Modular Gaming Table

A Major Qualifying Project Report Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

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Abstract

Tabletop gaming college students do not have suitable areas for playing games. This project designed a product to be affordable, weigh as little as possible, and maximize playing area while minimizing storage space. We gathered data on college students, existing tabletop gaming tables, ergonomics, and marketability of the potential product, which led to the final design. The design incorporated mechanisms to extend the tabletop, which increased the playing surface area, and to fold the legs of the table safely by using sensors. The product was fabricated as a prototype to prove the capabilities of the design. We recommend further testing be done to iterate the design closer to perfection, as well as significant market research before pursuing the business potential.

Acknowledgments

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1. Introduction

Over the centuries, the market for gaming tables has varied from backgammon tables to tables designed specifically for role playing games (RPGs). While tabletop games can be played virtually anywhere, it can be especially difficult for college students to find suitable spaces. The most common and widely played game is Dungeons and Dragons (DND), which usually has three to six players sitting around a table. Although standard dining room tables fit about eight people, most college students do not own dining tables. This is due both to cost and space issues. Additionally, locations on campus may be unreliable and unaccommodating for game play sessions. The team researched, designed and tested a table to be affordable, weigh as little as possible, and maximize playing area while minimizing storage space.

2. Background

Before designing anything, it was important to research past and current designs, as well as the current gaming table market. This comprehensive search guided us in features to implement into the table, pitfalls to avoid, and the direction the gaming table market is trending.

2.1. History of Gaming Tables

Tables designed specifically for games are not a new concept. The earliest tables for this purpose are tables designed for playing backgammon as far back as 3000 BCE (Smith, 2017). Gaming tables became more common and specific throughout the years, and their popularity grew in the 18th century. The multi-functionality of these tables was one of the reasons for the spike in their popularity, as the trend grew in prominence among and beyond the upper class. One such gaming table is on display at The Met Fifth Avenue. The “Game Table”, designed by David Roentgen (1780-83), is a transformable table with a leg that folds out to support the tabletop as it flips open to reveal a felted playing surface. This table can flip open two more times to transform into a wood top with a chess board built in, and a desktop with a leather writing surface. This is an example of an early premium gaming table.

As popular games of the time changed through the years, so did the gaming table market. In Victorian times, there was a Loo table named for the game played on it: Lanterloo (Jacobs, 2024). Moving into the 20th century, advancements in technology lead to significant changes in game design, introducing new games with more complex parts. The modern-day gaming table reflects this change, but we can still see some similarities to the early modular designs like the one by Roentgen.

2.2. Tabletop Gaming

Tabletop gaming has its roots in board games, which have existed for thousands of years (Kumar, 2022). DND was the first of the tabletop role-playing games, with the first release being published in 1974 (Hosch, 2023). Although tabletop games are primarily designed to be played on a table, any flat horizontal surface will work. In DND, players roleplay as a character they create in a fantasy world. The player chooses all actions they take, but whether or not the action is successful is determined by rolling dice. Tabletop games, such as DND, are intended to be played with groups of people over multiple sessions. The hobby is now much more mainstream than it used to be in the 1970s and 1980s, when it was, at times, vilified. Some tabletop players are introduced to the hobby through school clubs.

2.3. Current Gaming Table Market

Given the specificity of tabletop gaming, the market for tables specifically designed for this purpose is relatively small (Global, 2023). Additionally, not everyone has the space to accommodate, nor the financial means, to purchase a table strictly dedicated to the hobby. If a player were to purchase a tabletop gaming table, it would likely be from one of these leading manufacturers: Wyrmwood Gaming, Hammered Game Tables, and Game Theory Tables. All of these companies retail their tables at upwards of $2000, with the highest starting price being close to $10,000. The price is completely dependent on the options and addons selected, and can even go over the $10,000 price tag. As an example, the base configuration "Prophecy" table found on the Wyrmwood website is priced at $10,250 (Wyrmwood, 2024).

For those interested in obtaining a gaming table on a budget, there are other options. Players can design their own or buy/find instructions to build one. Both methods are valid ways to get a gaming table, but they present issues now other than just financial. Despite plans to build your own RPG table reliably affordable or even free, it neglects to account for the cost of materials, tools, and building space required. Additionally, to build a gaming table, the player must have woodworking experience, engineering knowledge, and design skills.

2.4. College Students in the United States

The average college student in the United States is far from affluent, typically relying on federal and private loans to pay tuition along with minimum wage summer jobs. In 2024, a student working 800 hours for minimum wage would earn about $5,800, according to the U.S. Department of Labor. Assuming the student works the same number of hours each week over the course of a year, then 800 hours is about 15 hours per week. It is unlikely that students can work additional hours while also enrolled in classes. Although it is unlikely that students are paying their tuition while in school, it is not feasible to purchase a gaming table with an annual income of $5,800, especially when the cost of living is taken into account. This annual income averages to a budget of $115 a week.

Colleges may require a student to live in a dormitory, which can be notoriously cramped. The average college student in a dorm is allocated 9.06 square meters, a very small area, especially when a bed and desk is present (Cedeno Laurent, 2020). Desks are frequently located under beds, decreasing the possible storage space. The space becomes even smaller if the student has roommates. Even if a student does not live on campus, it is likely that they will live in an apartment that does not provide a large, open interior space. Students in apartments pay for rent and utilities on a monthly basis, further decreasing their budget. Figure 1 is a photograph of a three-person dormitory room at Worcester Polytechnic Institute (WPI).

Figure 1: A typical dorm room in WPI's Daniels Hall

2.5. Marketing

There are many ways to approach marketing a design. The first step is to find funding for the product. For new businesses, there are angel investors, venture capital firms, or government loans/grants. In addition to funding, establishing a design as a profitable product requires calculations, such as the market size.

Angel investors are well-off individuals who are professionally investing in, usually, small business ventures and startups (Ganti, 2021). In return, they typically will receive equity, which is the amount of money that would be returned to the shareholders of the company if all of the company's assets were to liquidate. Equity also translates to ownership of the company.

Venture Capital firms are also looking to invest in promising small businesses and startups with potential for substantial and, preferably, rapid growth. These firms provide money they raise from a network of partners, including individual investors, investment banks, and other financial institutions (Hayes, 2024).

Market size is a calculation of the available market which a company wishes to enter into. This is calculated with either the number of transactions that occur within a year, or the amount of potential customers. This data can be used to understand the potential a business venture might have before starting out. Investors might also use this data to determine if they want to invest.

3. Methodology

This chapter explores the methods used to achieve our project goal. The project's goal was to design a game playing area for college students that was safe and affordable while maximizing playing surface area and minimizing storage space. To begin, we conducted a survey with college students to collect gaming information and table preferences. We also researched marketing strategies and interviewed a successful entrepreneur. Next, we designed the playing area through the use of drawings and sketches, as well as Computer Aided Design (CAD) assemblies. Additionally, we completed mechanical and electrical analyses of the chosen design. We then constructed the playing area based on the design and criteria discussed. Finally, we created a report to document the process and consolidate our findings. The results of our methodology are found in the next chapter.

Objectives

1. Gain knowledge of existing products.
2. Design an optimized tabletop gaming table.
3. Analyze the mechanical and electrical properties.
4. Construct the tabletop gaming table.
5. Consolidate findings in a comprehensive report.

3.1. Survey

To understand how to design and build our project to improve the tabletop gaming table, a survey was conducted.The team surveyed college students to gain an understanding of gaming history, table preferences, and marketability of a tabletop gaming table. This survey used the WPI subjects pool and online platforms to obtain survey results. The survey questions can be found in Appendix B. Our survey is organized into six main sections: Gaming Information, Tables, Value, Specific Features, Portability/Ease of Use, and General Information (demographics). This was done to make the survey simple and minimize bias, to encourage completion and avoid potential miscommunications. To begin, our Gaming Information section interests the participant by inquiring about their gaming habits. Inquiring about these gaming habits is engaging to the participant. It then segues to Tables, where information about their purchasing history, as well as table preferences are collected. This connects with the next section, Value. This brief section contains more sensitive questions which participants are likely now more willing to honestly answer after completion of the other sections. After this is the Specific Features section, pertaining to tabletop gaming tables. Penultimately, the participant completes the Portability/Ease of Use section, where transportation and assembly questions are answered to better understand the preference of portability over durability, and vice versa. Finally, General Information requests the participant to provide demographic information. This section was decided to be the last, as some participants may understandably not feel comfortable providing this data.

The survey was sent out on November 21, 2023 and accepted responses for four weeks. This both allowed students to respond anytime during a portion of a single seven week WPI term, and provided sufficient time to review the answers. We received approval from the Institutional Review Board (IRB) to complete our study. The approval letter can be found in Appendix A and the IRB record number is IRB-24-0192. For ethical considerations, the survey information was anonymous and no identifiable data was collected. Students could elect to provide their contact information, which was recorded separately from their survey answers. The full report can be found in Appendix B.

3.2. Market

During our initial brainstorming sessions, it was suggested by Professor Mortazavi to market our idea and launch a startup. Given that we were unfamiliar with the process of launching a startup, or marketing a product, our first step was to research. We used a combination of independent research on the internet, as well as an interview with an expert.

Given that the team did not have experience starting a business, we began with the exploration of elementary topics, such as how to market a product, and steps needed to start a business. From this, the group was able to gain a better understanding of the information we would need, and areas that required further research. In addition to our own research, we met with Professor Yan Wang, who has started a number of successful businesses. This conversation helped further our knowledge of the requirements to pursue this as a business venture, as well as strategies to approach the process.

Professor Wang first recommended that we find the market size, as this would also be the first question from investors. He recommended that a small market size would make investors less interested, thus it would be more difficult to market the product. This is because it is not worth their time to invest if there is not enough room for them to gain profit. According to an article by Alejandro Cremades on Forbes (2023), there are two possible main calculations to determine the market size: “number of potential [customers], or number of transactions each year”. From these values, the market value can be calculated by multiplying the average value by the market volume.

In addition, Professor Wang provided some steps to take, like deciding on a business model to present to investors and filing a patent for our design. Another recommendation was to find an angel investor. Professor Wang informed us of a program that WPI has to help students obtain funding to pursue ideas: the I-Corps Site Program. However, if we want to apply for the program, the group must be fully committed. The size of the potential market would dictate the decision of the group. A small market would not be profitable, but a larger one would encourage the venture.

The data found in our research process was used to help determine the best path forward for this design. The team was able to have an informed discussion of our options for pursuing the business aspects of the ultimate design that was created for this project.

3.3. Design

The team selected the audience as the most important aspect of our table, as the table was designed for college students. Safety is also critical, as the table needs to not harm its users. As mentioned previously, college students typically do not have access to thousands of dollars to buy one of the gaming tables currently on the market, and thus affordability was a priority in our design.

Drafting

Prior to creating the 3D model of our proof of concept table, the group worked in pairs to create a sketch of a possible table. The objective of this was to choose a "base" for the table that set enough constraints to design smaller sections - the extending tabletop and legs. Through the team's decision matrix process, a final "base" was selected from the three table designs we created. From there, two teams of three were formed - one group drafted designs for the tabletop while the other drafted designs for the table legs and its mechanisms. The tabletop team also presented designs for the rising middle section of the table. Each member of the subgroup presented a design, and the decision matrix process was again used to determine the design that best fit with our priorities. After this, the whole group created a complete sketch of the table shell.

CAD

Once we had decided upon a design for the tabletop surface and functionality, we set about creating a Computer-Aided Design (CAD) model for the different subassemblies of our proof of concept table. We used the CAD software SOLIDWORKS for a majority of the assemblies' design processes, as it is the software most familiar to the team. The modeled assemblies consisted of the extending tabletop, including the table leaves, bottom and middle sections, and the supports in the table, the legs, and the mechanisms needed to collapse the table and legs. A 3D model of the table allowed us to use software to further analyze it through a thermal and mechanical lens.

