songs, volume level, potential for other integration uses as well.

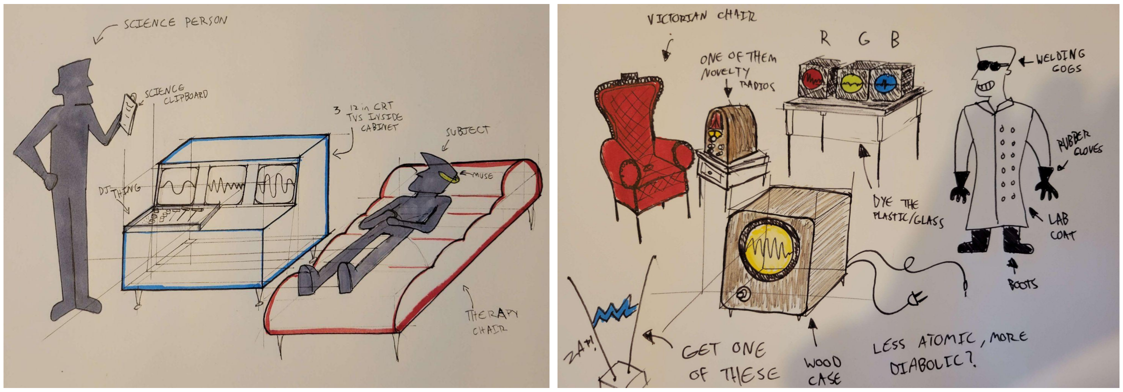


Fig. 19 *Ideation sketches by Parker.*

6.3 Implementation of Back End Architecture

6.3.1 Server and Muse Interaction

The backend is implemented as a TCP server. The frontend application sends information from the Muse 2 to the server to be processed. The transferred data is structured as packets. The structure of packets is described below.

<table>
<tr><th>Field</th><th>Information</th></tr>
<tr><td>Packet size</td><td>The total size of the incoming packet. This field is required if a malformed packet is received so we can know how many bytes need to be skipped.</td></tr>
<tr><td>Packet type</td><td>The type of data received. Possible values include:
<table><tr><td>0</td><td>Accelerometer</td></tr><tr><td>2</td><td>EEG</td></tr><tr><td>13</td><td>Alpha Relative</td></tr></table>These values are the same as the identifiers the Muse uses to identify their packets, so we decided to do the same.</td></tr>
</table>

Timestamp	Timestamp of when packet was received from the Muse.
Data length	Length of the packet data (array size)
Packet data	Data received from the Muse (array of double of length Data length)

Table 8 *Packet breakdown.*

Once these packets are received, they enter the “packet pipeline”. They are first aggregated by averaging the packets’ values over a configurable period of time. If this averaged value is considered small (less than 1) then the value is dropped.

These values are then translated into frequencies which are then passed into an audio synthesizer. The synthesizer we decided to use is JSyn (http://www.softsynth.com/jsyn/). This synthesizer then transforms these frequencies into an audio signal to be sent to an oscilloscope to display the analog values.

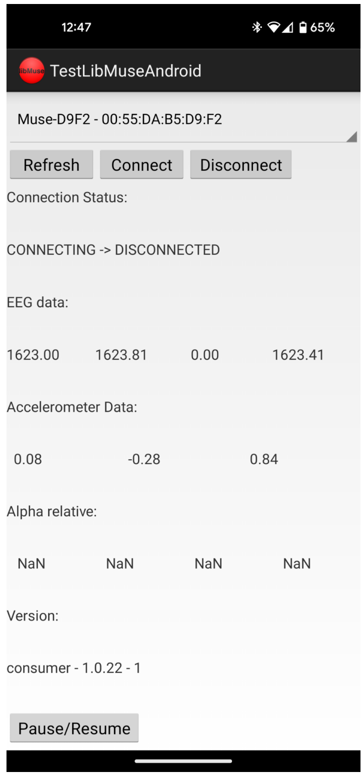


Fig. 20 *Raw data retrieved from Muse.*

6.3.2 Art Generation

As an initial version, MATLAB was used to generate art based on the user's Muse data. The Image Processing and Computer Vision toolbox allows the manipulation of digital photos through native functions. A CSV file created through the backend Muse connection is the source of a user's data. The MATLAB program accepts the location of this file, a unique user ID, and the desired save location of the generated image to create a computer-generated image:

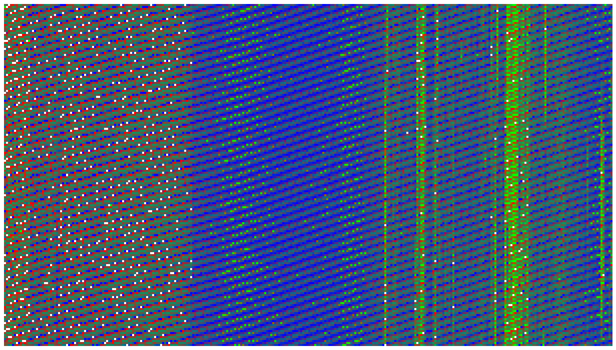


Fig. 21 *MATLAB image generated from Muse data.*

One stream of Muse data is used for red, green, and blue. The raw values are converted to proportions to limit the maximum value to one. The number of pixels in the generated image is capped based on the most common size of digital display, 9x16. To experiment with the most visually appealing art, a variety of sort methods and proportions were tested. Some examples are provided below:

