Design Project 2 - Dexii

Design Team 3

Cornerstone of Engineering II: GE 1502

Megan Anderson, Chaimaa Assli, Dominick Doyle, and Anjali George

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M. Anderson, C. Assli, D. Doyle, A. George
Design Team 3
Northeastern University

Professor R. Whalen
Northeastern University
Boston, MA 02115
April 18, 2023

Dear Professor Whalen,

For our final design project of the semester, we were tasked to solve an open-ended problem through a device of our choice. Our team chose to direct our focus on constructing an assistive device to assist people with a certain disability. After further refining this problem statement we decided, through the use of refinement techniques, that we wanted to construct a device to improve users overall hand dexterity, mental focus, and coordination through the use of a game-like interface. Within this problem statement we decided that we wanted to play to a wide range of audiences including children, individuals recovering from hand injuries, the elderly, and anyone looking to improve overall motor function and mental sharpness. We found the need for such a device and audience as the elderly experience a significant decline in hand dexterity as they age and our device works to counteract this. Also, fine motor skill exercises in developmental age children have been shown through studies to lead to enhanced problem-solving skills later in life. Our overall aim with our device was to provide a solution for those individuals looking for a simple way to improve hand coordination, focus, and patience.

Our initial ideas to solve this problem included a lot of different game oriented designs with the intent to maximize user engagement and actually incentivize people to use our device. With these designs in mind we landed on Dexii, our final prototype design. This prototype features ten colored 3D printed textured buttons placed to optimize user hand placement and comfortability. For this placement we considered average hand size as well as the orientation of common devices that require finger pressing such as keyboards and pianos. Each button also has a corresponding LED placed in a row above. For the game design we went with a simon says style game where the leds output a pattern and the user is expected to push the corresponding buttons in order to repeat the pattern back. With each win the pattern grows and the difficulty in turn gradually increases. At the top of the device is an LCD display which clearly walks the user through the start of the game and also displays the current level as well as the users all time high score. The hardware and components are all organized within a 3D printed shell containing multi-level interior shelves to house all necessary parts. The buttons, leds, and LCD can all be accessed by the user from the top faceplate of the device which contains corresponding slots for each. The device is battery powered and contains an on-off switch that can be accessed via the faceplate. Ultimately, our prototype successfully achieves our desired problem statement and provides users with a fun interactive way to improve both motor and cognitive function.

From this project we learned more skills essential to being a successful engineer such as 3D printing, modeling, construction, soldering, and coding. We learned how to professionally present our design including client updates and long-format presentations. Our team learned how to work better collaboratively and play to the individual skills that each team member brings to the table to achieve the best result possible. In the end, we gained a deeper appreciation for the circular orientation of the engineering design process and how sometimes you need to rewind to make steps forward. Our team as whole became a lot closer throughout this process and we feel that we have all grown exponentially as not only engineers but as people.

Sincerely,
Design Team 3

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Abstract:

Hands are vital in our daily life to perform tasks, solve problems, and even communicate. Many individuals, including the elderly and young children, experience a significant decline in hand dexterity without proper exercise. Common devices on the market tend to provide polarized solutions to this issue, focusing on only improving either motor function or cognitive skills. With this in mind we wanted to create a device that provides a fun and engaging way to improve hand dexterity, coordination, memory, and focus. Our prototype, Dexii, is a simple and interactive device with a game-like interface designed to help users develop their manual dexterity and mental function. Within the device we wanted to prioritize a simple user interface and construct a fun, level based game. The game design features a simon-says style game where the user is prompted to repeat a random pattern outputted through 10 LEDs by pressing the corresponding button. While the game progresses the LCD walks the user through the game, while also displaying their current level and all time high score. This device features an exterior 3D printed shell designed to hide all of the internal hardware components while also making the buttons, LEDs, LCD, and on/off switch accessible for the user. The interior components are arranged within a two tier shelving system in the form of a grid to make the hardware easily accessible and organized. Our prototype successfully accomplished our intended design function and objectives while also staying well within the 100 dollar cost constraint. If given more time we would make improvements to the buttons in the prototype, to make them more provide more spring resistance and be better accessible. One other improvement we would make would be to make the device slightly more compact as we realized that there was a bit of empty space not being used within the shell. Lastly, we learned a lot throughout the entirety of this design process and feel we really developed as engineers when getting to use our skills to solve a real-world issue.

Problem and Definition:

For this design project, our team saw a need for an improved way to improve hand coordination and strength. The use of one's hands is vital to day-to-day life. However, there is a large number of individuals including the elderly, those recovering from injuries, and even small children, who are unable to complete everyday tasks because of issues with hand function. Therefore, we identified a need for a device that can help improve this ability by training one's hand to improve functions, specifically coordination and strength.

Our initial idea to solve this problem was to create a game that helped an individual strengthen their hands and improve coordination. However, we utilized problem definition techniques (Figure 1 & Table 1) to narrow down and refine the true problem we were trying to solve. From these techniques, we concluded an interactive game was a suitable option to help address our need to improve hand function. Therefore, our team goal was to design and create this type of device. However, given the identified alternatives to solve this problem, we saw that depending on the progression of prototyping and design work, it might later become clear that an alternative physical therapy device is more effective or practical.

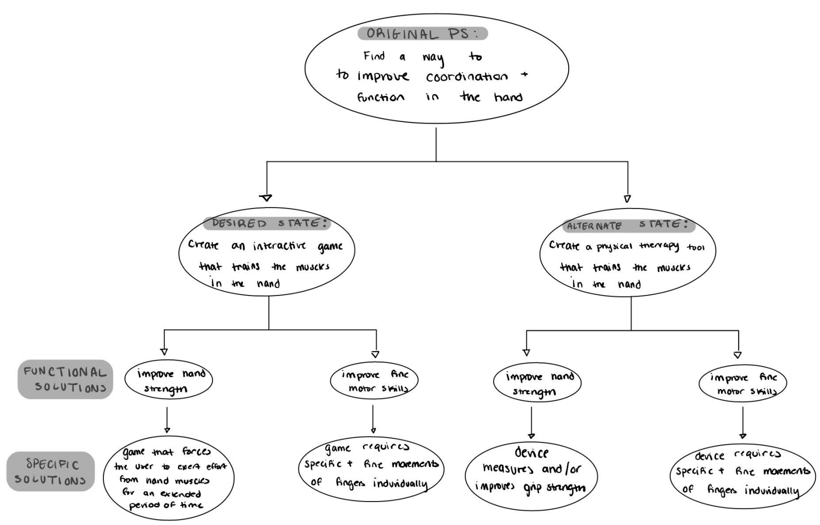

Figure 1, Duncker diagram problem definition; Diagram outlines multiple paths and creates multiple solutions, including solutions that do not satisfy the desired state. This diagram helped identify high-priority areas during the design stages of our project. (Team 3, 2024)

	Is	Is Not	Distinction	Possible Cause
What	Inefficient or under-performing hand function	Specific to one singular function of the hand	Versatility and range of needs and of applications	Dysfunction related to strength, coordination, dexterity, etc.
Where	In the hand and forearm	Specific to any one set of muscles, tendons, or joints in the hand or arm	The broadness of what anatomical areas must be addressed	The different parts of one's hand and arm work together, so dysfunction in one affects the function of all
When	Any age group or population that requires improvement in hand function; could be expanded to all people	Confined to one population, age group, etc.	Versatility and range of needs and of applications	Since hand function is vital to day-to-day life, 'dysfunction' can range in severity and affect many populations
Extent	Can vary in extent based on an individual's situation (ie. injury, the general decline in function, etc.)	Specific to one type of injury or dysfunction	Versatility and range of needs and of applications	Dysfunction can be caused by a range of conditions and can thus vary in severity

Table 1, KT problem analysis matrix; Matrix was created to aid in the identifying process of potential causes of our identified need. (Team 3, 2024)

The initial function of our design was to improve the overall function of the hand. Additionally, our original objectives included creating a device that could be used for both the left and right hand, was ergonomic and comfortable for the user, and included a game and interactive interface to incentivize use. Additionally, we wanted our design to be easy to transport and appeal to children and adults alike. Our design must also be able to be developed and prototyped for under one hundred dollars while limiting plastic use and overall environmental impact.

The final step in refining our problem statement was determining what objectives were most important to include in the design. We created a rank-order comparison of our various objectives (Table 2 below) First and foremost, the most important objective was creating a device that was functional, meaning it correctly took input and displayed outputs that followed the code of our intended game.

Accessibility was also important to our design as we wanted the device to be able to be used by a wide range of audiences. This specifically meant creating a device that was lightweight and did not need to be connected to external power so it could be moved. Next, we wanted our device to be compact. In order to achieve this objective, we aimed to create designs in which the top surface area of the device was approximately the size of a keyboard. This metric would allow for the device to be big enough to be ergonomic for the user without taking up any excessive space. Lastly, we wanted our device to be low-cost to produce in order to stay within the class budget and we wanted to be able to fabricate it in a timely manner.

Objectives	Compact	Accessible	Functional	Low Cost	Time Sensitive	Sums
Compact	X	0	0	1	1	2
Accessible	1	X	0	1	1	3
Functional	1	1	X	1	1	4
Low Cost	0	0	0	X	.5	.5
Time Sensitive	0	0	0	.5	X	.5

Table 2, Rank Order Comparison; Diagram outlines the importance of each objective of the potential design. This diagram helped identify high and low-priority objectives to focus on during the development stages of our project. (Team 3, 2024).

<u>Background Research:</u>

Audiences:

Our intended audiences for this device were the elderly, people recovering from hand injuries, and children. The elderly often experience a significant decrease in the strength, accuracy, and overall function of the hand. This can be due to metabolic and skeletal diseases, malnutrition, decreased physical activity, and minimal exercise. are commonly associated with aging and can contribute to this decline [7]. Additionally, degenerative diseases such as Parkinson's which is significantly more common in the elderly than in other age groups can contribute significantly to hand dysfunction [10].