Electrical and Coding

After determining the moving parts of the table design, the next step was to determine how each component would be powered. Along with the considerations for how systems would be powered were the safety considerations. It was critical to ensure the electrical design accounted for user safety. To move the parts of the table, we used stepper motors and momentary buttons, which are controlled through a programmable Arduino Mega 2560 microcontroller. For safety precautions, we implemented rotary encoders which monitor how many steps the motors make.

The powered systems are: the two table tops, the legs, and the scissor lift in the middle of the table. To help visualize what the code is doing some pictures and videos can be found through the QR code in Appendix E, and the code will be further explained in the results section. One motor was used for each system in our design. This was done to minimize weight and lower cost by limiting the overall number of motors required. Stepper motors were chosen each based on the required torque of the system they were controlling. To control the motors, momentary push buttons were selected. A momentary push button only holds one state at a time. When pressed, it goes into closed state, and almost instantly returns to open state. The momentary push buttons were a simple solution for the users to control the table's functions.

To design the code, a step by step diagram was created. This gives a general overview of how the code would run based on block code. Each choice is given, and then, depending on the choice, following the arrow will bring you to the next step that the code will run.

The code should initiate the motors to make the programmable number of steps in order for each moving part to reach their open position, and also make the same number of steps to reach its closing position. The Arduino was programmed to control the stepper motors used in the system by gaining input from the momentary buttons. Simultaneously, to ensure safety, rotary encoders monitor the angular displacement of the motor shaft compared with the theoretical displacement of the instructed code.

3.4. Analyses

Mechanical Analysis

Mechanical analysis is required to verify the structural integrity of the table. To ensure stability and function, we decided to use Finite Element Analysis (FEA). Finite element analysis is the use of calculations, models and simulations to predict and understand how an object might behave under various physical conditions. Engineers use finite element analysis to find vulnerabilities in their design prototypes (Brush, 2019). This allowed us the benefit of understanding whether or not the assembly would break or fracture under peak strenuous conditions.

Finite element analysis uses the finite element method (FEM), which is a numerical technique that cuts the structure of an object into several elements, and then reconnects the elements at points called nodes. The finite element method creates a set of algebraic equations in which engineers, developers and other designers can use to perform finite element analysis.

The basic principle of finite element method is to discretize the domain of interest, where the partial differential equations are defined, in order to obtain an approximate solution of the partial differential equations by a linear combination of basis functions, defined within each subdomain. By assembling the subdomains, which is based on the process of putting the finite elements back into their original positions, results in a discrete set of equations that are analogous to the original mathematical problem. In each finite element, the equations are solved by using basis functions that interpolate the unknown variables across the element. This altering aids in approximating the solution within the element. The basis function is determined within the finite element using the values of the unknown variables at the nodes, and then the approximate solution within the element is obtained by combining nodal values of the variables and the basis functions linearly.

Finite element analysis works by discretizing the domain of interest and then assembling physics equations to solve the engineering problem at hand. The finite element analysis process is broken down into three parts, the pre-process, process, and post-process. The pre-process step is the definition of physics and real world conditions used in the model. This involves selecting the analysis type, for example modal analysis or structural static analysis, including the element type. The materials properties must be defined as well as making the nodes, and finally there needs to be boundary conditions and loads applied. The process involves dividing the object into finite elements by meshing. Meshing typically uses different shapes like tetrahedra, prisms, and pyramids to discretize the geometry surface or volume into multiple elements. This is done by the computer to solve the boundary value problem and present the results to the user. The post-process computes results to analyze and interpret implications of the entire domain. Results are typically generated as factors of displacement, temperature, stress, strain, and natural frequency.

Some advantages that finite element analysis has is that it enables engineers to safely simulate potentially hazardous or destructive loading scenarios and failure modes, thus enabling the exploration of a system's physical reactions at various points. Other advantages include: increased accuracy due to the analysis of any physical stress that might affect the design and fast calculation times and relatively low investment costs. One of the major challenges and limitations of finite element analysis is that the output is only as good as the input. All the assumptions, such as the geometry, the material properties, and the analysis type, can affect the integrity of the model's results.

The table also underwent a torque analysis based on the calculations from Shigley's Mechanical Engineering Design textbook (Budynas, 2008). The systems were broken up into basic 2D loading conditions to make the calculations easier, since the motion of each system was only in one plane. A Free Body Diagram (FBD) was created for each system and subcomponent of some systems to show the forces acting on different points. The force and moment equations were then used in static conditions with open and closed configurations to find the max loading. This force was plugged into the Torque equation based on the type of mechanism used, and thus torque was calculated. The torque helped to select which motor would be used for each system.

Electrical Analysis

To ensure that the parts selected would meet the specific needs based on our electrical design, we completed electrical analysis. The maximum power capacity needed was found by adding the power that all components require, while working simultaneously. An electrical schematic of all electrical components of the table can be seen in Figure 2.

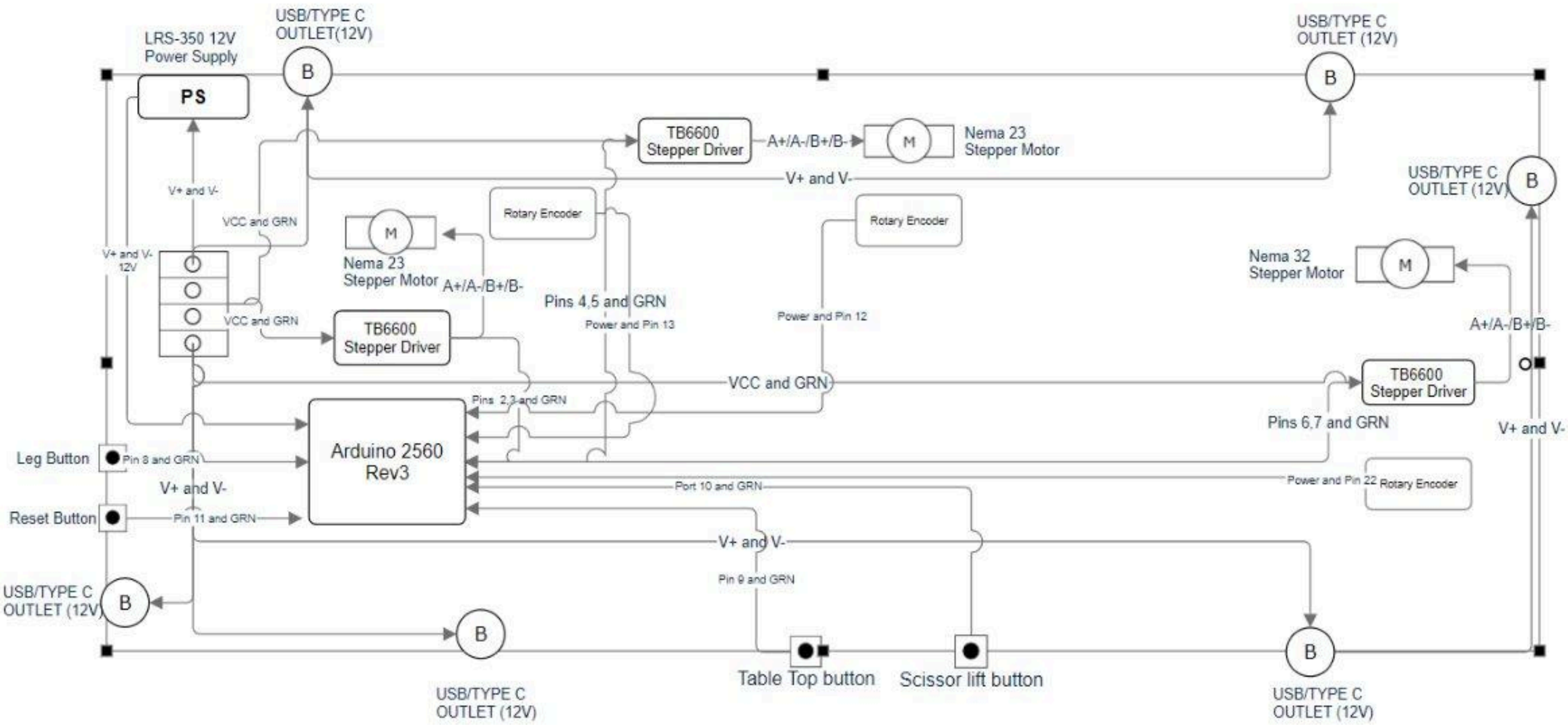

Figure 2: Electrical Schematic

In addition, thermal analysis of the power supply was necessary to ensure safe temperatures. We wanted to ensure that the power supply does not overheat, causing safety concerns and damages to the electrical components. To calculate the temperature that the table will run at steady state, we first calculated the power dissipation of the system by multiplying the load, under steady state, with one minus the efficiency of the power supply, provided by the datasheet of the manufacturer. Then, we calculated the temperature rise by multiplying the power dissipation with the thermal resistance of the power supply, which was also provided by the datasheet. Finally, we calculated the estimated temperature by adding the standard ambient temperature with the temperature rise.

3.5. Construction

We intended to create a working prototype and proof of concept for our table. The original plan was to make a full, working prototype. However, as we researched parts, it became clear that was not a viable option. Based on the advisor's suggestion, we opted to scale the model down to a 75% scale version. The main component that forced us to make this switch was the wood for the table top. In general, plywood is not sold in inch thickness from hardware stores. The team did contact a general contractor before changing the scale, but the quote received was for $1,500. This would have taken up the entire budget, so we decided to find a less expensive alternative. Scaling the table down by 25% percent made the table top thickness 19.05 mm, allowing us to purchase all the wood from local hardware stores for a reasonable price.

For the prototype, we tried to get materials that were as close as possible to our desired final parts. Through the design process, we selected our materials and created a list of items to purchase in the Bill of Materials (BOM). Once the design was finalized, we placed an order for the necessary parts to be purchased through vendors associated with our university.

We had access to a space on campus which could be used to store materials, build and test our systems before working them into the final prototype, and assemble the project's deliverable prototype.

3.6. Deliverables

Our deliverables for this project consist of three main items: A full CAD model of our design, a working prototype, and documented analysis validating the integrity of our designs. The full CAD model was used to aid in the design, construction, and mechanical analysis. The prototype was made at a 75% scale, as mentioned in the section above, but included all of the intended mechanisms and electrical components to show its function as a gaming table.

4. Results

The tabletop gaming table was created with 5 main criteria in mind: mechanisms, structural engineering, electrical, ergonomics, and marketability. For each criteria, the systems of analysis for validating the table's design are discussed.

4.1. Table Design

Design Drafting

Before designing the mechanisms of the table, a basic table design was chosen. As mentioned previously, this was done by creating three different designs and comparing them in a decision matrix (Table 1). An explanation of each design is as follows.

The "Rectangle" design, shown in Figure 3, was a proposed basic design for the table that consisted of a tri-fold hydraulic linkage tabletop system, detachable legs, and a tablet rail system. Additionally, a speaker and a dice launcher mechanism were considered. The two outer rectangular tabletop pieces would fold over and under the innermost piece. The hydraulic linkage would then retract, resulting in a wooden rectangular prism. The detachable legs would be stored under their respective third of the table, and thus in the prism. To avoid the bending of wires, a series of plugs would be placed at the interfaces of the outermost and innermost thirds of the table.