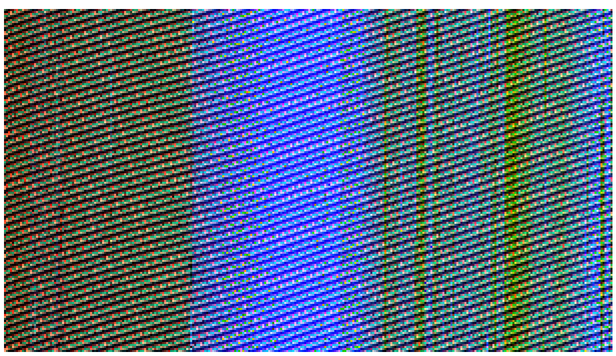


Fig. 22 *Generated image with max of each color proportion.*

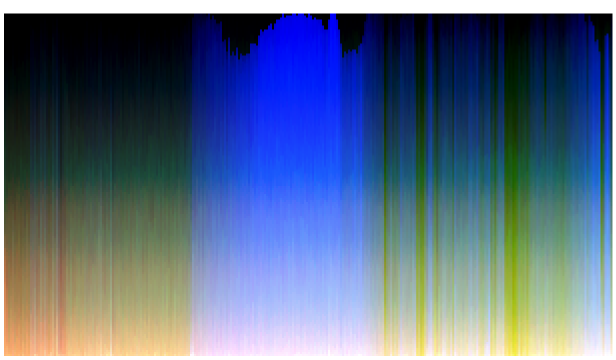


Fig. 23 *Generated image with max of each color proportion and RGB sorting.*

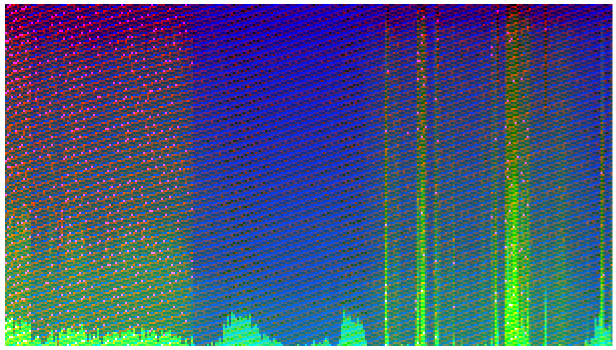


Fig. 24 *Generated image with RGB total proportion and only green sorting.*

Based on team and external feedback, we decided to use a proportion comparing the total of the three data streams and a sort of red, green, and blue separately.

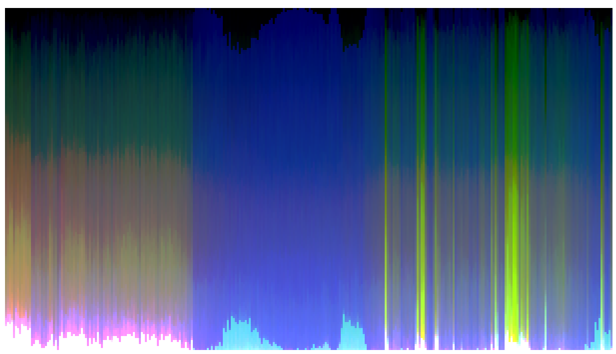


Fig. 25 *Generated image with RGB total proportion and RGB sorting.*

6.4 Implementation of Front End Architecture

6.4.1 Android Tablet App

The app for our Android tablet was designed for several purposes:

1. Receive data from the Muse and pass it on to the data collector
2. Display final artwork retrieved from the Backend team
3. Play audio files (alternative to DJ Board)
4. Provide some supplementary information about our project

The app was built in Android Studio in Kotlin using the fragment design pattern with a single activity. View Binding was used to make the process smoother. Implementation for each goal of the app is described below:

Purpose / Goal	Status and Process
Receive Muse data	**Implemented:** The company behind the Muse was nice enough to provide us with an API for interfacing with the device. This included an Android library and some sample code. The process for this was adapting their sample code to our specific use case (and translating it into Kotlin). This was easier said than done and constituted most of the work done toward this application.
Send Muse data to data collector	**Implemented:** The Muse sample application also had this functionality. Adapting the Java asynchronous calls to Kotlin equivalents was the bulk of what was done toward this goal..
Display final artwork	**Not Implemented:** Although the generation of the final artwork was successfully implemented, there was not enough time to complete the display.
Play audio files	**Implemented:** We used an open-source music player library for Android. The library's view is set to be invisible and is instead controlled by a simpler interface designed by Juno. This feature was implemented but was not used during user testing.
Provide supplementary information	**Partially Implemented:** All UI elements were prepared for it, but the code was never finished as we opted for other means to tell users about the project.

Table 9 *Android app goals and results.*

The app is designed as a 2-screen flow:

Screen 1 is a landing page with space and UI elements prepared for supplementary information. It also has a start button that sends users to the second screen.

Screen 2 handles the connection to the Muse. The UI here is very simple, consisting only of a button for connecting to the Muse and the simple music player UI (which is hidden due to it not being used). Muse connection was simplified by moving most of the process behind the scenes. Rather than having the user manually refresh, choose their Muse from a list, then connect, our app handles all of those steps itself and automatically connects to the first in-range Muse that is in pairing mode.

All UI for this app was built using Google's Material3 design guidelines concerning layouts, iconography, and color.