In order to resolve these control and strength issues, there are a few key areas of the hand that can be addressed with physical therapy. This includes prehension, which is the ability to grasp objects, often measured by a hand-grip strength test. Prehension abilities are heavily correlated to muscle mass in the hand. Therefore, since individuals over the age of sixty generally lose a substantial amount of the muscle fibers in their hands, prehension is often decreased in this population. Another area of decline is tensile strength, which is the maximum force the tendons in the hand can bear before breaking. In old age, tensile strength can decrease by up to fifty percent. Lastly, it has been proven that about twenty percent of motor axons in the hand are lost in old age. This part of the hand is responsible for the conduction of nerve impulses and its reduction results in less control of the hand [7].

While these struggles can be detrimental, they can be improved upon by simply using and exercising the muscles in one's hand regularly. People who exert a significant amount of time and effort into consciously exercising their hands generally see improvements in hand dysfunction. This is supported by the fact that musicians and people who play instruments for the majority of their lives face fewer struggles and dysfunctions in the hands [7].

Another audience that experiences struggles with hand function is individuals recovering from hand injuries. In injury rehabilitation, some of the main areas of focus are range of motion, sensory reeducation, and strengthening. Focusing on a patient's range of motion decreases the chances of joint contracture, which is a progressive weakness and reduced mobility in joints that is associated with inflammation or arthritis. Additionally, hand injury patients often face hypersensitivity that causes severe pain while completing normally stimulating tasks. This can be prevented by therapies that re-establish stimulation early on. Lastly, post-injury the hand is generally weaker due to lack of use. Therefore, therapies that increase muscle mass in the hand are ideal as they can help increase strength and prevent any disorders that could result from an injury [12].

The last audience we intended to benefit from our device was developmental-aged children. Children cannot master writing and many other essential motor skills without proper muscle development. In order to perform these tasks at a high level, children need to develop muscle control, patience, judgment, and brain coordination [2]. It has been found by past studies that children who have acceleration fine motor skills experience high achievement later in life. This same study identified a motor-cognitive dependency, indicating that both sides of the brain are active when motor and cognitive activities are performed independently. These results provide a strong basis that early motor skill development will not only lead to heightened hand skills but also to higher rates of cognitive development [1]. There are currently many activities directed toward children that utilize developmentally appropriate experiences to improve fine motor skills. These tasks include squeezing, matching, sifting, pressing, and other small task games [2].

Patents:

During the research stage, we found a few key patents and products that are relevant to the problem we aimed to address. The most common patented design we found was hand-exercising devices featuring independently activated spring buttons. These devices, such as the “Finger, Hand, and Forearm Developer” [4], the “Adjustable Grip Developer” [5], and the “Hand Development System" [6] (Fig 2) are intended to improve hand strength and motor skills of the user. While this technology is successful in that purpose, it does not maximize the users' use of both cognitive and motor skills, and thus other devices must be used to supplement those skills. Additionally, these devices are not incentivizing for the user, ultimately reducing their effectiveness as they would not be utilized as much.

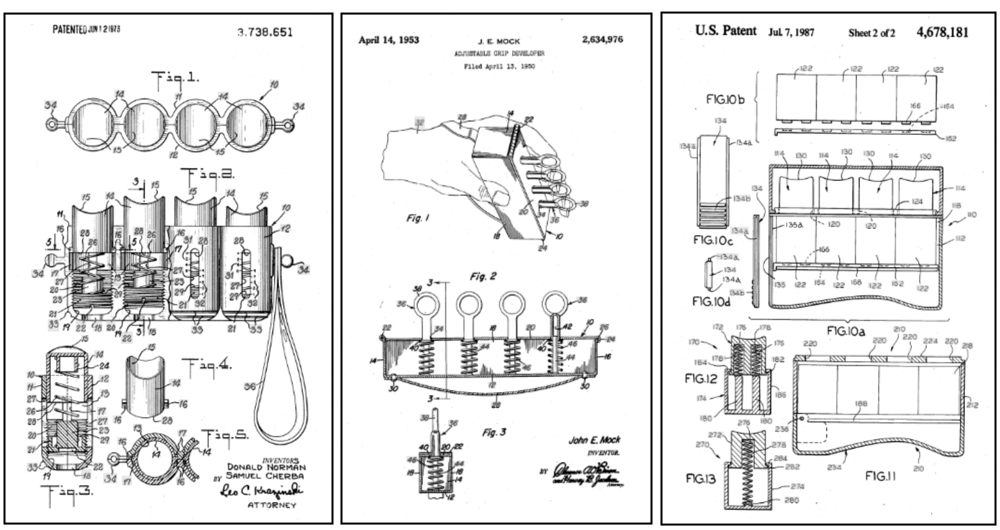

Figure 2, Motor Development Patents; Pictures of patents similar to our intended design that feature a spring-loaded button pressing feature to improve motor skills (Norman, Mock, Ditsch, 2024)

Other patents investigated include the “Game Panel Simulator” (Fig 3), developed by the Department of Neuro and Pathopsychology at Moscow State University [3]. This device directs its focus toward restoring fine motor skills, visual-spatial memory, and intellectual activity in patients of a neurological clinic. This device is meant to be used in neurorehabilitation and for restoration. The device features holes with corresponding cylinders which can be used to play a variety of games that utilize motor skills. The disadvantage of this design is that it is mainly intended for group exercises and doesn’t feature many games that allow individuals to restore fine motor skills without a partner. Another drawback is the sheer size of the device, as it requires a large flat surface to be played on.

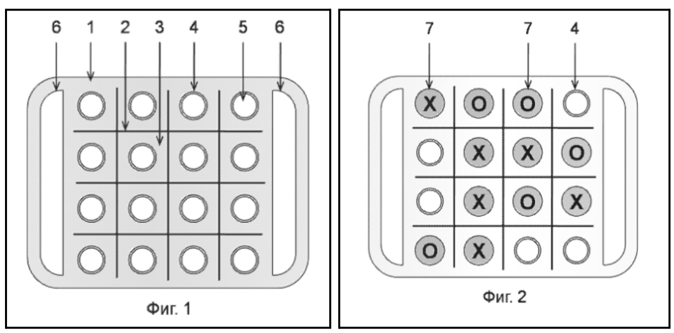

Figure 3, Neurorehabilitation Motor Restoration Device; Pictures from the patent of the game panel device which provides patients a means to play a variety of games working to restore and develop fine motor skills (Селявко, 2024)

In addition to patented products, we also researched current physical therapy techniques and the devices they use. Many of these therapies use devices that aren’t invented for the sole purpose of hand rehabilitation. For example, to improve strength, hand exercises are completed with stress balls and silly putty. These methods help build strength, grow muscle fibers, and focus primarily on hand dexterity. Additionally, exercises that involve stacking coins and pinching clothespins are often used to help improve coordination and fine motor skills [20]. In general, current methods emphasize the conscious use of muscles in the hand in order to improve upon or gain back control, coordination, and strength.

Technical Research:

In the initial stages of this project, we envisioned our device to be fabricated out using an Arduino red board and made Sparkfun electronics and components. Therefore, we had a significant amount of working technical knowledge about the intended components due to using them in previous projects. However, we quickly realized that in order to maintain the ergonomics of our device we would need to alter the Sparkfun buttons we intended to use. We initially looked into how the buttons functioned so we could learn how to solder them to jumper wires in order to maintain ergonomics in our device. Additionally, we did research on the specifications of the Sparkfun buttons (Figure 4 below) in order to design the shell of our device around the measurements.

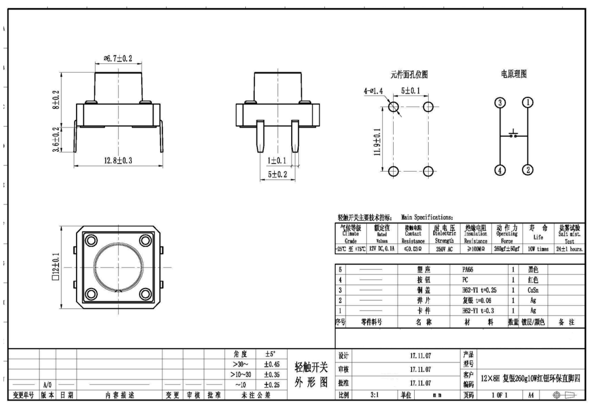

Figure 4, Sparkfun Multicolor Button Model; Technical drawings and specifications of Sparkfun buttons our group intended to use.(Sparkfun, 2024)

Final Problem Definition:

Problem Statement: Design and create a device that improves hand function, specifically coordination and strength. The device should be ergonomic, include a game and interactive interface, and should be able to be used with both hands. Additionally, the design should be easy to transport and appeal to users of all ages. Lastly, the device should be developed and prototyped for under one hundred dollars and should minimize the use of materials that are harmful to the environment.

Figure 5, Problem Statement; Refined problem statement for the design project (Team 3, 2024)

Generating & Decision:

Generating Design Alternatives:

In order to generate ideas to fulfill our design objectives, we utilized a few key generation methods. First, we used brainstorming techniques to come up with a variety of initial ideas that would achieve our main function of creating a game to improve hand function (Figure 6 below). We wanted to gather a large range of ideas and ways to creatively address the problems, so we spent multiple team meetings sharing and expanding on different ideas. These initial brainstorming sketches all feature a common aspect of utilizing the pressing activity in combination with a trigger event to prompt the user's hand development. What differs between these devices is the focus on multiple hands in comparison to a singular hand, as well as the mechanism intended to trigger the pushing of the button from the users.