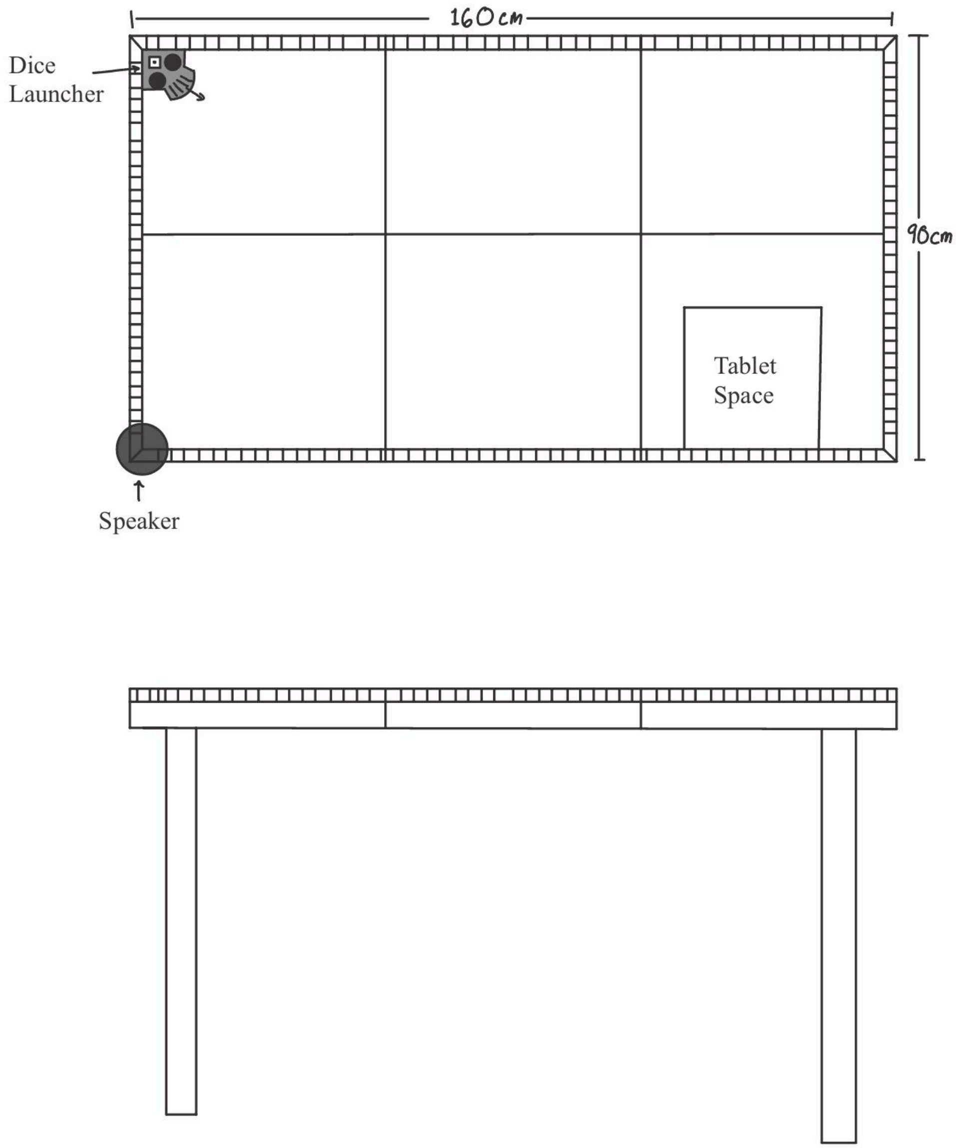

Figure 3: Suggested “Rectangle” design

The proposed “Extending” table shown in Figure 4 was a preliminary design that featured a modular system. Three sections of the table surface were easily removed and replaced, allowing for the switching of game surfaces. The table incorporated features such as motorized legs folding inwards for easy storage, cup holders, a tablet holder and outlets. The table was inspired by a dining table. The tabletop is supposed to slide on the sides and reveal a middle compartment which rises up and extends the table, allowing more people to use it. In closed form, the table legs are folding inwards, making it more compact and easy to store away.

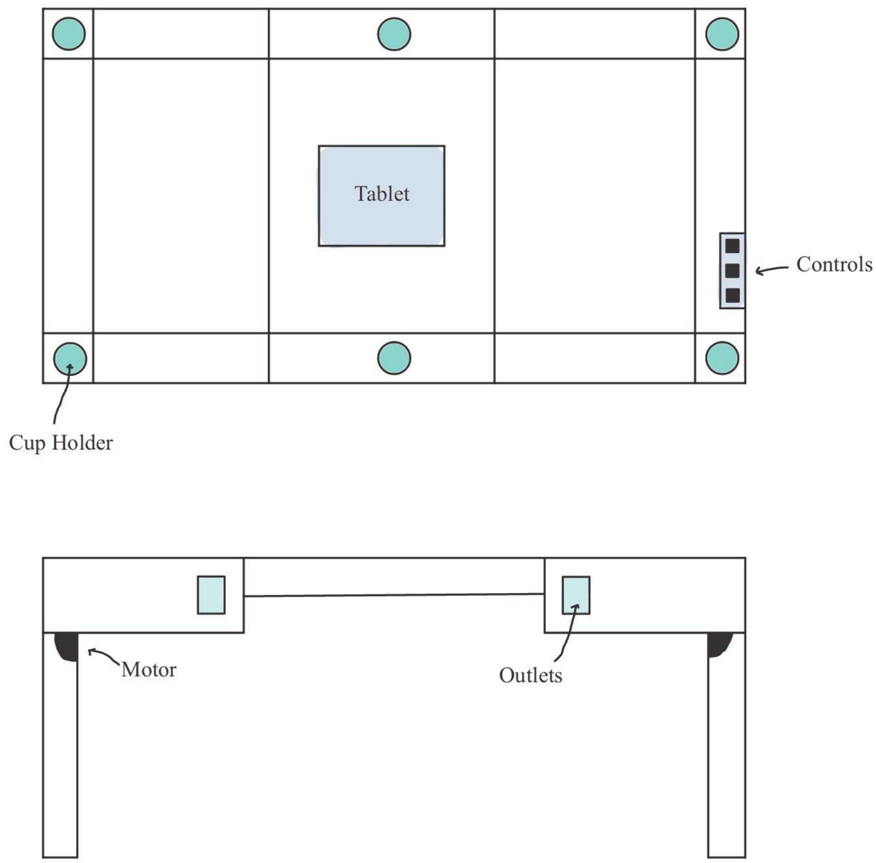

Figure 4: Suggested “Extended” table design

The final design proposed was the “square” table design shown in Figure 5. This design consisted of an outer rim with cup holders and recessed trays, for dice or other game pieces. Additionally the center portion of the table is sunken to create an enclosed playing space. The edges of the center surface contained built-in speakers. In order to meet the portability expectations the sides would fold down next to the legs for easy storage.

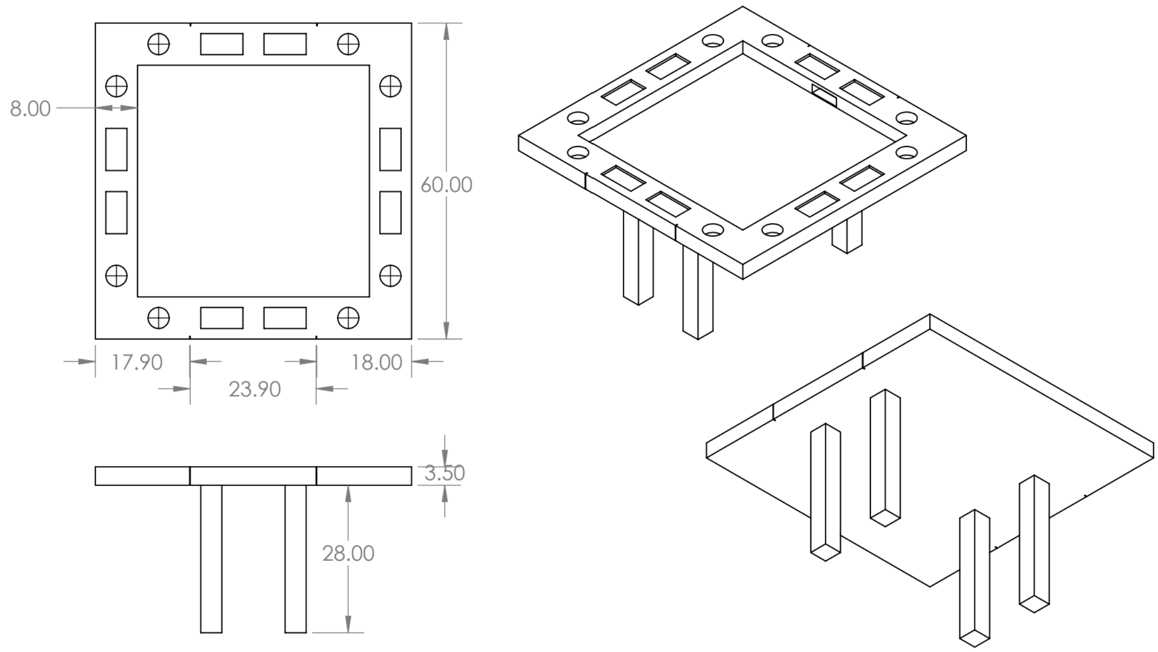

Figure 5: Suggested “Square” table design (dimensions are in inches)

Weight	Criteria	Rectangle	Extending	Square
10	Audience	0	0	0
9	Safety	3	4	4
8	Cost	0	0	0
7	Functionality	0	0	0
6	Durability	3	4	5
5	Size	4	5	3
4	Portability	5	4	4
3	Electrical Resilience	3	5	4
3	Electrical Features	5	3	3
2	TV/screen/projector	0	0	0
1	Extra Storage Space	3	1	2
		112	126	120

Table 1: Decision matrix for the table base designs

The three designs were graded based on a 5 point scale for each criteria. The numbers were then weighted by the first column numbers, as some of the criteria are more important for the design than others. A value of “0” was given when all three tables equally accomplished the criteria so as not to skew the data. Once calculated, the extending table design was the top choice for our given criteria which was then used to create the mechanisms.

Mechanisms

Tabletop Extending

The team created three different ideas for the tabletop extending mechanism. Each mechanism was designed to move the tabletop surface into a longer configuration. The surface needed to be cost effective, weigh as little as possible, move safely, and be easy to use. The team discussed three ideas, and a final design was created by combining elements from the proposed ideas.

The first idea for the extending table top was a rack and pinion design (Figure 6). The rack was on the tabletop, while the pinion was fixed to a motor or crank on the bottom of the table. This design worked by spinning the pinion in place, which in turn moved the rack. The rack continued onto the side of the tabletop to allow the middle of the table to be aligned. However, the tabletop was not attached to the rest of the table, which was difficult to remedy. This would also cause safety concerns, with it falling off on someone, or hitting them when it came unmeshed. Another issue with this design was the weight and cost of metal racks and pinions on this large of a scale. At least one was necessary for each side of the table, which doubled the weight of the system as well as the cost.