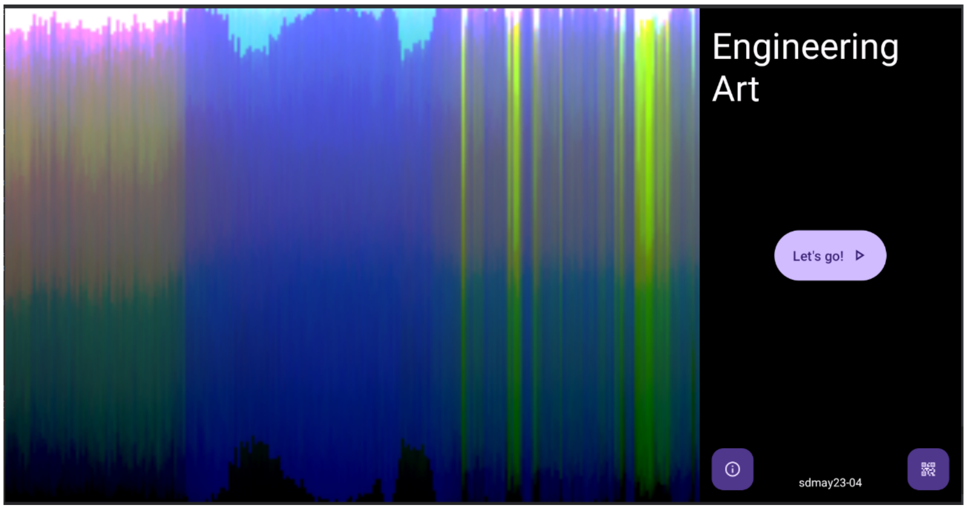


Fig. 26 *Frontend app UI.*

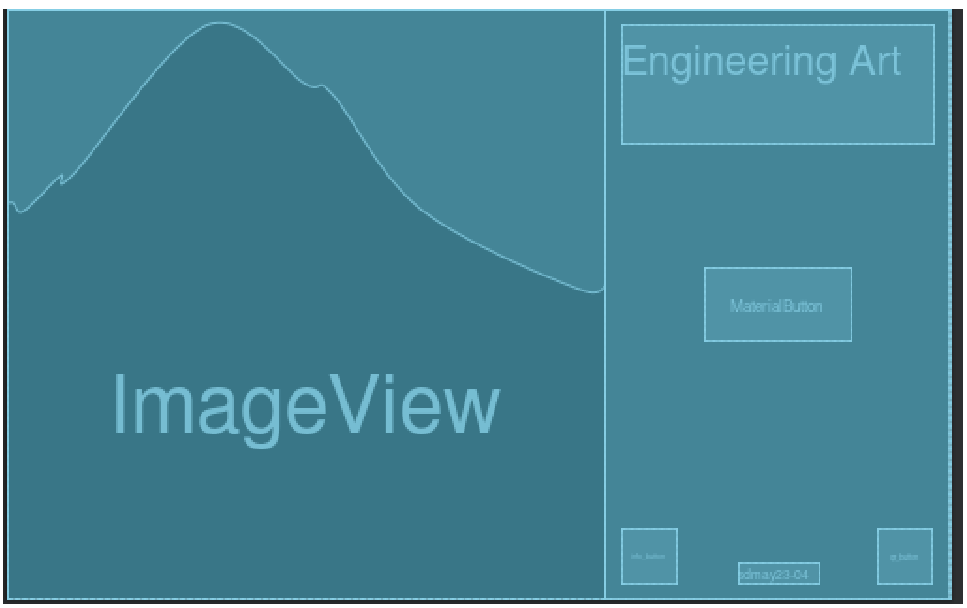


Fig. 27 *Frontend app constraint layout.*

6.4.2 React App

The web frontend will act as a portal for users to access their generated art via a QR code. It follows a React structure using Javascript and CSS. A MySQL database will store the user's generated image with a unique ID as a key. By scanning the QR code, users will request their ID's associated image, ensuring the data remains anonymous but accessible.

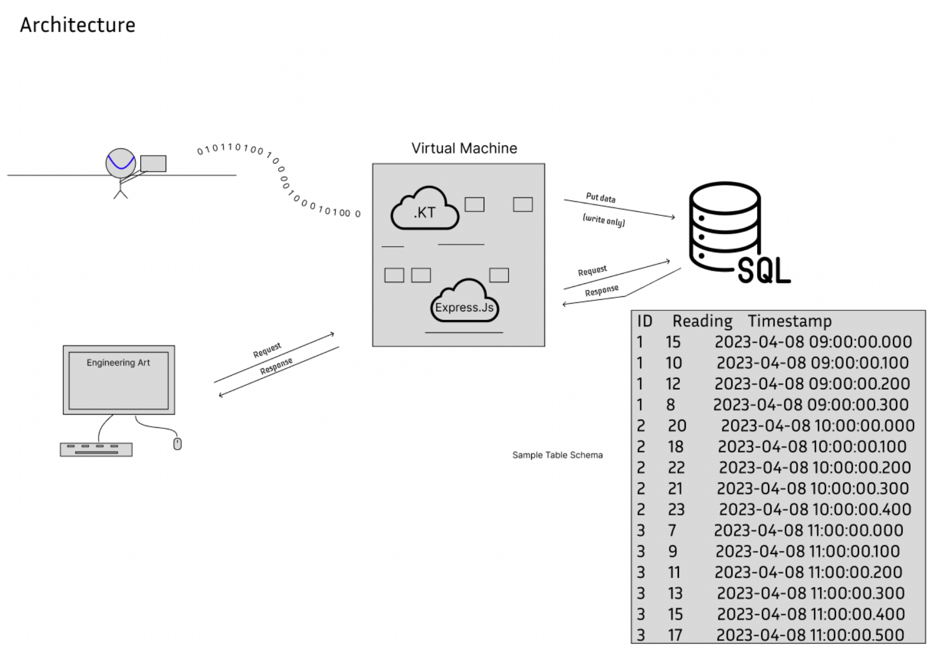


Fig. 28 *Web frontend architecture diagram.*

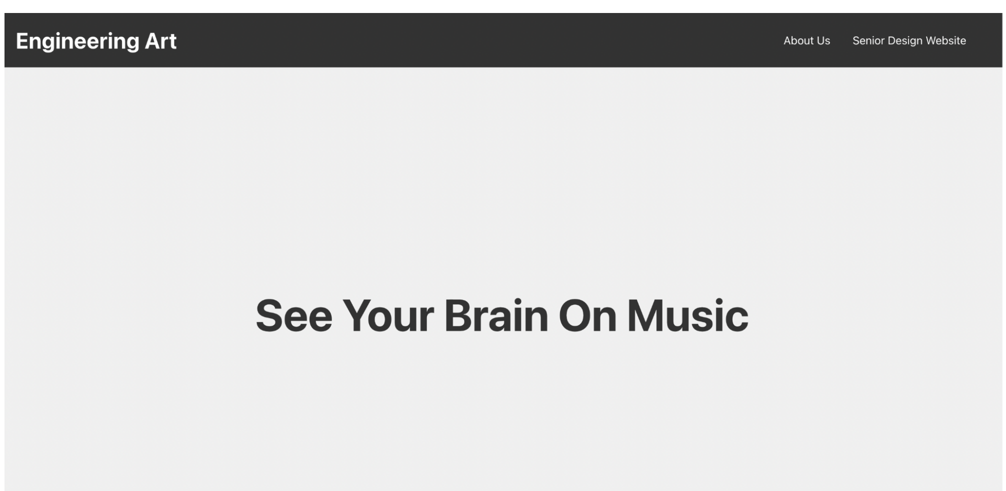


Fig. 29 *Initial React app UI.*

6.4.3 Process Book

The process book was requested by our advisor and client, Rachel Shannon, to show our work in a visual way. It is a common practice in the field of Industrial Design. We will host ours through GitHub. The implementation is modular to simplify uploading and captioning photos. The site is written using Javascript and CSS.