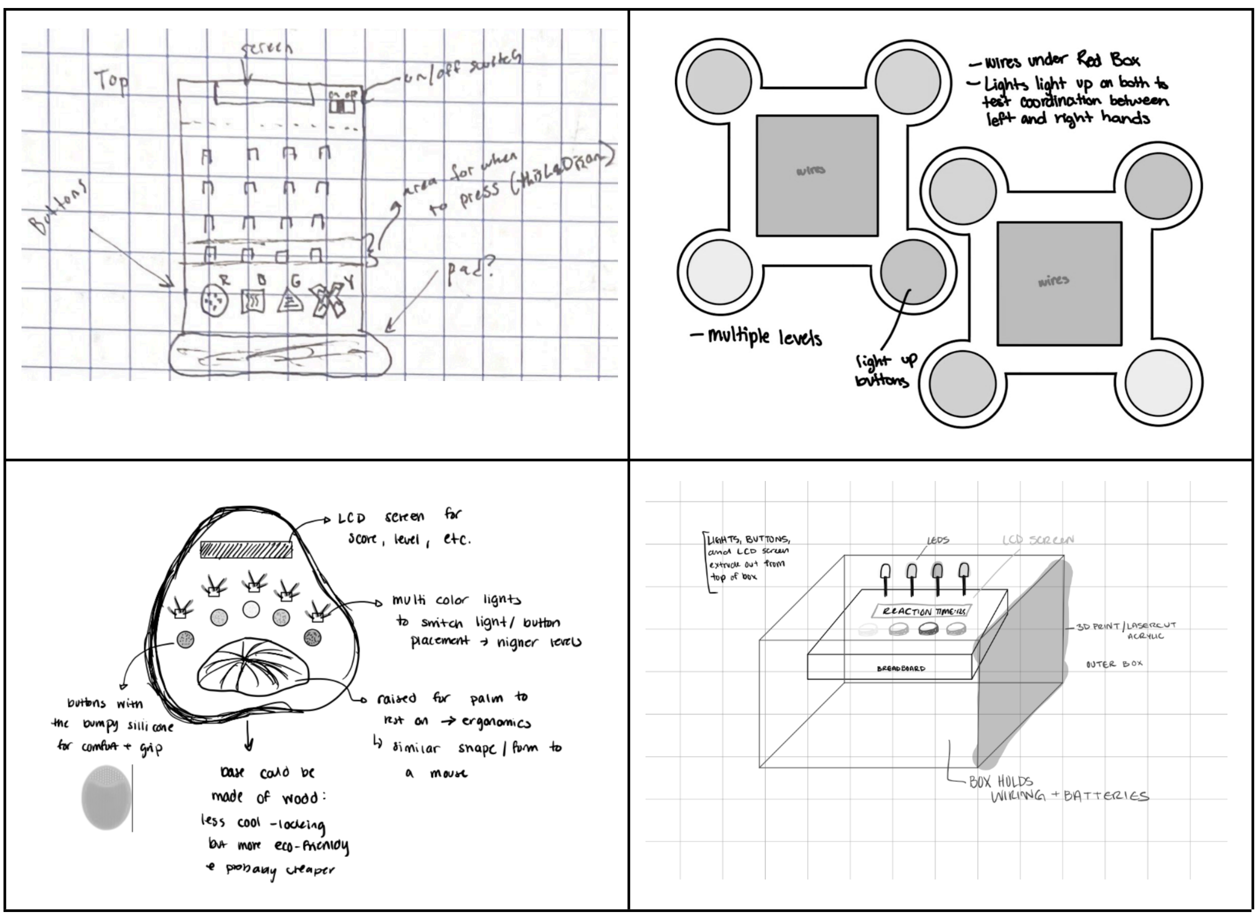

Figure 6, Initial Sketches; Each team member's initial design sketch of their design vision (Team 3, 2024)

After coming up with some initial ideas, we utilized the bionics brainstorming method in order to model our designs off of the human hand. This method allowed us to come up with various ways to prioritize and achieve ergonomics in our device. We researched statistics for average hand size, finger length, and ideal spacing between keys/buttons. We then used these measurements to map out an ideal button placement to be added to our design sketches (Figure 7 below).

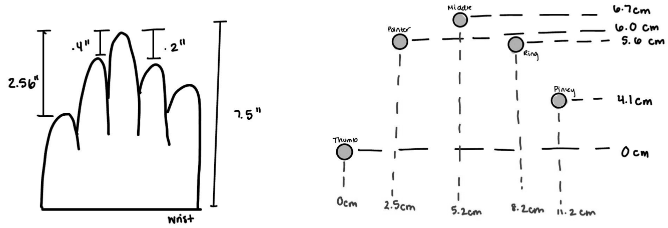

Figure 7, Initial Sketches and measurements for button placement. (Team 3, 2024)

From these initial brainstorming techniques, we narrowed down our designs which can be seen in the following figure (Figure 8). These designs work to successfully achieve our design objectives as previously described. Within both designs, it can be seen that the intended device featured ten buttons, for each finger, to be pressed in accordance to the game being played. Each button possesses a corresponding LED, placed directly above the button. Both designs feature a fun, visually appealing exterior design as well as hidden internal hardware. On the top of the designs, the LCD screen is situated to display the information back to the user. The main difference between these designs was how the internal wiring and components were to be organized. Design One featured a single-layer device in which all of the components would be placed on one layer. This design would be faster and easier to fabricate using 3D printing. However, Design Two featured a multilayer design in which the components could be stacked on top of each other creating a more compact device.

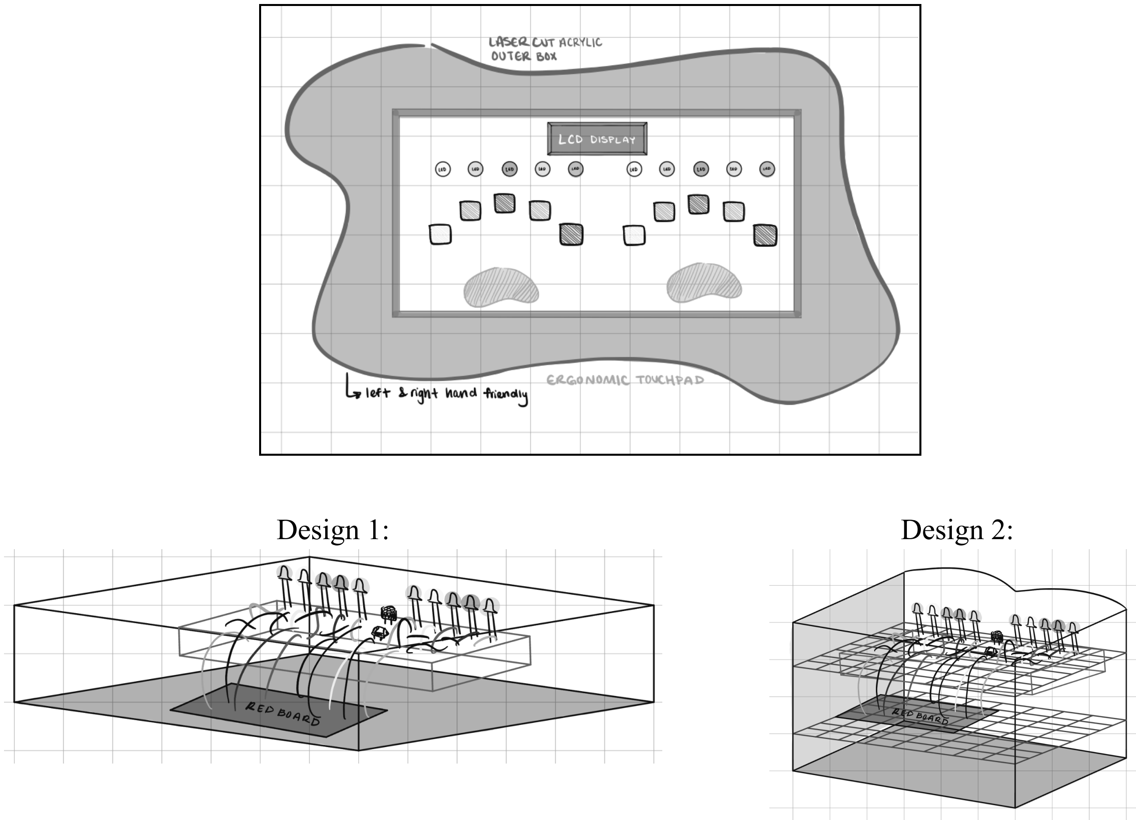

Figure 8, Final Design Sketches; Depicts developed designs used during the generation phase. (Team 3, 2024)

Evaluating Design Alternatives:

After coming up with our final two design alternatives, we utilized a Decision Matrix to finalize our plans. We created weighted categories based on our Rank Order Comparison Analysis (Table 3 below), and compared the two designs to determine which achieved our design objectives best.

Objectives	Compact	Accessible	Functional	Low Cost	Time Sensitive	
Weights	65	80	100	30	25	
Alternative Designs	Rate Value / Rate Value x Weight					Totals:
Design 1	9/585	6/480	7/700	8/240	7/175	2180 ✘
Design 2	8/520	10/800	8.5/850	7.5/225	10/250	2645 ✔

Table 3, Decision matrix; Made to help determine the best course of action in the fabrication of our device (Team 3, 2024)

Based on the results of this decision matrix, we ultimately decided to move forward with Design 2 and moved forward with final models and sketches to be used in implementing our design. This included the creation of our final design sketches (Figure 9 below). These final design steps were vital in ensuring that our ideas would achieve our design goals and objectives. The team agreed on these final sketches, and we began to move into the implementation phase of the design process by creating our initial prototypes.

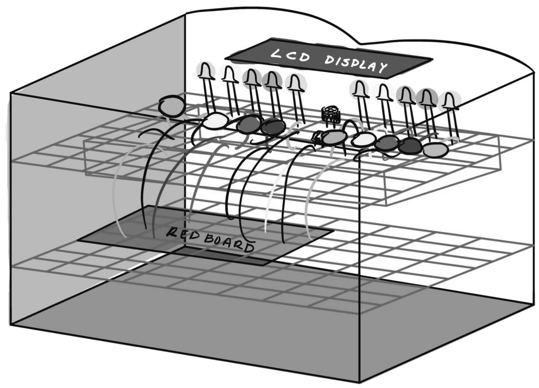

Figure 9, Final Design Sketch; Fabricated after deciding on our final design, used to assist implementation. (Team 3, 2024)

Implementation:

When first beginning to move into the implementation steps of the design process we first chose to model individual components of our device on a smaller scale to see their feasibility. With this in mind, we first began to prove our game concept using the "Sparkfun Circuit 2C: Simon Says Game", which is an example provided within the Inventor's Kit Experiment Guide. This smaller scale model (Fig 10) featured only four buttons with four corresponding LEDs, however, this circuit could easily be expanded to incorporate the ten buttons and LEDs to satisfy our design function and objectives. Another component that was present within this model was the buzzer, which allowed us to begin experimenting with the tones, patterns, and volume to make the design as effective as possible. An additional benefit of this small scale concept was that it enabled us to start thinking about spacing and placement early in the process.

This model proved our game concept to be viable and provided us with schematics to use when expanding and constructing our prototype.