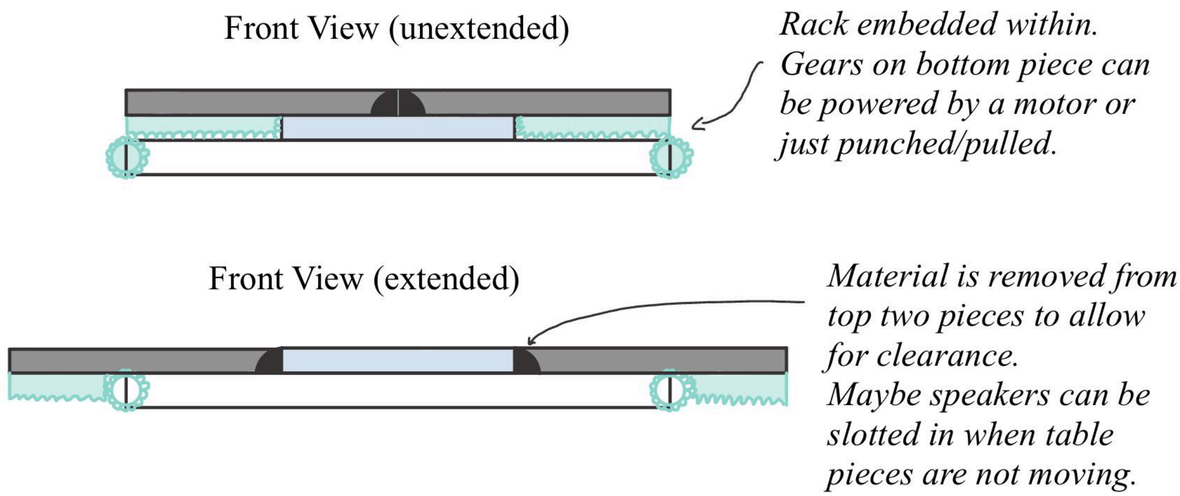

Figure 6: Initial drawing of the rack and pinion design

The second idea was a winch design. This design featured a winch attached to a rope that was wrapped around it, and the other end of the rope was attached to the tabletop (Figure 7). When the winch was turned, it would pull on the rope to open or close the tabletop. The design would be easy to construct, and the parts would be less costly than the first design. It also allows for interchangeable manual and automatic manipulation with a hand crank or a motor. However, this would take up a lot of the table space since four winches and shafts would be needed on each side of the table. Additionally, the ropes would be moving, which could interfere with electrical components. One benefit to this system compared to the rack and pinion is that it would weigh less. This is because the design requires the same number of motors to function, but incorporates less metal overall.

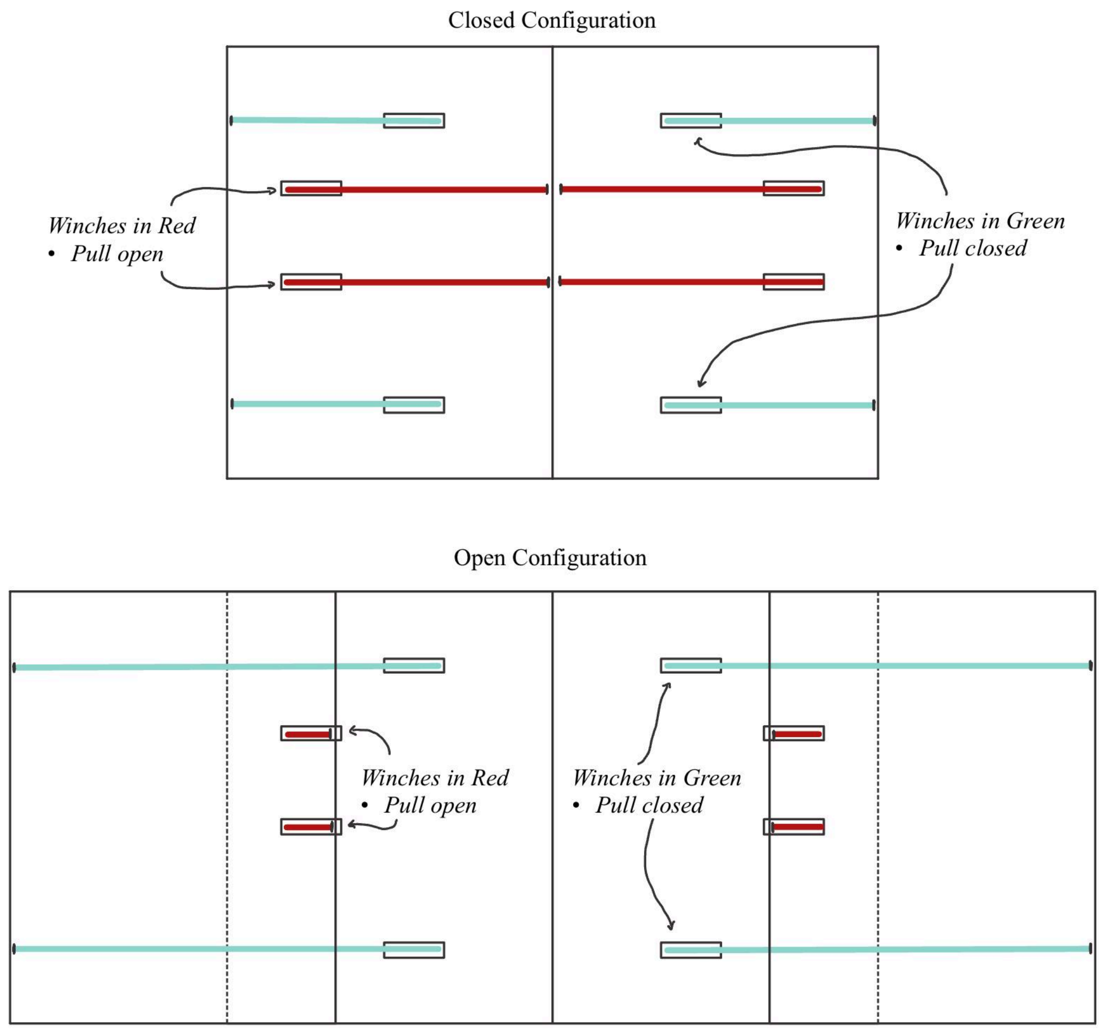

Figure 7: Initial drawing of the winch design

The third idea was the separate surface design. This design incorporated the classic leaf system of tables by having the ends extend and another piece of wood put in the middle of the table. The top surface would be the main surface of the table which means no storage area for the top was necessary. The leaves would be on rails, like a drawer, and move back and forth, as seen in Figure 8. The leaves would glide on wheels that are powered by a motor. This design was by far the safest, as the other tabletops had the ability to move off the rest of the table and uncover the system inside the table. Additionally, the cost of the parts would be similar or more than that of the pulley system. Lastly, the weight of the system is much more than the other designs because there is an extra surface for the table.

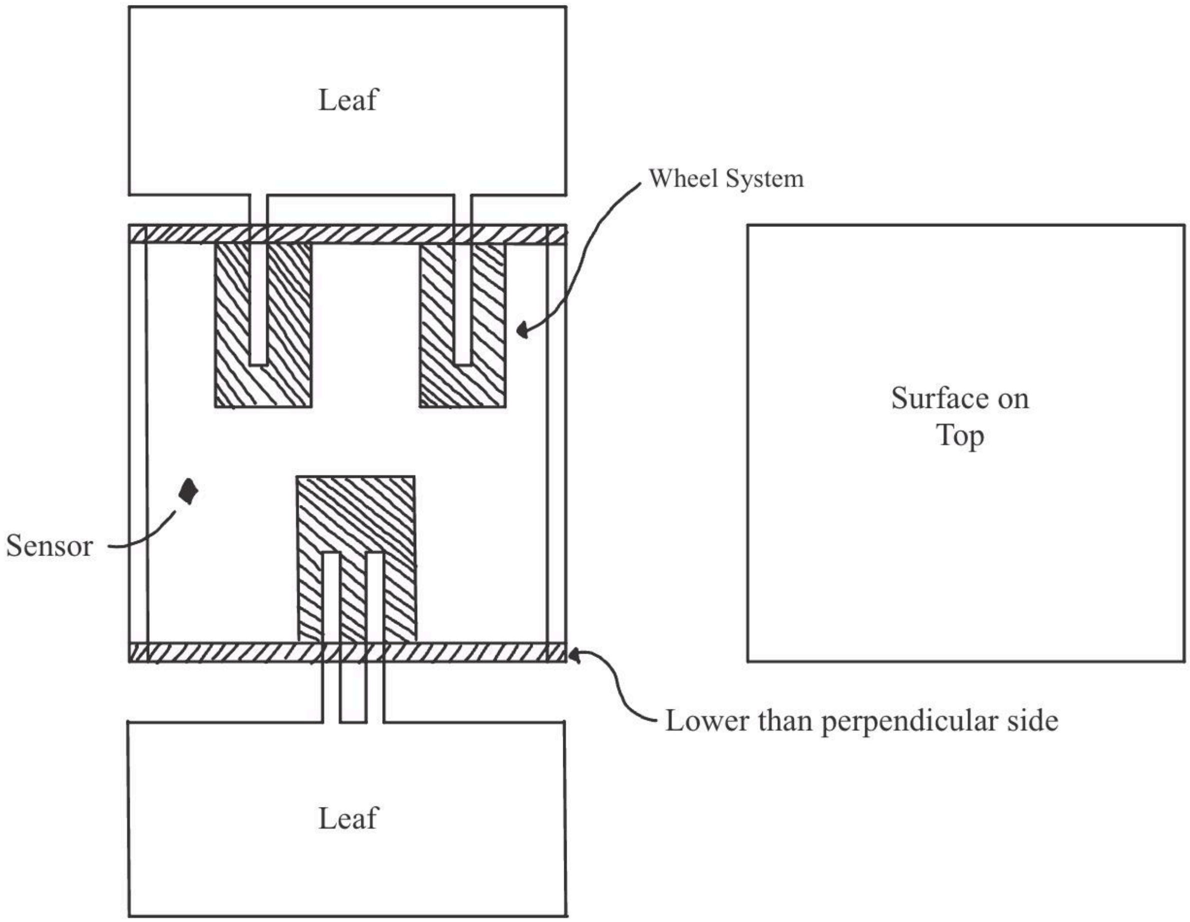

Figure 8: Initial drawing of the separate surface design

The final design combined the railing system of the separate surface design with the extending setup of the winch design. This made sure the system weighed a lot less, had the best safety, the cost was similar or less than the three designs, and would be easy to construct.

The design consists of a motor attached to two aluminum toothed pulleys, as seen in Figure 9. These pulleys turn the wheels whose rotational movement was translated into lateral movement by pushing or pulling the table top. The friction between the wheels and the tabletop would provide the necessary friction to move the system, thus opening and closing the table. The railing system on the sides were also there to limit the friction between the table top and the rest of the table, easing the strain on the motor.

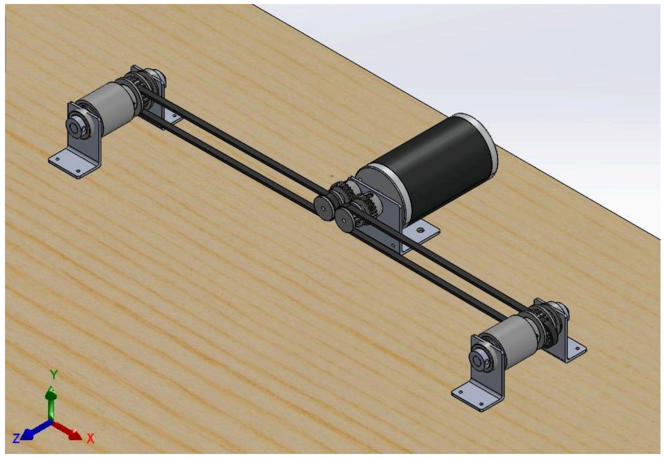

Figure 9: Preliminary CAD of the wheel system final design

Legs

We proposed two different concepts for how the leg mechanism would be designed to compress and compact the legs. The mechanisms needed to weigh as little as possible, and take up the least possible volume when in the closed position.

The first design idea would be a pneumatic piston leg, similar to that of a standing desk, that would be able to shorten the table legs to a reasonable height for storage, similar to a coffee table. This design idea would rely on the use of pneumatic lift kits from vendors that use an electric motor to control the hydraulic cylinder that was housed inside the leg shafts. An example of the potential pneumatic leg can be seen in Figure 10. The main issue with this concept was that the price to purchase only one of the legs would use up about a fifth of the project's total budget. Another concern with this concept was what the weight of the table would be with four metal legs attached to it, as portability was one of aspects we originally had as a higher priority.