6.5 Implementation of Installation Design

6.5.1 DJ Board

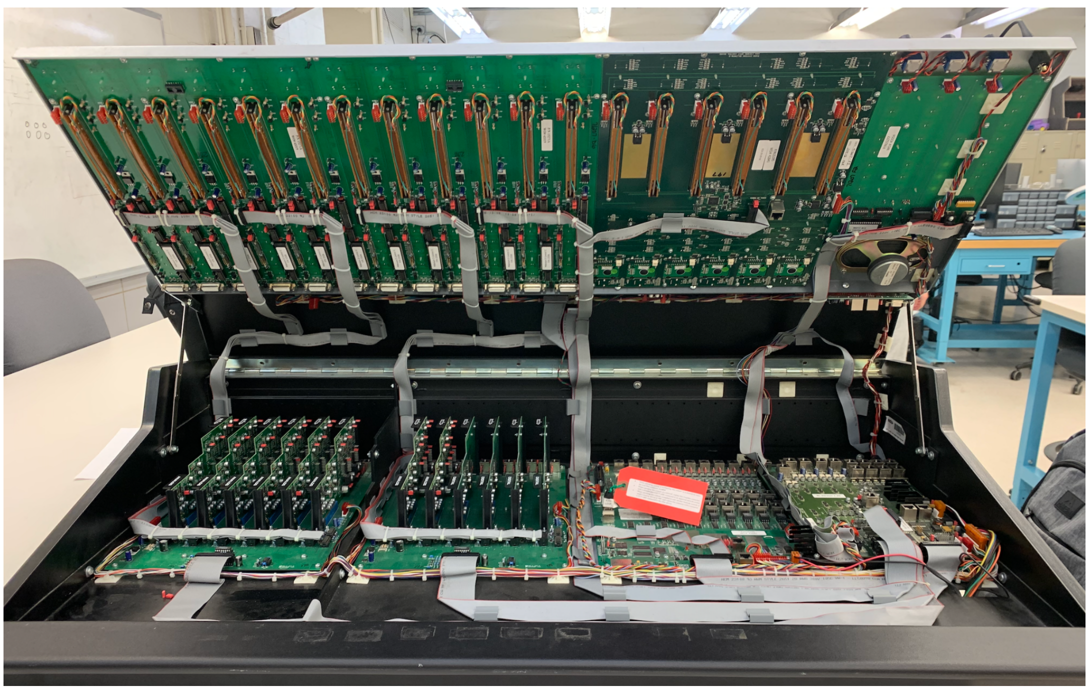


Fig. 30 *Internal components of DJ board.*

The main purpose of the DJ board was to provide a user interface that was tactile, interactive, and intuitive for choosing or changing music to see how different songs affect the brain waves visualized on the CRT Televisions we turned into Oscilloscopes.

We did not have the DJ acquired until after spring break due to reasons pertaining to lack of funds and the need to have the donation approved by the KURE advisors before using it.

Due to this, we were limited in the amount of time we had to troubleshoot and integrate the DJ board. The DJ board went through multiple iterations as an incorporation in the design. Initially, we attempted to use its standalone functionality, but after encountering issues with it (See section 6.6.2) we opted instead to interface with the Teensy 4.1 board.

We created a few designs for the wiring of the DJ board and the Wiring of the Teensy 4.1. By the time of the User Testing, we had completed the wiring of all the faders and working functionality of 4 out of the 18 faders on the board, which comes down to the limitations of the Teensy board and the need for further work in reducing the number of analog pins needed through the use of a multiplexer or other methods.

6.5.2 EEG CRT Signal Visualizers

Fig. 31 *Internal components of CRT.*

The main purpose of the CRTs was to provide the users with a method of visualizing the EEG signals when the users were waiting on their brain to be scanned while listening to music. By having the users able to see their brain waves in real-time, they were able to see how different actions and music affects their brain waves in real-time.

To implement these EEG signal Visualizers, we tried to gather a few different CRTs so that users could see different stages of brain wave data being transformed. The danger of working with the CRTs and the lack of manuals for the early 2000's versions we were able to get for free made the process of modifying the CRTs quite difficult and ended up blowing out the flyback transformer on one of the three CRTs we had when attempting a modification.

We realized very quickly that no two color CRTs are the same, and certain TVs can handle certain modifications that other TVs cannot handle, so with that said, we resorted to the one modification that we had NO smoking CRTs with, and that successfully displayed sinusoidal waves when testing.

We used many resources for modifying TVs; for color TVs, we realized we would need to cut all four wires, blue, yellow, red, and brown, going to the coils, and rewire them with the following modification:

Original Wiring:

- Yellow Wire: Vertical Coil and Supply
- Blue Wire: Horizontal Coil and Supply
- Red Wire: Horizontal coil and Supply
- Brown Wire: Vertical Coil and Supply

Modified Wiring:

- Vertical Supply (Yellow Wire) to Horizontal Coil (Blue Wire ()
- Horizontal Supply (Blue) - Unused with Electrical Tape
- Horizontal Supply (Red) - Unused with Electrical Tape
- Vertical Supply (Brown Wire) to Horizontal Coil (Red wire)

Fig. 32 *Initial waveform visualized on the CRT.*

6.6 Problems and Solutions in Implementation Phase

6.6.1 Backend

Problem:

A major issue that occurred when implementing the communication between the device backend and web backend was the frequency at which we were receiving packets from the muse. The issue occurred because whenever we received a packet, we would create a new thread to send the packet on a separate network thread. Network communication on a separate thread is a requirement for Android devices which is why we did this. The reason this issue occurred was because spinning up a new thread is expensive, so doing this 72 or more times per second was unfeasible.

Solution:

We were able to solve this issue by creating just a single network thread whose job was to send packets to the server, and the thread in which Muse data was received could queue packets to be sent. We discovered that this worked, and the speed at which packets were sent was sufficient.

6.6.2 DJ Board

Problems:

The DJ Board was donated to the Senior Design Team after Spring Break. We worked with the KURE station to ensure that the device was no longer in use at the station and attempted to confirm that the board worked by testing power and communicating with workers at the station.

As soon as the DJ board was acquired, we began testing its functionality and were unable to get sound of it. This preliminary testing period went on for about two weeks, where we studied the user manual and schematics, and contacted the company that provides support for the board.

Troubleshooting Work:

1. Testing the output of analog inputs to headphone jack
2. Connection to Configuration Software
3. Testing Test Points on the Board with Multimeter
4. Communicating Issues with The Company's engineers and testing their troubleshooting methods as well

Solution:

The solution for the DJ Board, after two weeks of troubleshooting its inability to output any analog inputs to any of the channels or headphone jack was to instead use the DJ board as dummy keys for an interface with an Arduino-like or Pi-like board. Considering the time, we had to work fast, and after researching the best methods of interfacing audio equipment, we settled on Teensy 4.1.