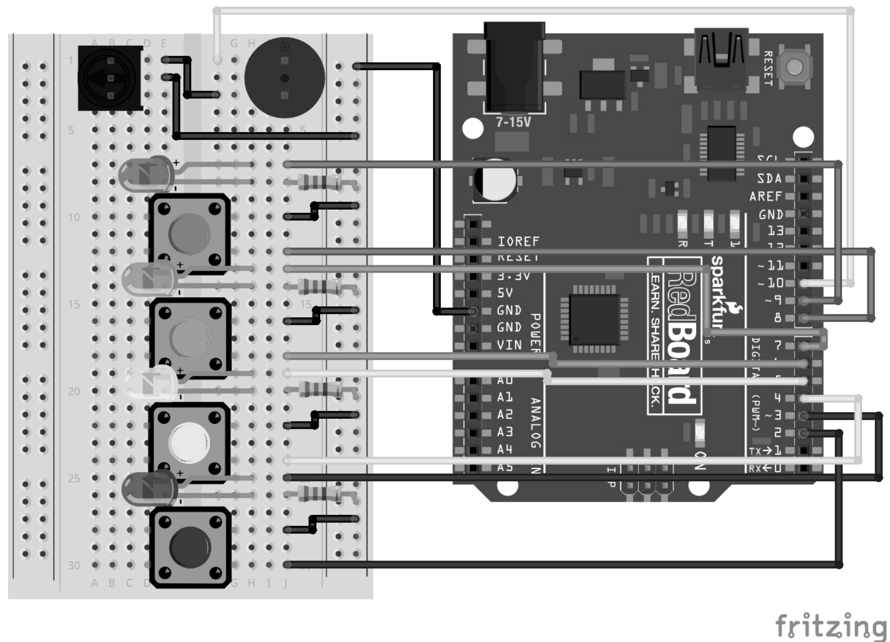

Figure 10, Wiring schematics for the Sparkfun Circuit 2C: Simon Says Game (Sparkfun, 2024)

After constructing the smaller-scaled Sparkfun model our next step was to model our initial button concept. First, multiple drawings were made to visualize our ideas for our spring-loaded button mechanism. Within these drawings (Fig 11) you can see the spring present for resistance, which would be fastened at the bottom to the original SparkFun buttons and connected at the top to our custom-made 3D-printed buttons. Another thing present within these drawings is the tapered sides on our button design which acts as a blocker to stop the high resistance spring from pushing the button above the cover, only allowing the button to stick out the desired amount.

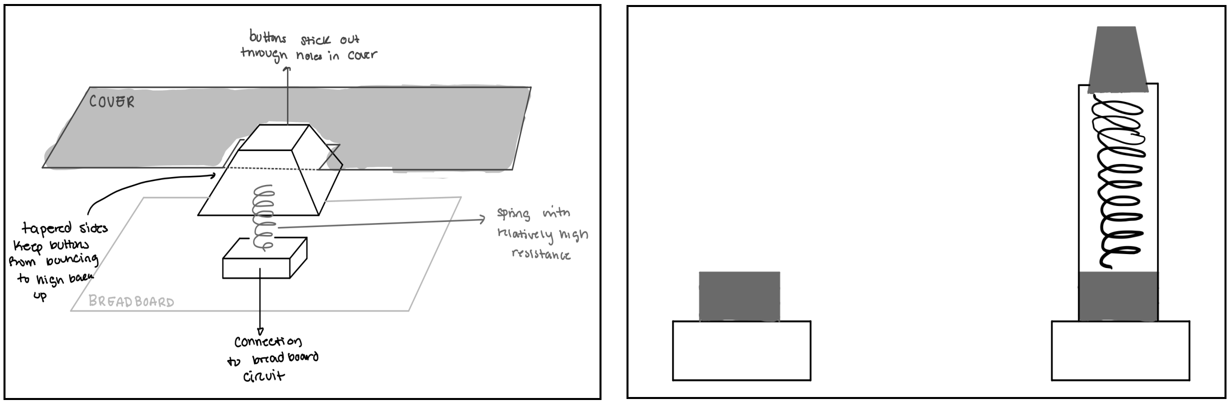

Figure 11, Drawings of intended design for spring loaded button mechanism (Team 3, 2024)

With these drawings in mind, we began to model the button design virtually through the use of SolidWorks. Ultimately we chose to do this as it enabled us full customization and the ability to easily adapt our 3D printed design. This button-keycap design (Fig 12) is a slightly complexified version of the drawings, as more was taken into account regarding size, ergonomics, and overall function. Within this drawing, you can see that the exposed part of the button which would be accessible to the user features a textured design for feel and aesthetic purposes. This top exposed part is also sized to be inline with average finger size to give the user a comfortable feel when placing their fingers on top of the buttons. On the bottom of the design, you can also see the column extending up into the button which acts as a slot for the spring to fit into, promoting button and spring stability. Lastly, you can see the chamfered aspect incorporated into this design with the intent of only allowing half of the height of the button to poke out and keeping the button securely fastened to the cover holes.

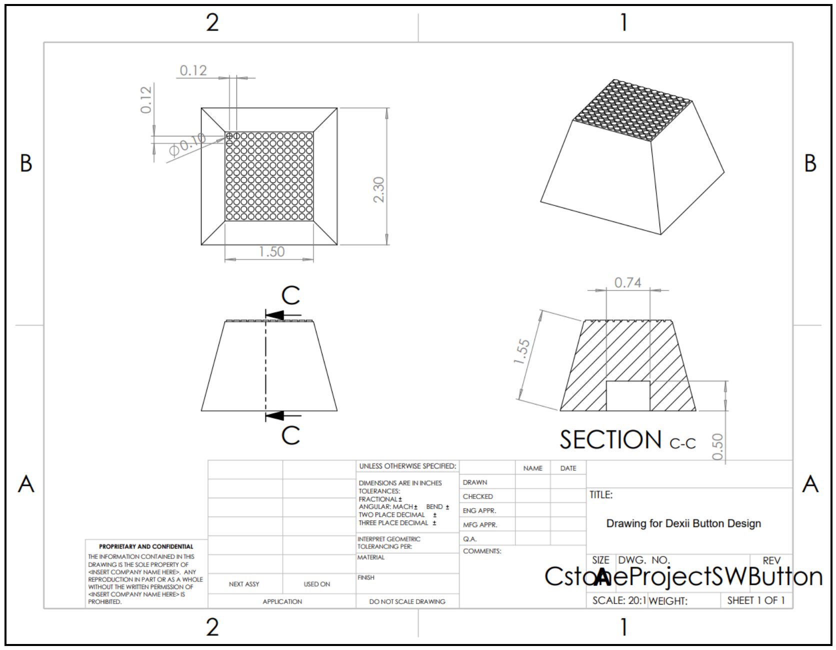

Figure 12, SolidWorks drawing of button-keycap (Team 3, 2024)

The next step was to make our shell design come to life, through the use of SolidWorks, to dimension and customize the shell to fit flush with the rest of the components while also concealing the inner hardware. We decided to construct the shell in two parts, a bottom and a top faceplate containing slots to allow access to the buttons, LEDs, LCD screen, and eventually the on/off switch. We chose to first focus on the bottom section as we could use this to begin organizing and fabricating the hardware within this without the top. We modeled the bottom shell (Fig 13) within Solidworks and you can see that this aspect is relatively simple and holds space for the hardware as well as two slots for the shelves to slide into to improve interior organization and accessibility. After providing space and establishing dimensions the shelves were then also modeled in SolidWorks. The shelve model (Fig 14) is a rectangular grid design, dimensioned to slide seamlessly into the slots in the bottom and to allow for wires to slide through while keeping larger components housed on top including breadboards, redboards, and buttons.

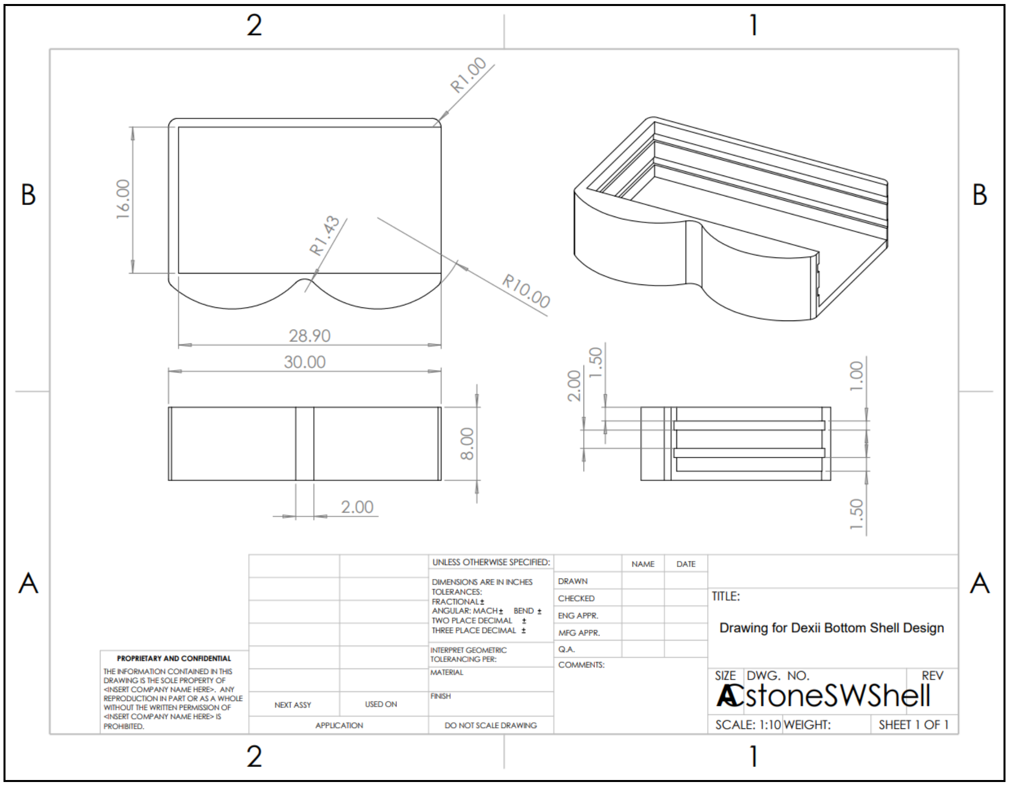

Figure 13, SolidWorks drawing of the bottom shell (Team 3, 2024)