Figure 10: Example of pneumatic leg design

The second concept design would involve a rotation of the legs upwards into the base of the table. To achieve this, a series of gears, pulleys, and belts would be attached to the bottom of the table using brackets and half inch metal rods, as shown in Figure 11. This design allowed us to be able to compact the legs better than using hydraulics, minimize weight, and also stay within our budget for the project. For these reasons, we decided to go with the second concept design for our final design. The parts used to build this system included the following: The four legs were 4.1 cm x 4.1 cm x 38 cm of ash wood, purchased from The Home Depot. These legs were machined to add 1.2 cm holes into them, which houses XiKe Flanged Ball Bearings on both sides, dimensioned at 13 mm x 28.5 mm x 13 mm, and the two 76 cm long 13 mm diameter 1566 Carbon Steel Rotary Shafts that were cut from a 152.4 cm stock shaft, ordered from McMaster-Carr. Another 60 cm long shaft was purchased and cut in two for the parallel shafts. The pulleys that were used were three V-Belt pulleys with an outer diameter of 5 cm with a shaft diameter of 13 mm, were ordered as is off of McMaster-Carr. The two belts are EPDM Rubber V-Belts with widths of 9.7 mm, thickness of 5.5 mm, and circumferences of 167.64 cm and 35.5 cm respectively, ordered from McMaster-Carr. Two metal gears with a round bore, 20 degree pressure angle, 20 gear pitch, and 24 Teeth were bought from McMaster-Carr and were used to change the rotation of the legs inward, so that we could use just one motor. The motor we used to move the legs was the Nema 34 Stepper Motor. The Nema 34 has a high holding torque of 4.5

N.m, and the stepper design allows great precision in positioning, in increments of 200 steps. In addition, the stepper design allows high torque at low speed.

Figure 11: CAD for one side of the leg mechanism

Supplementary Tabletop

Originally, three mechanisms for lifting the middle section of the tabletop were proposed. In all designs, the middle section of the tabletop folded outward into three pieces, filling the space left by the two extending tabletop leaves.The first mechanism was a rack and pinion system, and the second was a spring mechanism, but there were a number of impracticalities and issues with these designs. The third design, discussed in the final paragraph of this section, was a scissor lift and lead screw mechanism. Although challenging to design, it ultimately was the best of these three mechanisms for the purpose of lifting the middle section of the tabletop, and was the mechanism chosen for the final design.

The rack and pinion design was the first proposed design. Two gears attached to opposite sides of the middle section of the tabletop are powered by two motors. The rotation of these gears allow the folded tabletop system to travel along a straight, vertical rack, going either up or down. When at the top, the middle tabletop section side flaps would fold outward, as with all designs mentioned. While straightforward, the rack and pinion presented issues regardless of the material used to make them. Metal is strong and durable, making it the initial choice. Unfortunately, metal is heavy and expensive when compared to the other materials we considered, plastic and wood. Minimizing the weight of the table is a priority, and the amount of metal and additional motor in this design would significantly increase the table's weight. The team lacked direct access to technology that could be used to machine these racks and gears, so ordering inexpensive metal stock was not an option. Racks and gears that have already been manufactured would need to be ordered for this design, and the prices of these were too expensive for our goal when accounting for the cost of other mechanisms and electric parts. Our team's design matrix process prioritized a lower cost over long term durability. The metal rack and pinion would provide long term durability, but at the greater expense of our budget. We also thought to 3D print the racks and gears, which would greatly save on cost and weight, but plastic is not a suitable load bearing material in this application. Wood racks and pinions were the "middle ground" between plastic and metal, but we lacked the capability of creating them from raw wood.

The simplest of proposed designs for lifting the middle section was the spring mechanism. The idea had the middle tabletop section rest on compressed springs so that when the leaves extend, the spring force would push the tabletop upward until the system of the spring and tabletop reached equilibrium. This equilibrium height would make it so that the surface of the middle section tabletop was at the same height as the surface of the leaves. The force produced by the springs would be equal to the weight of the tabletop, which are the only two forces in this tabletop/spring system. The equation for force produced by a spring is $F = - kx$, where F is the force produced by the spring, k is the spring constant, measured in N/m, and x is the distance the spring is compressed, measured in meters. More spring compression results in more force produced by the spring. This design would not require extensive construction nor cost as much as the other designs, making it initially a strong candidate. Springs can be purchased in the required size or can be cut from a larger size. However, while this design would greatly simplify the lifting mechanism, it was found to be unsafe. When the leaves are not extended, it was thought the weight of the leaves would counteract the increased upward force from the springs that were now more compressed. However, when calculated, it was found that this was not the case - the weight of the tabletop and leaves was less than the force produced by the compressed springs. This meant that the middle section of the tabletop would not rest where it needed to. It also meant there would need to be a tether to act alongside the weight of the tabletop and leaves in order to counteract the force produced by the compressed springs. This tether would need to be strong enough to withstand constant tension when unextended, as well as tension when extending and unextending in order to limit the speed of the upward movement of the middle section of the tabletop. It would also require a motor to pull the tabletop/spring system into the table.

The most mechanically complex design of the three is the scissor lift and lead screw mechanism. Working in conjunction with the table extending mechanism, the scissor lift will allow the middle section of the tabletop to rise from within the table. A basic scissor lift with a push bar powered by a lead screw was conceptualized in Figure 12 below.

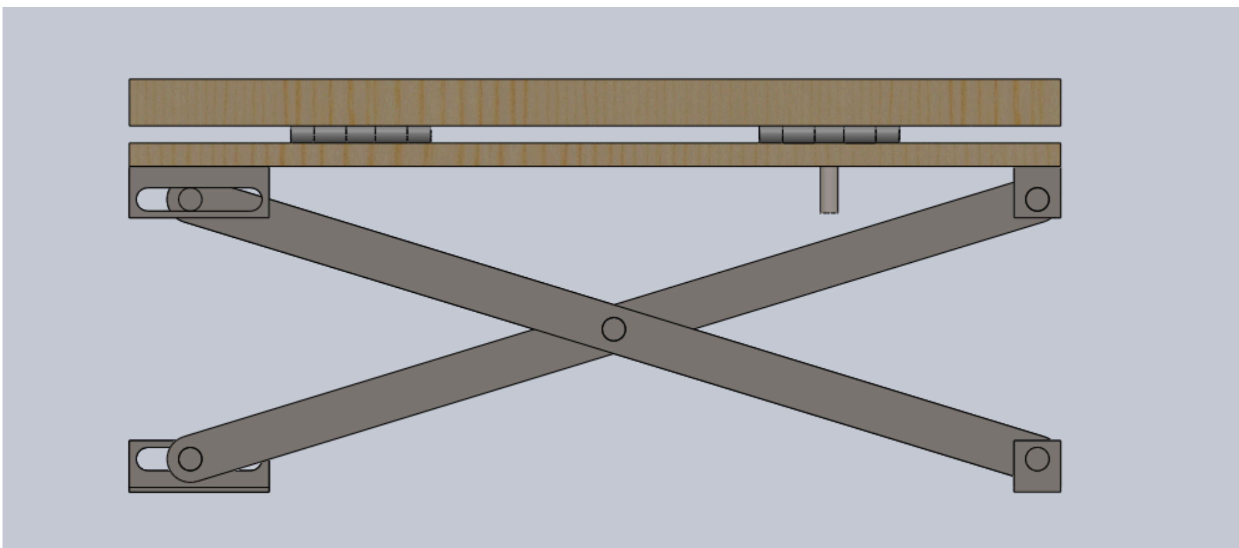

Figure 12: 2D profile of the scissor lift

In this explanation, there was a motor coupled to a lead screw that intersected with a bar clamped to a lead screw nut that was going into the page. There were four foundational pieces - the Upper and Lower Hinges, and the Upper and Lower Rails. There are two of each part. As the lead screw turns, the nut will move horizontally along the screw. This causes the bar and lift arms to move along with it, raising the additional tabletop from within the table. This will result in a completed extended tabletop. The largest challenge with this mechanism was the height constraint. In the final design, the total height of the scissor lift and folded tabletop system must be under 5.7 cm, such that when the leaves are not extended the scissor lift and tabletop system can fit within the table. To accomplish this, we decided to make the additional tabletop thinner than the tabletop leaves. We also chiseled into the bottom plate of the table. Chiseling allowed for an additional 0.76 cm of height, which was crucial to secure the motor, the lower hinges, and lower rails to the bottom plate. It also allowed clearance for the lead screw to pass under the scissor lift at its minimum height. Figure 14 shows our preliminary CAD design of the scissor lift.

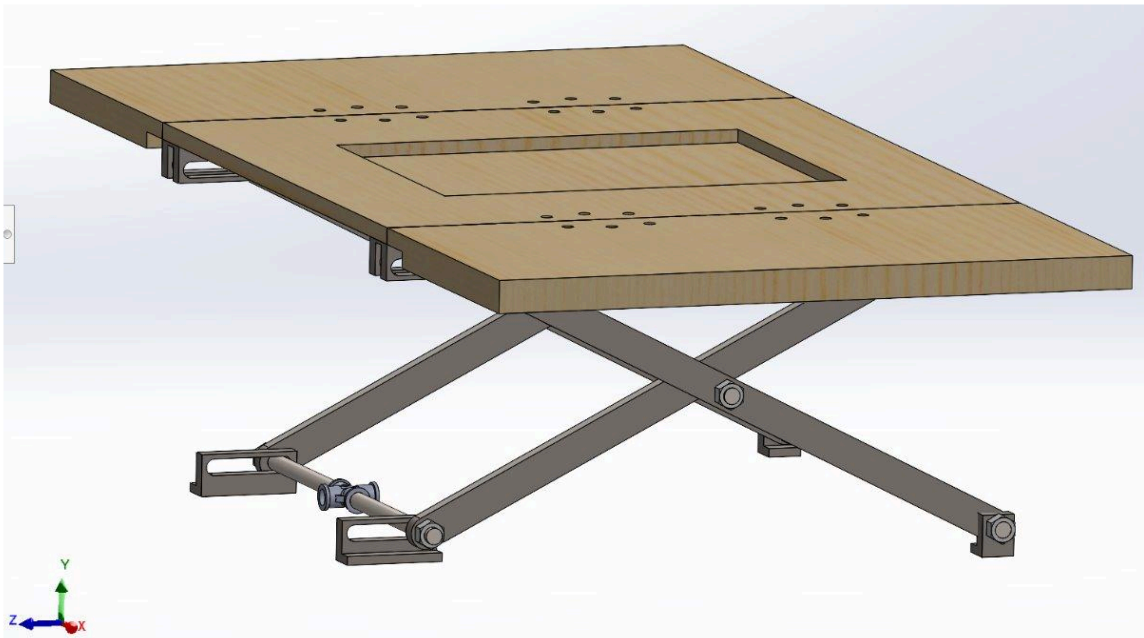

Figure 13: Preliminary CAD of scissor lift final design

Final Design

The design incorporated the wheel/rail extending tabletop system, rotating leg system, and the scissor lift lead screw system. After all the design aspects were decided, the final design was sketched out with the whole team to get a better understanding of how all the mechanisms would fit together. The drawings can be seen in Figure 14 below.