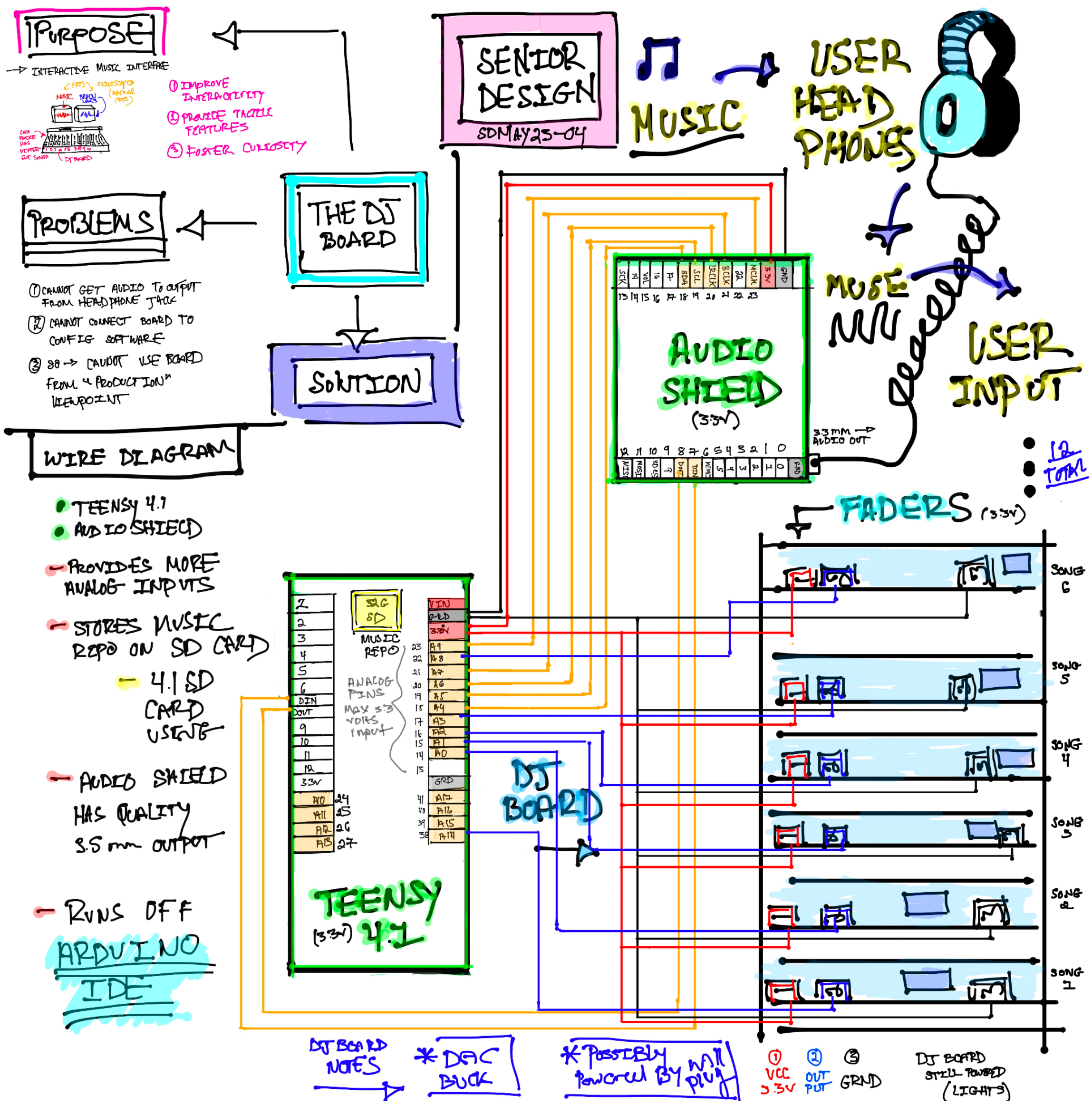


Fig. 33 *Sketch of solution to DJ board issues.*

6.7 Integration Testing Results

Initially, during Integration, we simply converted values received to CSV. An example of the output of this program formatted as a table can be seen below:

EEG	1678205 4170740 86	824.7985 348	825.2014 652	825.2014 652	825.2014 652	NaN	NaN

EEG	1678205417075216	824.7985348	822.7838828	825.2014652	819.96337	NaN	NaN
EEG	167820541707538 4	850.5860806	826.007326	797.8021978	828.4249084	NaN	NaN
EEG	167820541707548 2	769.5970696	848.974359	901.7582418	869.9267399	NaN	NaN
EEG	1.67821E+15	1089.120879	667.6556777	437.5824176	570.5494505	NaN	NaN

Table 10 *Partial output of Muse CSV.*

Once we had data, we then worked to convert that data to an analog signal, which we could view. Below is a photo during user testing, which shows an analog signal.

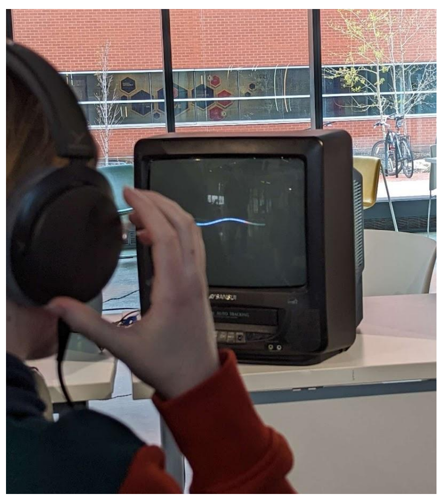


Fig. 34 *Analog signal on CRT.*

6.8 Problems and Solutions Integrating

During the integration, we occasionally ran into errors. First was the difficulty using the built-in Java audio synthesis framework. With some research, we did find an open-source library that worked (Jsyn), and we decided to use that.

Our next problem was that we had no idea what values would look good on our oscilloscope. In order to get a pretty looking wave on our oscilloscope, we had to experiment with different values and also change values on our amplifier. We eventually found values that pleased us, but even on user testing day, we had to reconfigure our amplifier when demonstrating.

The day of user testing, we had issues with one of our modified oscilloscope-TVs not displaying data. To resolve this, we decided to open up the tv and fix it on the spot. We believe this actually helps bring our exhibit attention because of people's curiosity.

The other problem we had with integrating the DJ board was related to the fact that only four of the faders had sound coming out of them, so to integrate the DJ Board, we decided to open it up as a method of bringing people over and talked about the issues we were having, and what they would like to see the DJ board do, since the Teensy 4.1 opens up many doors for us, such as turning the DJ board into a device that allows the users to make their OWN music instead of listening to songs, which is our current design.

6.9 Future Goals of Implementation

Backend:

- Store the generated art to allow users access at a later date
- Transition to AI-generated art through P5.JS
- Use accelerometer and gyroscope data from the Muse to correct EEG

Frontend:

- Integrate MATLAB art generation
- Display generated art for users via QR code

Installation:

- Implement audio-mixing with different instruments, tempos, etc. based on user testing feedback
- Color changing waveform on CRTs
- Additional CRT displays for multiple brainwaves, music audio, etc.

Fig. 35 *Red waveform on CRT.*

7 Professional Responsibility

This discussion is with respect to the paper titled "Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", International Journal of Engineering Education Vol. 28, No. 2, pp. 416–424, 2012

7.1 Areas of Responsibility

Area of Responsibility	NSPE Definition	Corresponding Code of Ethics
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence	**IEEE:** To have high standards of your own work. I. To uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities. **ACM:**

		Don't bite off more than you can reasonably chew, and complete as quality work. 2.1 Strive to achieve high quality in both the processes and products of professional work. / 2.6 Perform work only in areas of competence.
Financial Responsibility	Deliver products and services of realizable value and at reasonable costs.	**IEEE:** To follow laws and regulations, and not take bribes. I4. to avoid unlawful conduct in professional activities, and to reject bribery in all its forms; **ACM:** Don't spend excessively or unnecessarily, and don't accept payment unfairly. None applied.
Communication Honesty	Report work truthfully, without deception, and are understandable to stakeholders.	**IEEE:** To give and receive criticism, correct any issues that arise, do not lie about data, and give credit where credit is due. I5. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others; **ACM:** Be honest. Respect confidentiality.