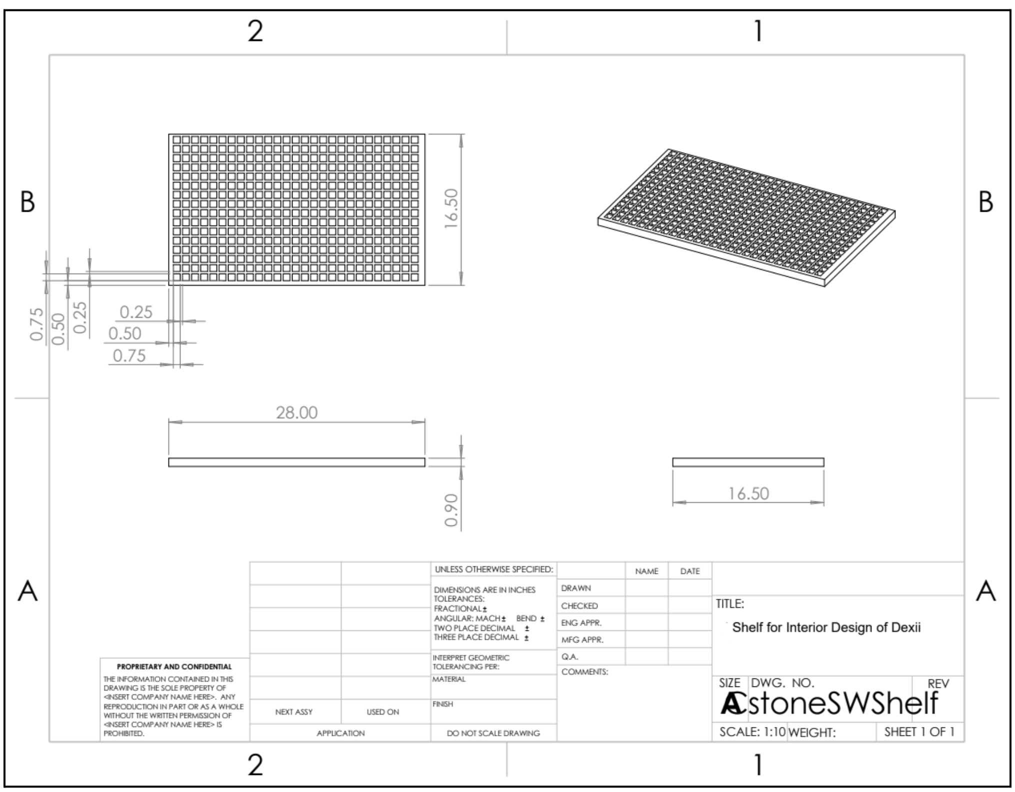

Figure 14, SolidWorks drawing of the internal shelf (Team 3, 2024)

The final component that required modeling was the top faceplate of the design. This design for the cover (Fig 15) was completed in Solidworks and features holes for all ten buttons as well as a long slot above the buttons to house the rows of LEDs and the on/off switch in the middle. Above this row you can also see a cutout slot for the LCD screen to fit flush with the top and be easily visible for the user from all angles. This top also has a side piece intended to slide down and fully enclose the shell and stop the shelves from sliding around. On the top there were screw holes designed into each corner to allow for the top to be firmly secured to the bottom shell component. We also designed both the top and bottom to have the half circles at the bottom rather than making the device perfectly rectangular not only for aesthetic purposes but also to give the user more room to place their hand/wrist.

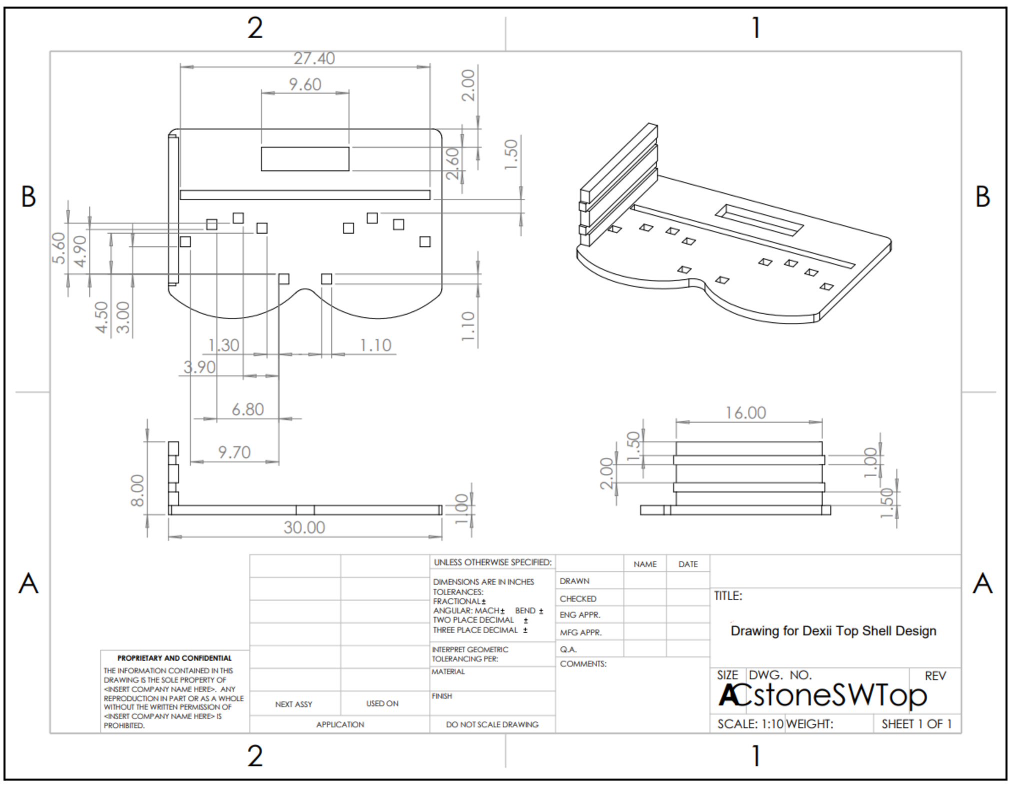

Figure 15, SolidWorks drawing of top faceplate (Team 3, 2024)

With each individual component modeled it was then time to piece together each individual component in SolidWorks to make sure that all parts fit together correctly and to correct any dimension issues prior to printing. This assembly drawing (Fig 16) shows how the shelves are intended to slide into the slots as well as how the top and bottom fit together to form the entirety of our shell design.

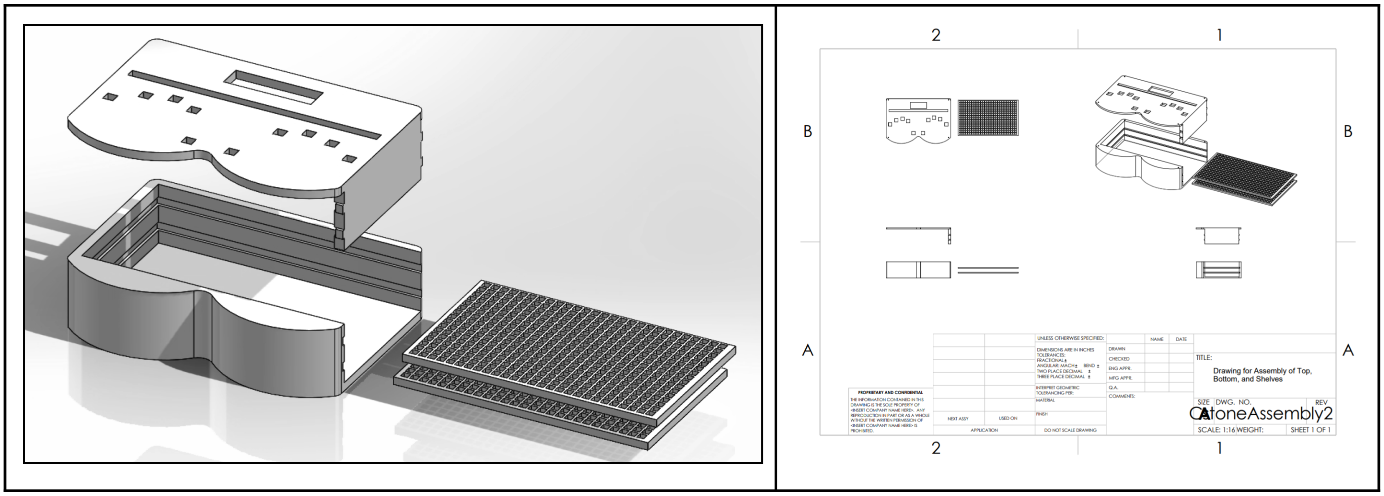

Figure 16, SolidWorks assembly and drawing of faceplate, bottom, and shelves in exploded view (Team 3, 2024)

After modeling and prepping all custom components for 3D printing the next step was to fully complete the wiring. Using the small-scale model we initially constructed we were able to quickly complete this step and get our wiring all laid out and functioning with a very simplified version of the code which can be seen below (Fig 17).