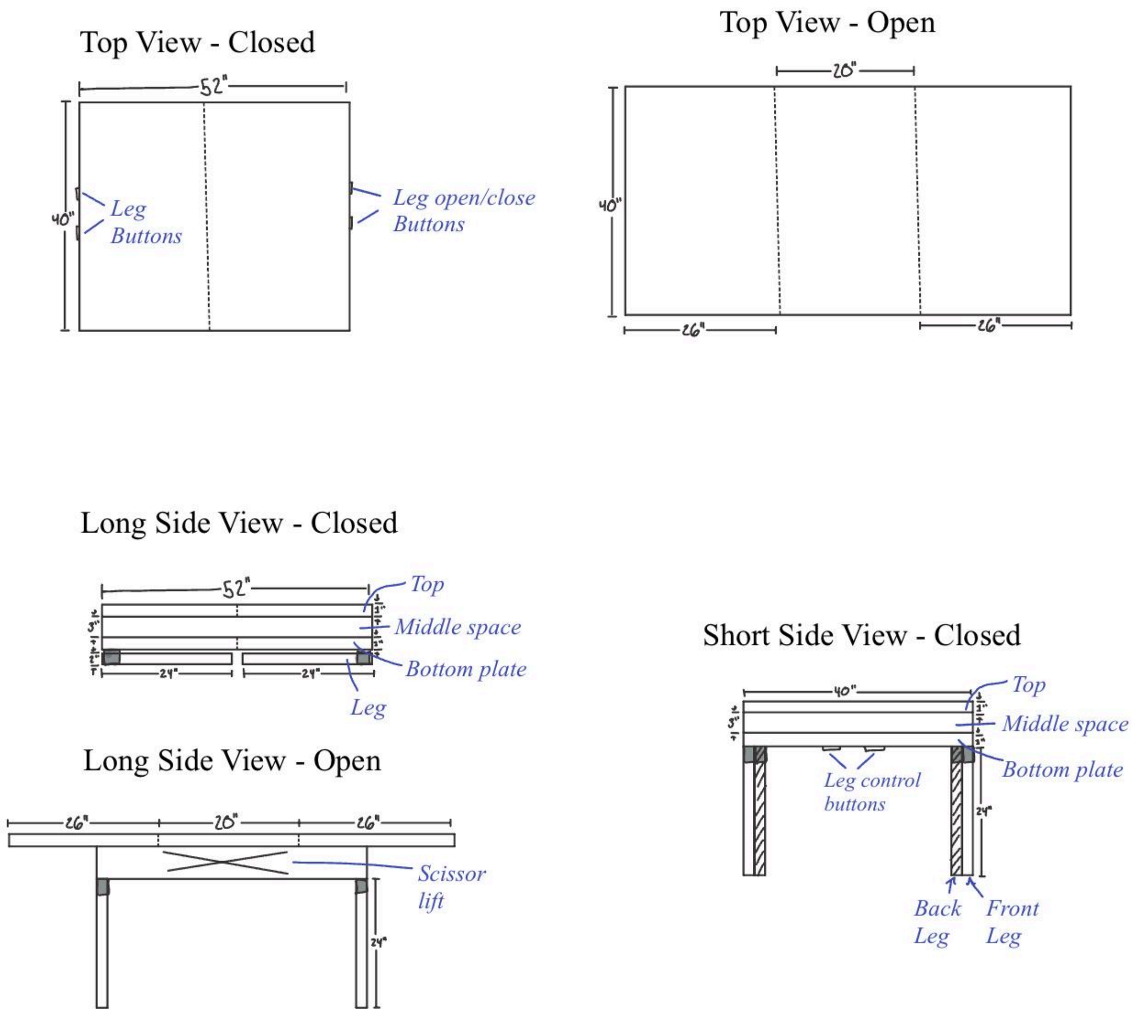

Figure 14: Final table design for extending closed and open configurations and measurements

4.2. Structural Engineering

With the final design decided on, the team started the analysis of the design. The design was first created as a CAD assembly which was used for further analysis of the table. Then a torque analysis of each mechanism was conducted to choose to correct motors to power the systems. With the design validated and detailed the prototypes could be constructed.

CAD

CAD parts, assemblies, and drawings were drafted to aid in the construction of the table. The parts were downloaded from the manufacturers or designed by the team. Each part was then assembled as individual mechanisms or sub-assemblies. All mechanisms were compiled in a full assembly which allowed the team to have a visual representation of the product and prevented potential discontinuity. For a few of the parts, we made drawings so that they could be sent to professionals for fabrication. Each drawing had multiple iterations to improve the manufacturability of the parts for machinists. When changes were finished, the CAD was used to facilitate the table parts' construction. The full CAD assembly (Figures 15) was also used to conduct simulations for stress and strain points of the table and for thermal activity of the power bank.

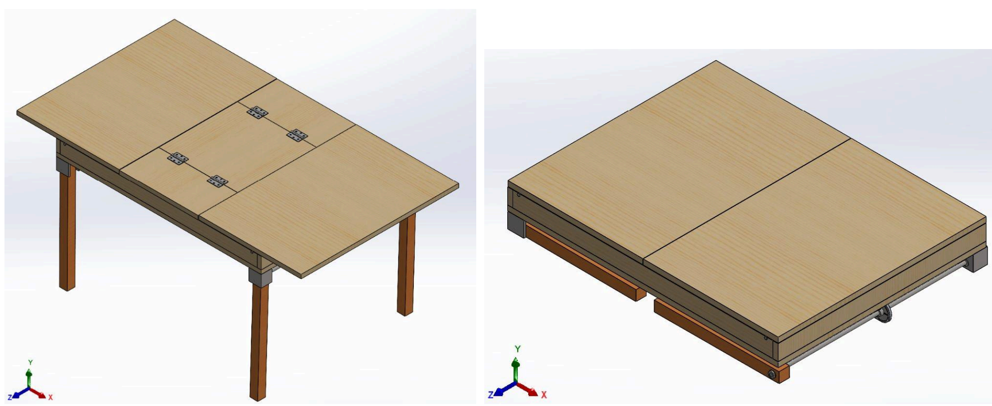

Figure 15: Full CAD assembly, open configuration (left) and closed configuration (right)

FEA

Our goal was to use FEA to predict how our final table assembly and subassemblies would react to expected stresses in a static position. To run this simulation, the team used a Solidworks Static Simulation study. Given the options between a coarse or fine mesh: if a fine mesh is used, the stress concentration occurs at the surface with a small curvature. If a coarse mesh smoothens the stress irregularity within the domain of stress applied. By using the previously mentioned CAD assembly, an ultrafine mesh was applied to the model as this would allow for smaller elements to display and produce more accurate results. This mesh can be viewed in Figure 16. It is noted that the areas with more activity consisted of smaller parts with more complex and fine meshing.

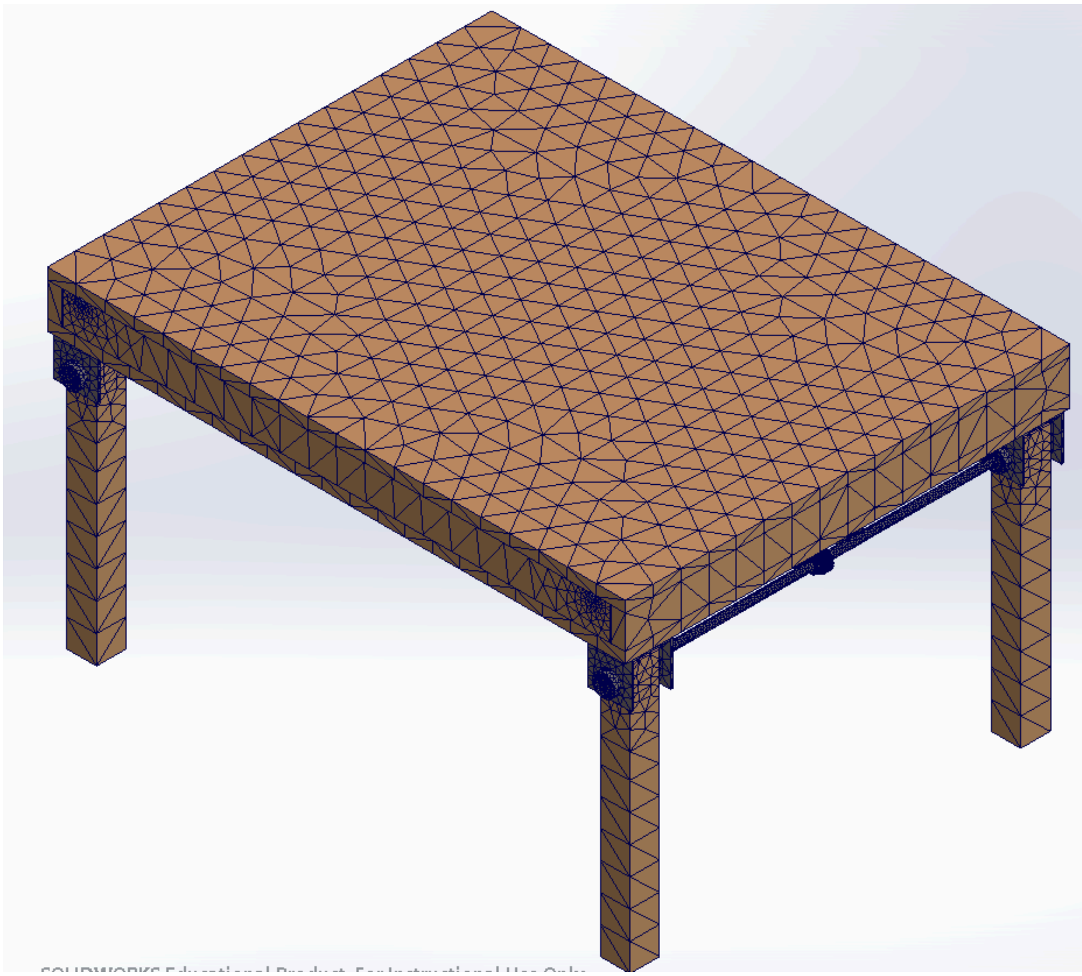

Figure 16: Meshed assembly as viewed in Solidworks

The loading conditions were applied to the assembly by applying an evenly distributed load of 667.2 N to the table top surface, with the legs being anchored in place. We chose this value for the load as it was the theoretical maximum weight that the table should be able to handle. In Figures 17 and 18 the applied load is represented with the purple arrows shown in the simulation.

Figure 17 below, shows that the relevant maximum equivalent strain found is 2.431e-05 strain. The maximum deformation reported occurs at the center of the table on the rail systems wood, shown in Figure 18 highlighted in the red box. This was likely due to the rail system having a thin outer wall that supports most of the load. Also noted is the similar strain additionally occurring close to where the legs meet the table.