		1.3 Be honest and trustworthy. 1.6 Respect privacy. 1.7 Honor confidentiality.
Health, Safety, and Well-Being	Minimize risks to safety, health, and well-being of stakeholders.	**IEEE:** Respect safety, privacy, well-being, and the environment. I1. to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment; **ACM:** Prioritize safety above all else. 1.2 Avoid harm.
Property Ownership	Respect property, ideas, and information of clients and others.	**IEEE:** Don't do anything that will cause physical or mental harm to others. I9. to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses; **ACM:** Respect others' work and contributions. Don't plagiarize or steal. 1.6 Respect privacy. 1.7 Honor confidentiality.
Sustainability	Protect the environment and natural resources locally and globally.	**IEEE:** To have empathy for the public. Think of ethics in the design process. Disclose information that users or consumers should know. Such as data breaches.

		I1. to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment; **ACM:** Maintain sustainable manufacturing and supply practices. Focus on sustainability for the environment and company/people. None applied.
Social Responsibility	Produce products and services that benefit society and communities.	**IEEE:** To help society in general understand technologies. I2. to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems; **ACM:** Work toward the benefit of humanity and society. Follow Wheaton's Rule. 1.1 Contribute to society and to human well-being, acknowledging that all people are stakeholders in computing. 1.4 Be fair and take action not to discriminate.

Table 11 *Areas of professional responsibility.*

7.2 Project Specific Professional Responsibility Areas

Area of Responsibility	Definition	Project Application
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence	High - Obviously in our context this is one of our first big projects in our career. It is important to have integrity.
Financial Responsibility	Deliver products and services of realizable value and at reasonable costs.	Low - We are not working with a lot of money, but we still need to be reasonable with the cost of items.
Communication Honesty	Report work truthfully, without deception, and are understandable to stakeholders.	High - Working with a large group it is important to communicate effectively. Our project needs to create interest in a certain topic, it can be tempting to use deception to create even more interest in the topic.
Health, Safety, and Well-Being	Minimize risks to safety, health, and well-being of stakeholders.	Medium - Safety is always an important aspect. We need to create a safe product as well.
Property Ownership	Respect property, ideas, and information of clients and others.	Medium - We need to respect the ideas of teammates and the experts that we work with.

Sustainability	Protect the environment and natural resources locally and globally.	Low - What we will make will not affect the environment in a positive or negative way directly.
Social Responsibility	Produce products and services that benefit society and communities.	High - The purpose of our project is to create an installation that educates the public. Social responsibility is built into our project goals.

Table 12 *Project-specific priority for areas of professional responsibility.*

7.3 Most Applicable Professional Responsibility Area

The most applicable Area of Responsibility for our project is Social Responsibility. Our project aims to create an experience for the public and for those users to be impacted by the said experience. As mentioned in section 7.2, the project goals include Social Responsibilities.

8 Closing Material

8.1 Discussion

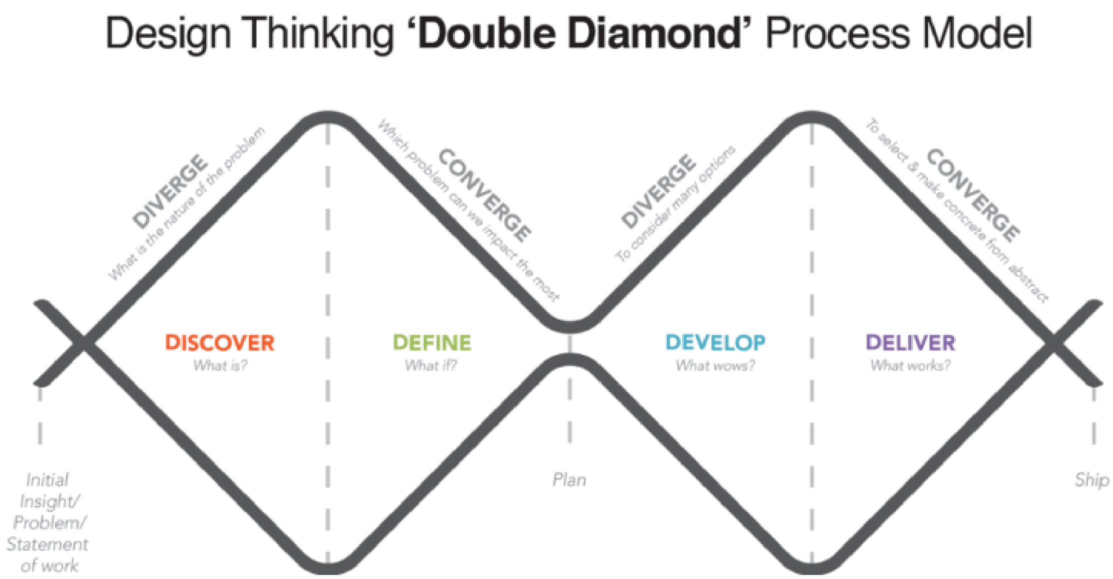


Fig. 36 *Double diamond diagram.*

Our design is currently following the double-diamond process. Our project differs from other groups because our group started without a defined project or many constraints. We were given a general direction and have been narrowing our focus throughout the semester. Much of our first semester has been the Discover and Define phase of the double diamond; we've been conducting a lot of primary and secondary research individually and as a team. After finally nailing down our problem statement, we've decided to create an interactive art exhibit to help gain interest in reverse engineering the brain to help improve AI.

Our second semester focused more on implementation, which is where more teams began their project. We were provided the opportunity to practice our engineering skills and learn new ones as we journeyed through an Industrial Design-style of thinking.

8.2 Conclusion

Since our project is unique, we have gone through great learning and growth.. We have selected a problem--reverse engineering the brain--and created a rough draft of a problem statement to give us direction. We discovered and did a ton of primary and secondary research. We've interviewed multiple faculty members around campus and visited locations pertaining to our project, such as museums and exhibits. Next, we re-addressed our problem statement and refined it. We did some higher-level research after readdressing our problem statement. After conducting additional research, we finally reached our final problem and created our project. Where most groups had their assigned problem and general solution from the start, we have worked from scratch to define our problem and develop a solution. Overall, our group has enjoyed collaborating and following the Double Diamond Process model to solve our problem. Most engineers don't go through this model, so it gave us some insight into Industrial Design (which we enjoyed).