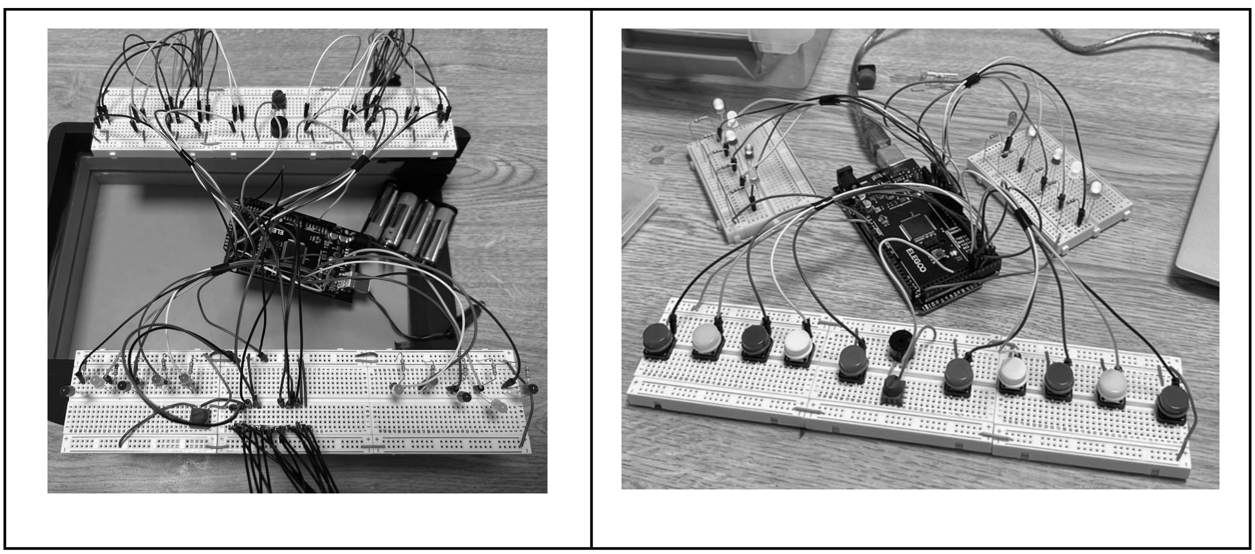

Figure 17, Full completed wiring schematic and layout (Team 3, 2024)

With the wiring fully functional we then turned our focus toward the software of our device. We first flowcharted our code (Fig 18) as a team to give us direction and guidance when actually writing the program in the Arduino IDE. Within this flowchart you can see that the game was intended to begin when any button is pressed by the user. After the button is pushed, the code fills an array with random integers ranging from 0 to 9 with each number corresponding to an individual LED. This array then acts as the pattern for that round which is different with each play using an analog read as the seed mod. After the array is filled, the program first checks to see if the current round exceeds the number of rounds to win, which was set at 10 to give users a chance to feel accomplished and see the win sequence. The program then enters the actual game where it starts by outputting the first LED in the array to the user and playing the corresponding buzzer tone. The next check is to see if the user pushed the correct corresponding button(s) in line with the pattern outputted by the array. If the button pattern is relayed correctly by the user the game keeps adding one more LED to the output sequence until the user ultimately either messes up and the game ends or reaches the round win threshold.

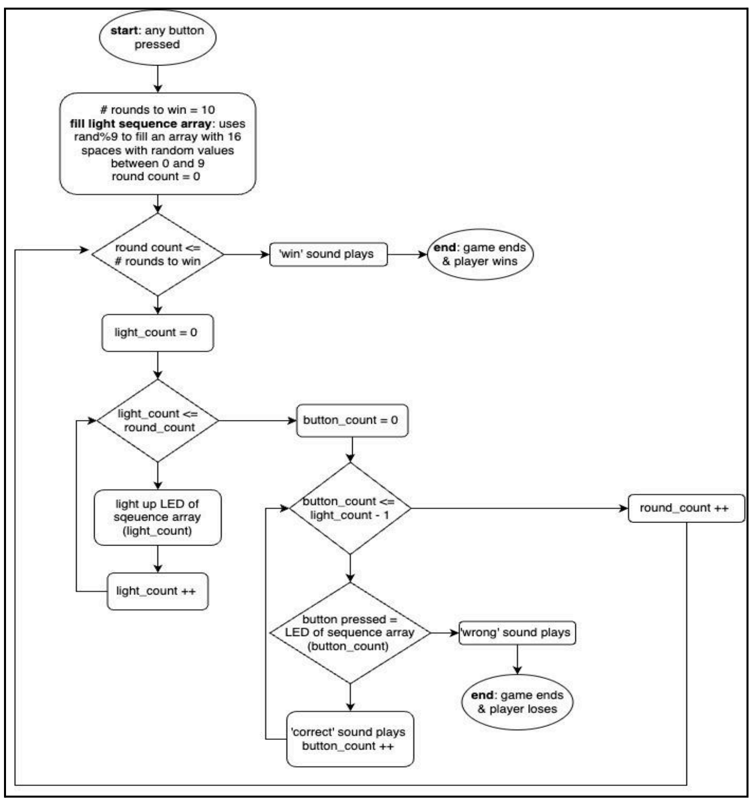

Figure 18, Simplified flowchart of Dexii game code (Team 3, 2024)

With this simplified flow chart in mind the team then constructed the completed final version of the code which can be seen in Appendix A. This version features not only the code for the game but also incorporates the LCD output sections. The LCD progressions as the game goes on can be seen below (Fig 19) and include directions for the user on how to start the game when the device is turned on. After the game is entered the LCD then outputs the current level as well as the users all-time high score to incentivize the user to beat their past best. When the game ends the LCD displays another message to the user prompting them to play again simply by pressing any button once again.

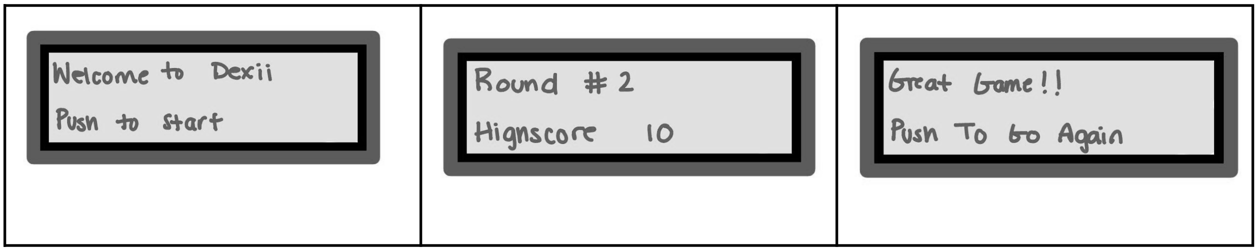

Figure 19, Progression examples of LCD output to user (Team 3, 2024)

With all software and hardware components functional the device was then ready to be laid out and fabricated. The two-tier interior shelf design made this step easy for the team as it allowed us to easily access individual components, lay out the hardware to fit requirements, and work on the construction separately as individuals. The first step in this process was arranging everything within the bottom shell and shelves without the use of the top faceplate yet as this would be the final step. Below you can see an image of the components properly arranged including wires, buttons, caps, LEDs, and the on/off switch (Fig 20).

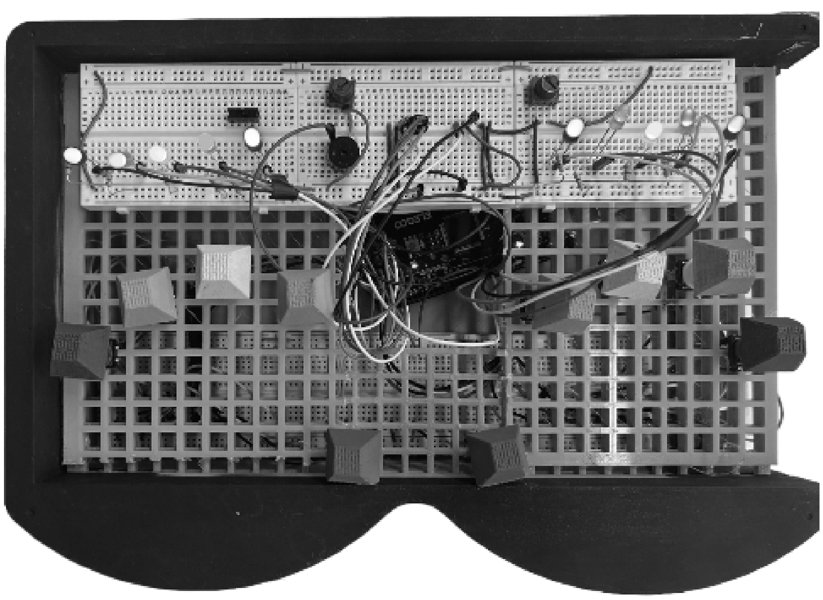
Figure 20, Completed prototype and full internal layout without faceplate for viewing (Team 3, 2024)

With everything assembled within the bottom housing, including the shelves and all of the hardware, the final step was to slide the faceplate on and fasten it to the bottom. After completing this step our prototype Dexii was fully constructed and functional. An aerial view of the final prototype with the painted faceplate fastened on can be seen below (Fig 21).

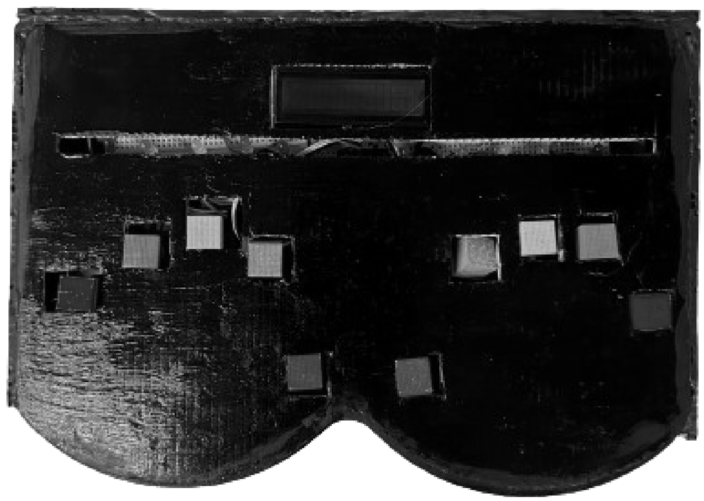

Figure 21, Aerial view of completed prototype with faceplate attached (Team 3, 2024)

With this design in particular our costs were very low and only totaled to be $35.23 and was truly only a result of costs to 3D print in EXP. These costs would have been avoided entirely had we been able to print in FYELIC, however, due to time, space, availability, and size requirements of the 3D printers in FYELIC we decided that the slight cost was necessary to achieve our desired outcome in a timely manner. Below you can find our final bill of materials (Table 4) which contains all costs, dates, and exactly what money went toward what 3D printed components.