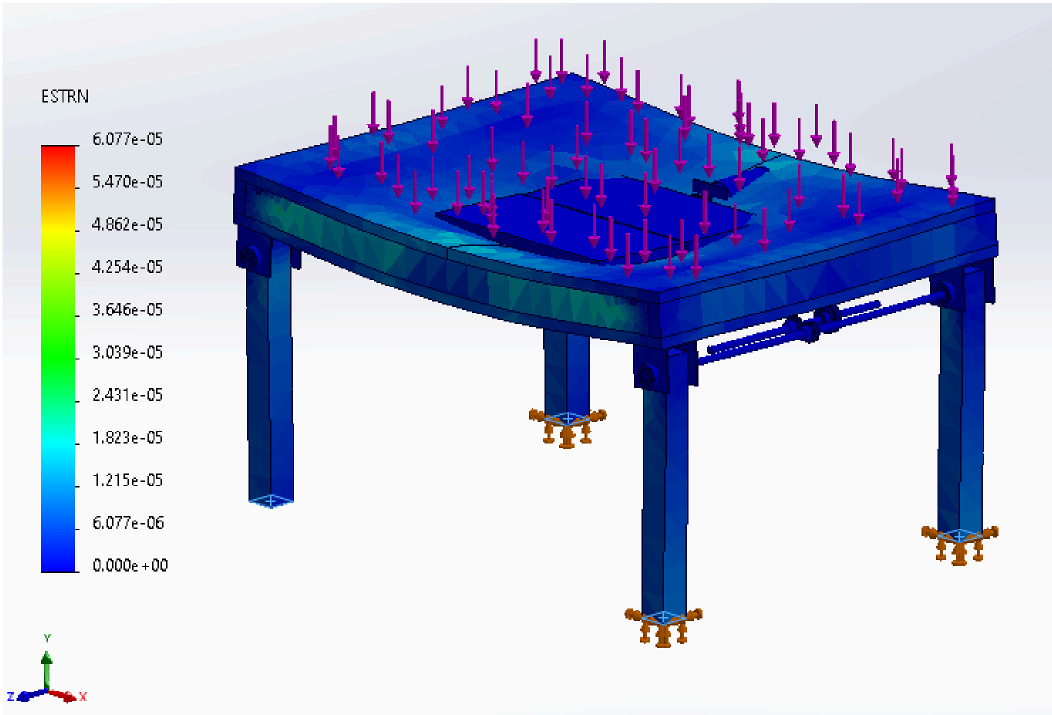

Figure 17: Solidworks statics simulation of equivalent strain

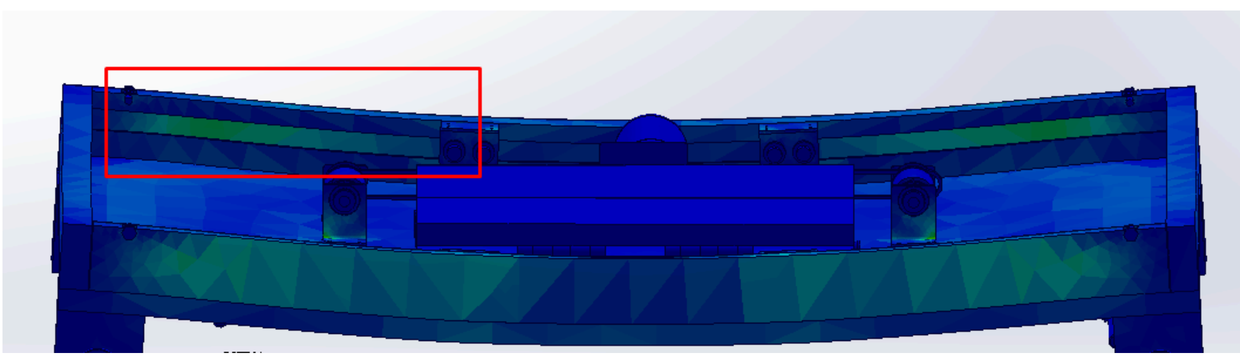

Figure 18: Area where maximum equivalent strain is found

Additionally, Figure 19 shows what the normal strain in the Y-Axis would be. This data is helpful as it shows what the compressive stresses are directly related to the applied load. This maximum value takes place near the center of the table on the rail system and has a maximum of 1.845e-05 strain.

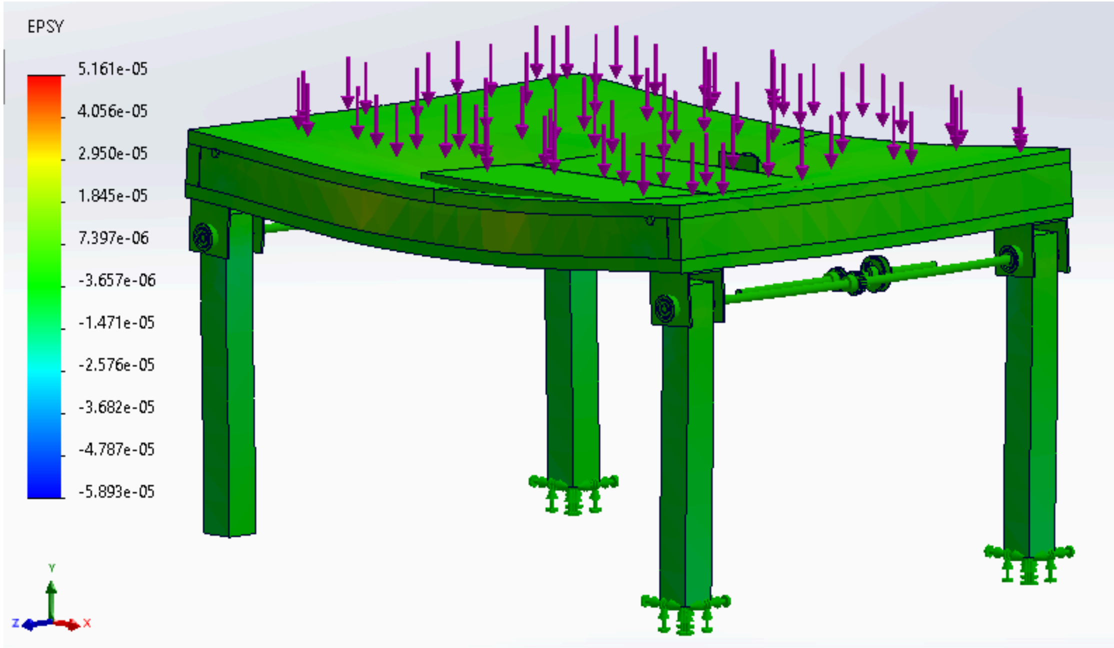

Figure 19: Solidworks static analysis of normal strain in the y-axis

Interpreting this data, given the use of pine plywood, the typical allowable yield strain for this material is <0.0002 strain. As a result, we found the yield strength of pinewood exceeds the strain placed by the load by over a factor of two; indicating the table was structurally sound and would not significantly deform under the loading conditions and further validating our results. This deformation that occurs within the internal hardware and on the wooden body would be classified as an elastic deformation. The applied stress and strain is within the force load allowances for the given materials based on their modulus of elasticity, therefore the materials will return to its original form when the forces are removed.

Torque Analysis

A torque calculation was done to calculate the forces on the lead screw within the scissor lift to ensure mechanical operation, in both a closed and open state. The motor must surpass the calculated torque of 1.02 N.m by over a factor of two. The motor selected, the Nema 23 stepper motor, has a holding torque rating of 2.83 N.m, which meets the required torque. The FBD can be seen in Figure 20, below, and the full calculations can be found in Appendix F.

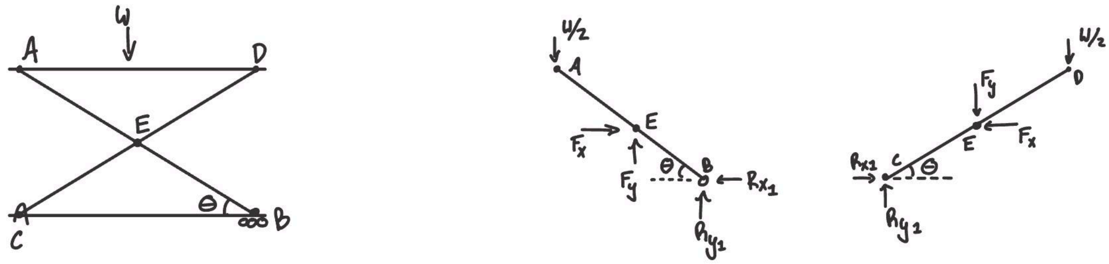

Figure 20: FBD of the scissor lift mechanism as a whole and broken into components

A torque calculation was also done to calculate the forces on the wheels from the tabletop to ensure mechanical operation. For both closed and open states the weight of the tabletop does not cross the side of the table, thus is supported and will not fall. When both states were calculated the normal force on the wheel was the same which meant the force on the wheel in a closed state equals the force on the wheel in an open state. To conduct the calculations only the closed system (Figure 21) was completed, and the calculations are given in Appendix F. Forces with subscript w are acting on the wheel, ones with subscript R are reactions from the side of the table, Rx and N are from the railing wheel bracket acting on the tabletop, and Wg is the weight of the table top. From the analysis, the motor must surpass the calculated torque of 0.6152 N.m when using a factor of two. The motor selected, Nema 23 stepper motor, has a holding torque rating of 2.83 Newton meters, which meets the required torque. The motor also had to fit inside the table. The interior of the table allows 57.15 mm of height, meaning the 57 mm Nema 23 motor meets the required criteria.

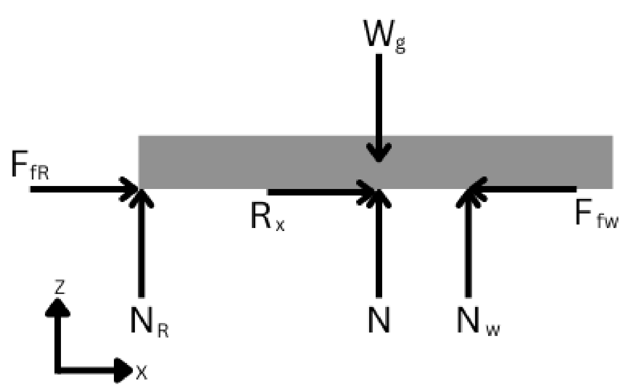

Figure 21: FBD for tabletop in the closed configuration

Prototypes

In order to both visualize and validate the design, our team built two prototypes. The first was a small-scale version out of standard size LEGOs (Figures 22, 23, 24, and 25). The second was a 75% scale version made from actual parts. From this, we were able to learn a lot about what worked well with our design, but even more about what needed to be improved.

The LEGO prototype can be seen in figures 22-25, and for reference it is about 25.6 cm closed or 35.2 cm open by 19.2 cm and 16.32 cm tall. From the LEGO prototype, we were able to gain a better understanding of the way the parts interacted. It served as a proof of concept for the overall design by allowing us to fit the components together. The LEGO prototype moves as the real design would, validating the chosen methods for expanding the table.

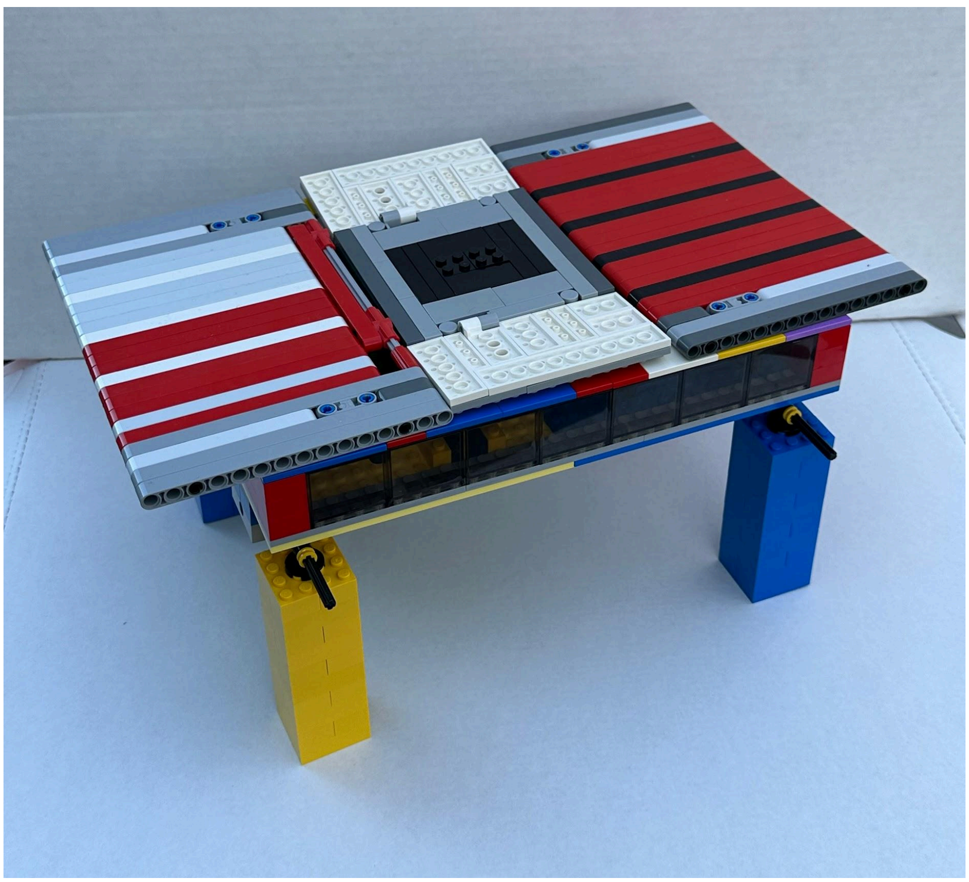

Figure 22: LEGO prototype in isometric view (open configuration)