8.3 References

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Note: Most of the research done is in reference to reverse engineering the brain, specifically around how this research helps improve AI

Resources on Extracting Data From Muse 2 Device

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Steens, Camille. "The Best Interactive Museum Experiences around the World." *Tiqets.com*, 19 July 2021, https://www.tiqets.com/blog/interactive-museum/.

Note: We're not following any previous work as we are building a new interactive exhibit, but we are not the first people to build an interactive exhibit. There are specific benefits that interactive exhibits give, such as the ability to gain more interest and keep users engaged, but with drawbacks, such as complexity. These pros and cons were balanced before we started the project and decided as part of the requirements given to us.

Installation Resources

Teensy 4.1 Website **https://www.pjrc.com/store/teensy41.html**

Turning CRT Into Oscilloscope

https://www.instructables.com/How-To-Make-A-CRT-TV-Into-an-Oscilloscope/?amp_page=true

9 Appendices

9.1 Operation Manual

9.1.1 Starting the Backend

The first process that must be started is the backend server which receives packets from the device. This can be done by using the command `./gradle run` within the `data-receiver` project. This requires the user to have both gradle and Java installed. At this point, you will want to connect an audio cable to the device you are using. Typically, this is through a 35 mm headphone jack.

9.1.2 Starting the Frontend

Once the backend is up and running you are able to start the Android application which will be used to connect to the backend. Open the application on an Android device. The device will automatically connect to the server which is specified in the code. If the IP address does not match your server's IP address in the code, update this and rebuild the application. Once the device is connected you will receive a message on the server saying "client connected"--at this point connect the Muse using documentation provided by your Muse device. On the application, click "Connect Muse" to get connected. At this point, you should be receiving messages on the server noting the data that is being received.

9.1.3 Connecting the Backend to Displays

Once the backend is running, you can connect the backend to the oscilloscopes. To do this, connect the amplifier to the pc running the server and the amplifier to the CRT. Turn on the CRT. Once the backend and frontend are running, you should see a signal on the CRT.

9.1.4 Brain Wave Oscilloscopes (CRT EEG Visualizers)

Warning: *CRTs are high-voltage devices. Be careful of serious injury from capacitors, the flyback transformer, and the cathode ray tube. Always make sure the CRT is powered off and unplugged before making any major modifications, especially ones you are uncertain of.*

Unfortunately, no specific manuals exist for most CRTs. The operation of the CRTs solely dedicated our purpose in the installation requires previous modifications as described in our documentation.

Using the CRTs in Conjunction with the Installation:
Each CRT has a spliced audio cord routed through the back. These allow for ease in connecting the CRTs to the amplifier speaker. The amplifier speaker should be connected to the computer with the server running the backend. The other CRT may be connected to it as well using an audio splitter.

1. Turn on the CRTs, ensuring the backend is running as well, and the signal will be visible on the CRT.
2. Adjusting the volume of the amplifier will adjust the amplitude of the signal
3. Turn off, unplug, and store safely with the backs screwed on when not in use.

Modifying the CRTs:
The backs of the CRTs can be unscrewed to adjust modifications if needed. However, this should be done with caution and proper research on the color CRTs. The aforementioned connections, included below, are the only major modifications to the CRTs besides the disconnecting of the audio wires to the CRTs speakers.

Original Wiring:
- Yellow Wire: Vertical Coil and Supply
- Blue Wire: Horizontal Coil and Supply
- Red Wire: Horizontal coil and Supply
- Brown Wire: Vertical Coil and Supply

Modified Wiring:
- Vertical Supply (Yellow Wire) to Horizontal Coil (Blue Wire ()
- Horizontal Supply (Blue) - Unused with Electrical Tape

- Horizontal Supply (Red) - Unused with Electrical Tape
- Vertical Supply (Brown Wire) to Horizontal Coil (Red wire)

9.1.5 DJ Board Audio Interface

The DJ Board Audio Interface has a standalone Operations Manual included in hardcopy, and a PDF version is included here as a resource. However, since heavy modifications were made to the integration of the DJ board, a guide on operational use of the board interfaced with the Teensy 4.1 and it's associated audio shield is included below.

Using the DJ Board In Conjunction with the Installation:
Songs are already loaded on the Teensy, but can be changed by opening up the DJ board. To insert the DJ board, insert an Allen wrench into the fader slider and pulling up on the board. Using pliers to hold the Allen wrench is easiest.

The Teensy is located inside of the DJ Board. If songs are loaded, and the Teensy is running on the standalone powersource, then the only other optional set-up is connecting the DJ board to its own power source for the lights on the DJ board. Other than this, the DJ board is ready to go.

Users can move the faders on the DJ board to change songs, or mix their own music depending on the sketch loaded to the board. The current state of the sketches is limited to songs, but can expand to other applications such as having users mixing samples together to create their own music while seeing their brain waves on the CRTs.

The pin connections are included in the extra information section of the manual.

Using the Teensy 4.1 to Load Songs/Samples:
The Teensy is an Arduino based microcontroller designed for audio applications. This board has 18 analog input pins, which are the main focal point of the interface with the DJ board. Each analog pin is connected to an analog input of a sliding fader on the DJ board. To load or change songs, simply connect a micro-USB from the Teensy to a computer running the Arduino and Teensy 4.1 software. Arduino and Teensy 4.1 software can be downloaded at this web address: https://www.pjrc.com/store/teensy41.html

The code for the DJ board is included in the Git repository.

1. Connect the Teensy 4.1 to a computer running the Teensyduino or Arduino software with the Teensy extensions added to their library.
2. The Teensy 4.1 has a 32 GB SD card associated with it. This SD card can be loaded into an SD card reader and connected to the computer for the addition or removal of audio files. Connect the SD card.
3. Drag and drop or copy over the files with the names you would like to the SD card. Eject the SD card before removal.
4. Open the sketch titled "Installation_Configuration" and change the names of the files to the desired ones you would like to load into the respective faders.
5. Very and Load the sketch to the Teensy 4.1 board.
6. The Teensy can be unhooked from the computer and powered via a portable power bank.

At this point, test the DJ board to ensure no errors were made in loading the sketch or its functionality.

9.1.6 MATLAB Art Generation

The location of the MATLAB art generation program must have MATLAB and the Image Processing toolboxes installed. It can be run remotely on a server or on a local computer.