Component	**Cost**	**Date**
Shelf x2	$9.88	3/26/24
Bottom Shell	$15.26	4/2/24
Top Shell	$10.09	4/4/24
Total	$35.23	

Table 4, Bill of materials for entire prototype (Team 3, 2024)

Evaluation:

Overall, Dexii performed well compared to our expectations set up by our design functions, objectives, and constraints. Our goal was to design a simple and engaging method for users to exercise their hands, in an accessible and comfortable manner while staying under the one hundred dollar budget. The game functioned exactly as designed, prompting the user with directions to start the game through the LCD screen then outputting a LED pattern to the user while tracking the user's high score are played by pressing down the corresponding buttons. The outer shell design did perform as needed, housing all the internal components while maximizing usability and overall aesthetics, however we did have to use a cardstock version of the top portion of the shell due to the intended top shell breaking unexpectedly. Because of this shift in material, the top portion of the shell did not provide the intended durability and sturdiness we would have expected from a plastic 3D printed material but this did not appear to hinder the device's functionality as the test audience played the game with the device.

The 3D printed buttons were able to function and communicate between the user and the redboard, however they did not meet our ergonomic design goal as we had hoped. Due to the unexpected break in the intended face plate, we had to fashion new buttons to fit with the new cardstock face plate. These newly constructed buttons were made on a shorter timeline, so we had to compromise our ergonomic design objective in favor of our main design functions which led to the ergonomic quality of the newly fashioned buttons not meeting the previous buttons. If given more time, we would reprint the shell with a thicker infill, allowing us to use our original button design and fully meet our ergonomic design goal. The sizing and hand placement of the device did prove to be effective, as we noticed all users were able to comfortably use the device to play the game. Another major design goal was simplicity, and the device design proved to be relatively intuitive for users with the instructions prompted by the LCD screen.

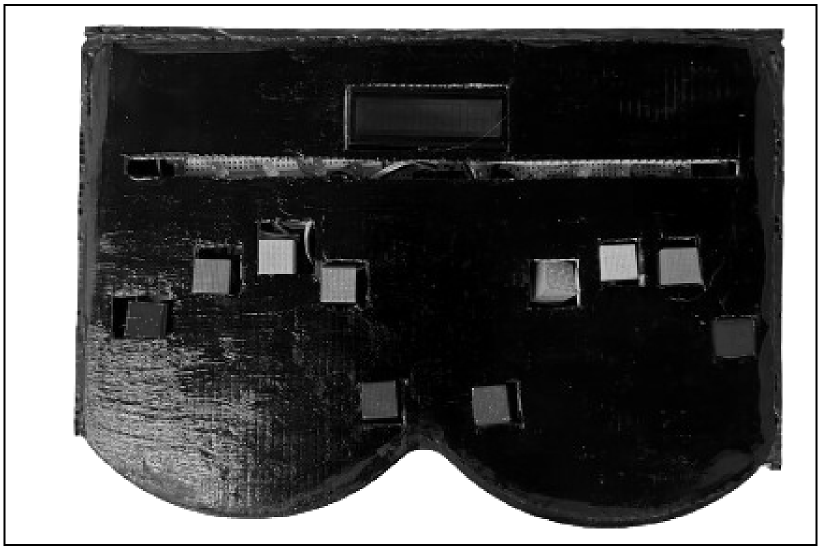

Figure 22: Aerial view of Dexii interface, with backup cardstock top shell

Reflection:

We made sure that our product is able to serve a diverse range of audiences, spanning from children in developmental stages who would find it both beneficial and engaging, to people looking for an easy and fun way to rehabilitate their hands after certain hand injuries. Additionally, it extends to the older population who may want a simple exercise to help preserve motor function and even cognitive skills, as well as to anyone seeking an interactive game to challenge their memory, patience, and focus.

Dexii does not have the potential to cause harm to anyone, and there are no hazardous aspects or materials involved in our device. We structured our design process around our value statement (depicted below) to guide the way in which we generated ideas and chose our design path. The only possible ethical issues that could arise from our device is individuals who may not have function in one or both hands may not be able to use our device its intended way. One way we could combat this if given more time would be to add a feature to that game that can shut off one hand if prompted to. The only other possible caution is for small children, as our device does contain small parts which could be a choking hazard.

“We are guided by our core values - Inclusivity, Accessibility, and Impact, as well as our desire to improve the lives of people spanning all capabilities and age groups”

Figure 23, Values Statement; The values our team plans to prioritize in the design and production of this device. (Team 3, 2024)

As pictured in the value statement above, Dexii’s major goals are inclusivity and accessibility. This means appealing to audiences of all ages, from young, developmental-age children to the elderly. Being inclusive and accessible means the design should be as cost-effective as possible so it can be distributed at a low cost to the user. Our last value is impact, which relates to both how our device impacts the user and how it impacts the environment. We also aimed to create a device that would positively impact the user and improve their quality of life in some way, shape, or form. Also, we want to be conscious of our environmental impact, which means limiting excessive use of harmful and non-recyclable materials. Limiting the excessive use of plastic materials was an ethical decision we decided to make, in effort to be conscious of our environmental impact. We also opted to borrow and use material from FYELIC, and scrap pieces of acrylic to minimize the amount of plastic materials we consumed. This ethical choice did require us to be more mindful and cautious of how we modified our device components, especially the parts from FYELIC, as we couldn’t permanently modify borrowed items from FYELIC.

If we were to have more time, we would improve our button design to be more ergonomic, since we had to unfortunately change the button design last minute for a better fit. We want the design to better fit the users for ultimate comfort. We might consider adding some sort of cushions for the users wrists to rest on while they are playing the game while keeping in mind that we don’t want the cushions to interfere with the user playing the game. We would also find a way to better secure the internal hardware, since we had challenges with getting the jumper wires to stay connected to the breadboard and redboard, especially when moving the device. We would also try to decrease the overall size of the device to make it even more compact. After completing the final design we realized that we had a lot of unnecessary space that we thought would be needed to fit all of the internal pieces. For example, having two shelves internally was unnecessary and we only have a use for one. We feel that it would be better for the user if we found a way to limit the space needed to house everything inside the device. Not only will making our device more compact be and useful in terms of carrying it and traveling places with the device but it will also become more suitable for kid's hand sizes.

This project taught us a lot, not only about technical skills like Arduino, SolidWorks, and Sparkfun, but also about problem solving, thinking outside the box, and working as a team to quickly find new solutions when things don't go as expected. We were able to overcome many challenges throughout this process while still delivering a well functioning device. We really embraced the circular path of the Engineering Design process, going from implementation back to generation many times, to finally land on a solution. Overall, this project really pushed us creatively, and we got to apply a lot of skills we learned in the classroom in a real context.

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Appendices:

Appendix A:

```
/*LATEST WORKING VERSION OF CODE FOR DEXII
  Cornerstone of Engineering II Design Project - Milestone 3
  D.Doyle M.Anderson A.George C.Assli
  doyle.do@northeastern.edu

  The Simon Says game flashes a pattern using LED lights, then the player must repeat
the pattern.
  This 2.0 Version of the Dexii code incorporates the LCD display into the software
and eventually the hardware design
  This version also includes the use of a switch to turn on and off the game
  This version incorporates a highscore as well which is displayed to the user
  This version includes the game and UI code

  4/11/2024
*/

#include <LiquidCrystal.h>          //the liquid crystal library contains commands for
printing to the display

//0.0 Initialize the pins where the buttons, LEDs and buzzer connect
int button[] = {33, 32, 31, 30, 50, 28, 27, 26, 22, 25};  //BUTTONS --> Left Blue is
[0], Left Yellow is [1], Left Red green is [2], Left White blue is [3], Left Green is
[4], Right Green is [5], Right White is [6], Right Red is [7], Right Yellow is [8],
Right Blue is [9]
int led[] = {13, 12, 4, 5, 6, 7, 8, 9, 10, 11};     //LEDS --> Left Blue is [0], Left
Yellow is [1], Left Red green is [2], Left White blue is [3], Left Green is [4], Right
Green is [5], Right White is [6], Right Red is [7], Right Yellow is [8], Right Blue is
[9]
int tones[] = {220, 247, 261, 294, 330, 349, 392, 440, 494, 523};   //tones to play
with each button (ABCDEFGABC)

int switchPin = 2;

int j;
int highscore = 0;

int roundsToWin = 10;          //number of rounds the player has to play before they
win the game (the array can only hold up to 16 rounds)
int buttonSequence[16];        //make an array of numbers that will be the sequence
that the player needs to remember

int buzzerPin = 37;            //pin that the buzzer is connected to

LiquidCrystal lcd (47, 46 , 23 , 44 , 43 , 38 );

int pressedButton = 4;         //a variable to remember which button is being pressed.
4 is the value if no button is being pressed.
int roundCounter = 1;          //keeps track of what round the player is on


long startTime = 0;            //timer variable for time limit on button press
long timeLimit = 2000;         //time limit to hit a button

boolean gameStarted = false;      //variable to tell the game whether or not to play
the start sequence

void setup() {
```

```
  lcd.begin (16,2); //Set the number of rows and columns to initialize the lcd
  lcd.clear();

  //set all of the button pins to input_pullup (use the built-in pull-up resistors)
  pinMode(button[0], INPUT_PULLUP);
  pinMode(button[1], INPUT_PULLUP);
  pinMode(button[2], INPUT_PULLUP);
  pinMode(button[3], INPUT_PULLUP);
  pinMode(button[4], INPUT_PULLUP);
  pinMode(button[5], INPUT_PULLUP);
  pinMode(button[6], INPUT_PULLUP);
  pinMode(button[7], INPUT_PULLUP);
  pinMode(button[8], INPUT_PULLUP);
  pinMode(button[9], INPUT_PULLUP);

  //set all of the LED pins to output
  pinMode(led[0], OUTPUT);
  pinMode(led[1], OUTPUT);
  pinMode(led[2], OUTPUT);
  pinMode(led[3], OUTPUT); //RGB RED LEFT
  pinMode(led[4], OUTPUT);
  pinMode(led[5], OUTPUT);
  pinMode(led[6], OUTPUT); //RGB RED RIGHT
  pinMode(led[7], OUTPUT);
  pinMode(led[8], OUTPUT);
  pinMode(led[9], OUTPUT);

  pinMode(buzzerPin, OUTPUT);   //set the buzzer pin to output
  pinMode(switchPin, INPUT_PULLUP);
}

void loop() {

if (digitalRead(2) == LOW){
  if (gameStarted == false) {   //if the game hasn't started yet
    lcd.clear();
    lcd.setCursor(0, 0);               //set the cursor to the 0,0 position (top left
corner)
    lcd.print ("WELCOME TO DEXII");        //print hello, world! starting at that
position
    lcd.setCursor(0,1);
    lcd.print ("Game Started...");
    startSequence();             //flash the start sequence
    roundCounter = 0;            //reset the round counter
    delay(1500);                 //wait a second and a half
    gameStarted = true;          //set gameStarted to true so that this sequence
doesn't start again
  }

  //each round, start by flashing out the sequence to be repeated
  for (int i = 0; i <= roundCounter; i++) { //go through the array up to the current
round number
    flashLED(buttonSequence[i]);           //turn on the LED for that array position
and play the sound
    delay(200);                            //wait
    allLEDoff();                           //turn all of the LEDs off
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print ("Round #");
    lcd.setCursor(9,0);
    j=i+1;
    lcd.print (j);
    lcd.setCursor(0,1);
```

```
    lcd.print ("Highscore ");
    lcd.setCursor (11,1);
    lcd.print (highscore);
    delay(200);
      if (j > highscore) {
        highscore = j;
        lcd.clear();
        lcd.setCursor (0,0);
        lcd.print ("NEW HIGHSCORE");
        delay (200);
        lcd.clear();
        lcd.print ("NEW HIGHSCORE");
        delay (200);
        lcd.clear();
        lcd.setCursor(0,0);
        lcd.print ("Round #");
        lcd.setCursor(9,0);
        j=i+1;
        lcd.print (j);
        lcd.setCursor(0,1);
        lcd.print ("Highscore ");
        lcd.setCursor (11,1);
        lcd.print (highscore);

    }
  }

  //then start going through the sequence one at a time and see if the user presses
the correct button
  for (int i = 0; i <= roundCounter; i++) { //for each button to be pressed in the
sequence

    startTime = millis();                 //record the start time

    while (gameStarted == true) { //loop until the player presses a button or the time
limit is up (the time limit check is in an if statement)

      pressedButton = buttonCheck();      //every loop check to see which button is
pressed

      if (pressedButton < 10) {            //if a button is pressed... (4 means that
no button is pressed)

        flashLED(pressedButton);          //flash the LED for the button that was
pressed

        if (pressedButton == buttonSequence[i]) { //if the button matches the button
in the sequence
          delay(250);                   //leave the LED light on for a moment
          allLEDoff();                  //then turn off all of the lights and
          break;                        //end the while loop (this will go to the next
number in the for loop)

        } else {                          //if the button doesn't match the button in
the sequence
          loseSequence();               //play the lose sequence (the loose sequence
stops the program)
          break;                        //when the program gets back from the lose
sequence, break the while loop so that the game can start over
        }

      } else {                            //if no button is pressed
        allLEDoff();                      //turn all the LEDs off
```

```
      }

      //check to see if the time limit is up
      if (millis() - startTime > timeLimit) { //if the time limit is up
        loseSequence();                       //play the lose sequence
        break;                                //when the program gets back from the
lose sequence, break the while loop so that the game can start over
      }
    }
  }

  if (gameStarted == true) {
    roundCounter = roundCounter + 1;      //increase the round number by 1

    if (roundCounter >= roundsToWin) {              //if the player has gotten to the
16th round
      winSequence();                      //play the winning song
    }

    delay(500);                           //wait for half a second between rounds
  }
}
else {
  lcd.clear();
  allLEDoff();
}
}

//-------------------------FUNCTIONS------------------------------------

//FLASH LED
void flashLED (int ledNumber){

  digitalWrite(led[ledNumber], HIGH);
  tone(buzzerPin, tones[ledNumber]);
}

//TURN ALL LEDS OFF
void allLEDoff () {
  //turn all the LEDs off
  digitalWrite(led[0], LOW);
  digitalWrite(led[1], LOW);
  digitalWrite(led[2], LOW);
  digitalWrite(led[3], LOW);
  digitalWrite(led[4], LOW);
  digitalWrite(led[5], LOW);
  digitalWrite(led[6], LOW);
  digitalWrite(led[7], LOW);
  digitalWrite(led[8], LOW);
  digitalWrite(led[9], LOW);


  //turn the buzzer off
  noTone(buzzerPin);
}

//CHECK WHICH BUTTON IS PRESSED
int buttonCheck() {
  //check if any buttons are being pressed
  if (digitalRead(button[0]) == LOW) {
    return 0;
  } else if (digitalRead(button[1]) == LOW) {
    return 1;
```

```
  } else if (digitalRead(button[2]) == LOW) {
    return 2;
  } else if (digitalRead(button[3]) == LOW) {
    return 3;
  }else if (digitalRead(button[4]) == LOW) {
    return 4;
  }else if (digitalRead(button[5]) == LOW) {
    return 5;
  }else if (digitalRead(button[6]) == LOW) {
    return 6;
  }else if (digitalRead(button[7]) == LOW) {
    return 7;
  }else if (digitalRead(button[8]) == LOW) {
    return 8;
  }else if (digitalRead(button[9]) == LOW) {
    return 9;
  }else {
    return 10; //this will be the value for no button being pressed
  }
}

//START SEQUENCE
void startSequence() {

  randomSeed(analogRead(0));   //make sure the random numbers are really random

  //populate the buttonSequence array with random numbers from 0 to 3
  for (int i = 0; i <= roundsToWin; i++) {
    buttonSequence[i] = round(random(0, 9));
  }

  //flash all of the LEDs when the game starts
    for (int i = 0; i <= 2; i++) {
    digitalWrite(led[0], HIGH);
    tone(buzzerPin, tones[0]);
    delay(50);
    digitalWrite(led[0], LOW);
    digitalWrite(led[1], HIGH);
    tone(buzzerPin, tones[1]);
    delay(50);
    digitalWrite(led[1], LOW);
    digitalWrite(led[2], HIGH);
    tone(buzzerPin, tones[2]);
    delay(50);
    digitalWrite(led[2], LOW);
    digitalWrite(led[3], HIGH);
    tone(buzzerPin, tones[3]);
    delay(50);
    digitalWrite(led[3], LOW);
    digitalWrite(led[4], HIGH);
    tone(buzzerPin, tones[4]);
    delay(50);
    digitalWrite(led[4], LOW);
    digitalWrite(led[5], HIGH);
    tone(buzzerPin, tones[5]);
    delay(50);
    digitalWrite(led[5], LOW);
    digitalWrite(led[6], HIGH);
    tone(buzzerPin, tones[6]);
    delay(50);
    digitalWrite(led[6], LOW);
    digitalWrite(led[7], HIGH);
    tone(buzzerPin, tones[7]);
```

```
    delay(50);
    digitalWrite(led[7], LOW);
    digitalWrite(led[8], HIGH);
    tone(buzzerPin, tones[8]);
    delay(50);
    digitalWrite(led[8], LOW);
    digitalWrite(led[9], HIGH);
    tone(buzzerPin, tones[9]);
    delay(50);
    digitalWrite(led[9], LOW);
    }
  for (int i = 0; i <= 3; i++) {

    tone(buzzerPin, tones[i], 200); //play one of the 4 tones

    //turn all of the leds on
    digitalWrite(led[0], HIGH);
    digitalWrite(led[1], HIGH);
    digitalWrite(led[2], HIGH);
    digitalWrite(led[3], HIGH);
    digitalWrite(led[4], HIGH);
    digitalWrite(led[5], HIGH);
    digitalWrite(led[6], HIGH);
    digitalWrite(led[7], HIGH);
    digitalWrite(led[8], HIGH);
    digitalWrite(led[9], HIGH);

    delay(100);         //wait for a moment

    //turn all of the leds off
    digitalWrite(led[0], LOW);
    digitalWrite(led[1], LOW);
    digitalWrite(led[2], LOW);
    digitalWrite(led[3], LOW);
    digitalWrite(led[4], LOW);
    digitalWrite(led[5], LOW);
    digitalWrite(led[6], LOW);
    digitalWrite(led[7], LOW);
    digitalWrite(led[8], LOW);
    digitalWrite(led[9], LOW);

    delay(100);   //wait for a moment

  } //this will repeat 4 times
}

//WIN SEQUENCE
void winSequence() {

  //turn all the LEDs on
  for (int j = 0; j <= 9; j++) {
    digitalWrite(led[j], HIGH);
  }

  //play the 1Up noise
  tone(buzzerPin, 1318, 150);   //E6
  delay(175);
  tone(buzzerPin, 1567, 150);   //G6
  delay(175);
  tone(buzzerPin, 2637, 150);   //E7
  delay(175);
  tone(buzzerPin, 2093, 150);   //C7
  delay(175);
```

```
  tone(buzzerPin, 2349, 150);   //D7
  delay(175);
  tone(buzzerPin, 3135, 500);   //G7
  delay(500);

  //wait until a button is pressed
  do {
    pressedButton = buttonCheck();
  } while (pressedButton > 9);   //Make sure that this line is correct...if not 9 make
3
  delay(100);

  gameStarted = false;   //reset the game so that the start sequence will play again.

}

//LOSE SEQUENCE
void loseSequence() {
  lcd.clear();
  lcd.setCursor (0,0);
  lcd.print ("Great Game!!");
  lcd.setCursor (0,1);
  lcd.print ("Push To Go Again");

  //turn all the LEDs on
    digitalWrite(led[0], HIGH);
    digitalWrite(led[1], HIGH);
    digitalWrite(led[2], HIGH);
    digitalWrite(led[3], HIGH);
    digitalWrite(led[4], HIGH);
    digitalWrite(led[5], HIGH);
    digitalWrite(led[6], HIGH);
    digitalWrite(led[7], HIGH);
    digitalWrite(led[8], HIGH);
    digitalWrite(led[9], HIGH);

  //play the 1Up noise
  tone(buzzerPin, 130, 250);   //E6
  delay(275);
  tone(buzzerPin, 73, 250);   //G6
  delay(275);
  tone(buzzerPin, 65, 150);   //E7
  delay(175);
  tone(buzzerPin, 98, 500);   //C7
  delay(500);

  //wait until a button is pressed
  do {
    pressedButton = buttonCheck();
  } while (pressedButton > 9);     //Same thing with this line make sure that its
working if not back to 3
  delay(200);

  gameStarted = false;   //reset the game so that the start sequence will play again.
}
```