To run the MATLAB art generation algorithm, the CSV file created through the backend connection must exist. After connecting to the server, the MATLAB file can be run using:

```
matlab -nodisplay -r "generateImg(input-path-and-filename>,
<output-path>, <userID>)"
```

An example usage of this command with a unique user ID is provided here:

```
matlab -nodisplay -r "generateImg('output.csv', '~', 47)"
```

9.2 Team Contract

Team Members:

1) Nathan Underwood
2) Ayden Boehme
3) Liz Fransen
4) Shelby Murray

5) Tomas Elias
6) Juno Robertson
7) Cosette Thompson
8) Derrick Brandt

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:
    a. Scheduled on when2meet
    b. Usually at Parks Library, prefer to meet in-person and virtual if needed
    c. Once a week, with additional meetings planned as needed
2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):
    a. Discord, preferred face-to-face, otherwise online option
3. Decision-making policy (e.g., consensus, majority vote):
    a. Consensus so far, majority vote if needed if consensus fails
4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):
    a. Shelby – note taking
    b. Tomas – note organizing
    c. Shared in Discord server or Google Docs/Drive

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
    a. Arrive to planned meetings on time, and notify if unable to attend on time or at all
2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
    a. Reach out if need help
    b. If you can't make a deadline, don't wait till the last minute to communicate with group members
3. Expected level of communication with other team members:
    a. Expect to be in communication with each other on a daily basis, several times in the week at the very least
4. Expected level of commitment to team decisions and tasks:

a. It's a senior design: “Make it count.”

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):
    a. Note-Organizing: Tomas
    b. Note-Taking: Shelby
    c. Communication & Team Organizing: Liz
    d. Additional roles to be added as the project is developed
2. Strategies for supporting and guiding the work of all team members:
    a. Join the work channel on discord even if you're alone to encourage collaboration
3. Strategies for recognizing the contributions of all team members:
    a. Dedicated time during our meetings for shout-outs of accomplishments

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

Group Members	Tomas Elias	Nathan Underwood	Ayden Boehme	Liz Fransen
Skills	4 years of coding experiments, with experiences in various group projects	Frontend and backend development, hardware and network security / forensics	Knowledgeable in Java, as well as a familiarity with C. Currently learning	Industrial experience in full stack development

			frontend development.	
Expertise	Software development, lots of experience with frontend coding,	Network security and architecture, unix, embedded systems	Java coding; unix; theoretical foundations and proofing of CprE and ComS	Great with cloud development, architecture, and design patterns
Unique Perspectives	Very approachable and open to new ideas, really big geek	Previous experience in secure programming in commercial setting	Lots of experience with group projects; enjoys psychology and taking unique approaches	A lot of experience doing consulting.

Group Members (Cont.)	Shelby Murray	Juno Robertson	Cosette Thompson	Derrick Brandt
Skills	various programming languages (Java, C, C++, MATLAB), development practices	Strong in C, Java, Kotlin. Experience with SQL, Neo4j. I have a knack for more visual things, but I perplexingly also like embedded software.	Lots of C, C++ knowledge. Experience with signal processing, hardware interfaces, and software interfaces	Web development. SQL. Figma. Java. C#. Cloud engineering. Angular. React. Linux.

Expertise	firmware, frontend software development, education / TAing	2 years professional experience with Android Studio and Kotlin. UI/UX design. i like to ***polish*** my apps	Signal processing techniques, acoustics, C based languages, MATLAB Simulink	Figma
Unique Perspectives	previous experience in industrial design, world film	screenwriting, photography, cinematography, video game design, sketch art, piano, acting. I do all sorts of stuff. It could be relevant!	Probably taken too much philosophy for an electrical engineer. Love working with students as a mentor on the EE 185 team.	

2. Strategies for encouraging and supporting contributions and ideas from all team members:
    a. Brainstorm and list/draw on the whiteboard, discussion to build on and narrow down, reach consensus

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)
    a. Communicate
    b. Reach out to members if they seem disengaged
    c. Stand up time at each meeting

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
    a. Develop something that is unique, creative, and interesting
2. Strategies for planning and assigning individual and teamwork:
    a. Plan to assign work catered to group member's strengths and interests
3. Strategies for keeping on task:
    a. Planned working sessions
    b. Open and honest communication

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?
    a. First infraction – Addressed by team members
2. What will your team do if the infractions continue?
    a. Second infraction – Communicate with advisor or professor
    b. Third infraction – request removal from team

****

a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*
b) *I understand that I am obligated to abide by these terms and conditions.*
c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

1) Elizabeth Fransen	DATE 09/22/2022
2) Tomas Elias	DATE 09/23/2022
3) Ayden Boehme	DATE 09/22/2022
4) Shelby Murray	DATE 09/21/2022
5) Juno Robertson	DATE 09/22/2022
6) Nathan Underwood	DATE 09/23/2022
7) Cosette Thompson	DATE 10/27/2022
8) Derrick Brandt	DATE 03/06/2023

9.3 Miro Board

Link to Miro Board

9.4 Team Website

http://sdmay23-04.sd.ece.iastate.edu/

9.5 "Anything Funny but Relevant"

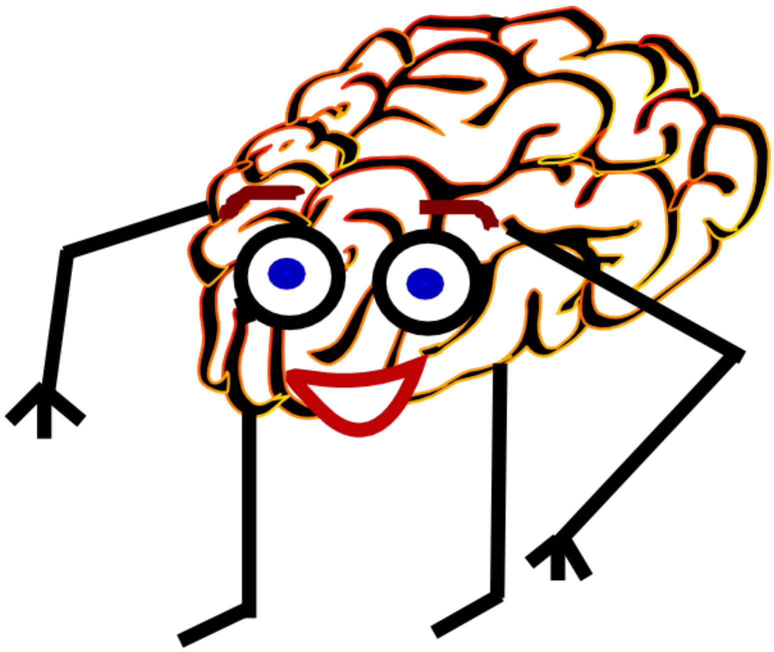

Fig. 30 *Our team mascot, Brian.*