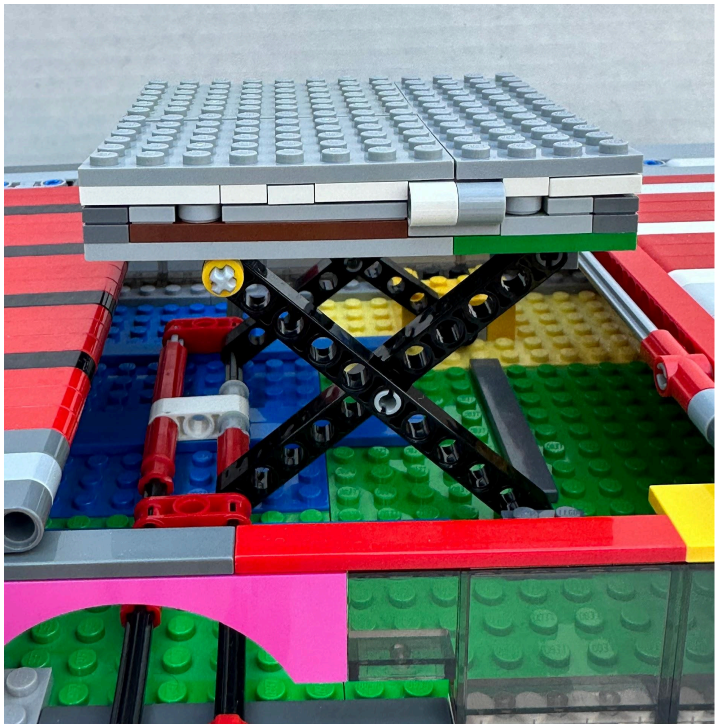

Figure 23: LEGO prototype, scissor sub mechanism

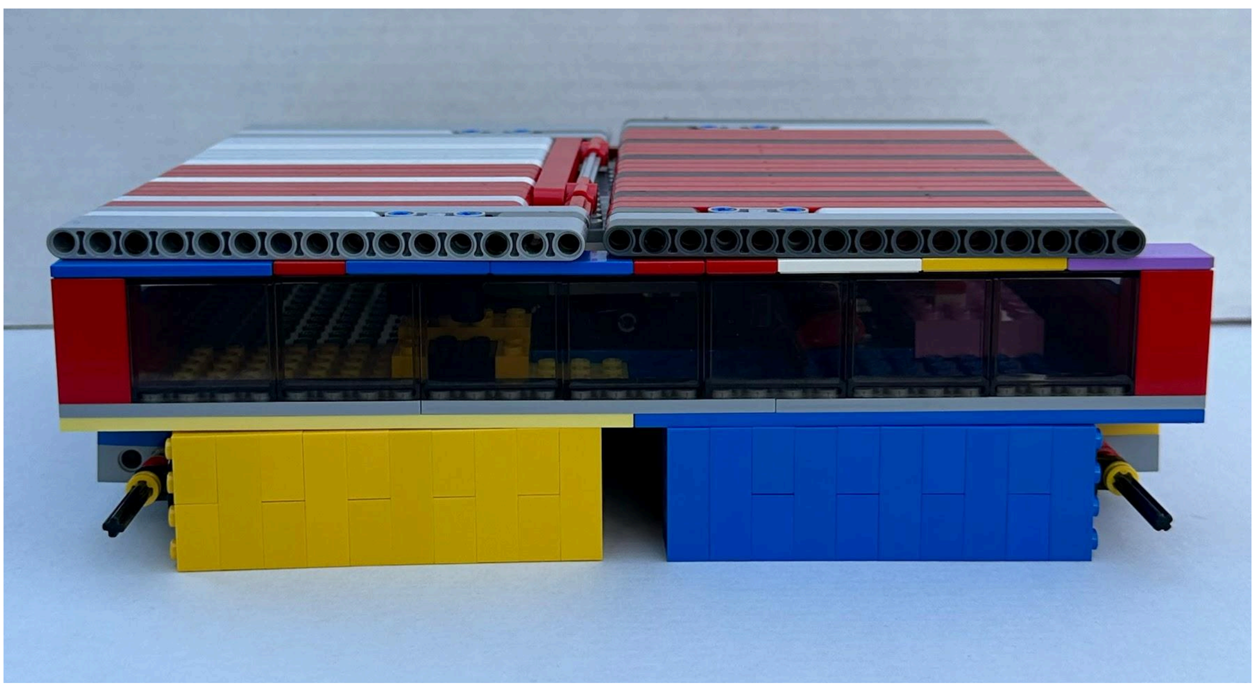

Figure 24: LEGO prototype, side view (closed configuration)

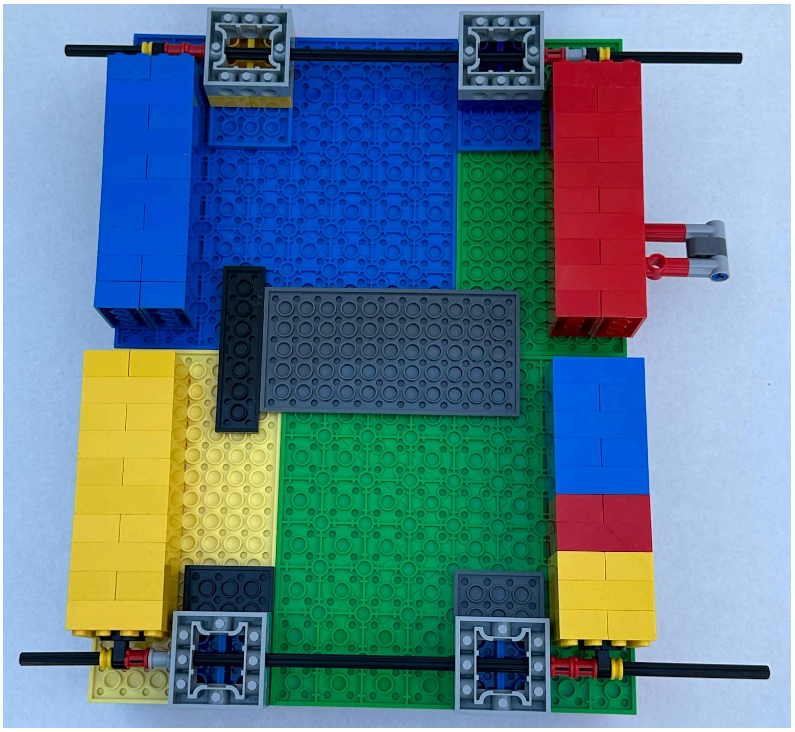

Figure 25: LEGO prototype, bottom view

The 75% scale model worked as a great way for the team to visualize flaws in our design. Specifically, some spacing issues could be seen that were difficult to visualize in the LEGO prototype and CAD versions. Once we began assembling the prototype, we realized the thickness of wood selected would make the table heavier than anticipated coming out to 17.4 kg for the total weight of the wood (Figure 26). This meant that it would not be as portable as originally anticipated. Additionally, the National Institute for Occupational Safety and Health (2007) gives an equation to calculate how much a person can lift with the maximum being 34.8 kg. Compared to the prototype's total mass it is reasonable to say two people could lift it however the full scale model would weigh too much. Lastly, the prototype allowed us to see that the rail system we used was not a viable long term solution as the wear on those parts would not sustain long term use.

Mass of Prototype $m = \rho V$

Parts made from pine plywood $t := \frac{3}{4} \cdot in$ $\rho_1 := 1.9 \frac{lb}{ft^3}$

$V_{bottom} := 2.5 \cdot 3.25 = 8.125$

$V_{tabletop} := 2(2.5 \cdot 1.25) = 6.25$

$V_{middlesides} := 2(1.25 \cdot .625) = 1.563$

$V_{plywood} := V_{bottom} + V_{tabletop} + V_{middlesides} = 15.938 \ ft^2$

$m_{plywood} := \rho_1 \cdot V_{plywood} = 30.281 \ lb$

Middle of Middle from pine plywood $\rho_2 := 1.12 \frac{lb}{ft^3}$

$V_m := 1.25 \cdot 1.25 \cdot .02864583 = 0.045$ $m_{middle} := \rho_2 \cdot V_m = 0.05 \ lb$

Legs for table

rectangle - hole = V $\rho_3 := .0145 \frac{lb}{in^3}$

$$V_{legs} := 4\left[(2 \cdot 2 \cdot 18) - \left[\pi\left[\left(\frac{.5}{2}\right)^2\right] \cdot 2\right]\right] = 286.429 \quad m_{legs} := \rho_3 \cdot V_{legs} = 4.153 \ lb$$

Sides of common board $\rho_4 := .0126 \frac{lb}{in^3}$

$$V_{short} := 2\left[\left(\frac{7}{8}\right) \cdot 37 \cdot 2.25\right] = 145.688 \qquad m_{short} := \rho_4 \cdot V_{short} = 1.836 \ lb$$

rectangle - rail cut out = V

$$V_{rails} := 2[(1 \cdot 37 \cdot 2.25) - (.375 \cdot .62\text{:}lbs2) - [.5 + (.25 \cdot .75)]] = 164.656$$

$$m_{rails} := \rho_4 \cdot V_{rails} = 2.075$$

Total mass of wood of table

$$m_{total} := m_{plywood} + m_{middle} + m_{legs} + m_{short} + m_{rails} = 38.395 \ lb$$

Figure 26: Mass calculations of each piece of wood for the scaled prototype

The assembly of the 75% scale prototype revealed several potential difficulties if mass production were to be pursued. Some individual parts of the table were designed by us, as stock parts from our available vendors did not suit the requirements of the mechanisms. Half of the plywood plates required extensive hand-chiseling which would lengthen manufacturing time. In order for the scissor lift's lead screw nut to not rotate to facilitate translation along the lead screw, a threaded clamp was designed. We lacked the capabilities to machine this part due to the complex shape and instead used a 3D printer to create it. The PLA material is not as durable as metal. Additionally, custom rails and hinges were designed for the scissor lift mechanism. Features were required on three faces of each rail and hinge. Specifically, a feature on the upper hinges and rails were too thin due to the compact space allocated to the scissor lift and produced an error while machining. However, some custom parts with features on one simple face, such as the scissor lift arms, were able to be outsourced, which did not hinder the time to manufacture the table. Additionally, the cost of the prototype was found to be $1000 which compared to the expensive tables described prior was a great improvement (BOM can be found in Appendix E). Figures 27 and 28 show the finished prototype in closed and open configuration respectively. Figure 29 shows the functioning scissor lift in full height and Figure 30 shows the internal wiring of the table.

Figure 27: Prototype in closed configuration

Figure 28: Prototype in open configuration

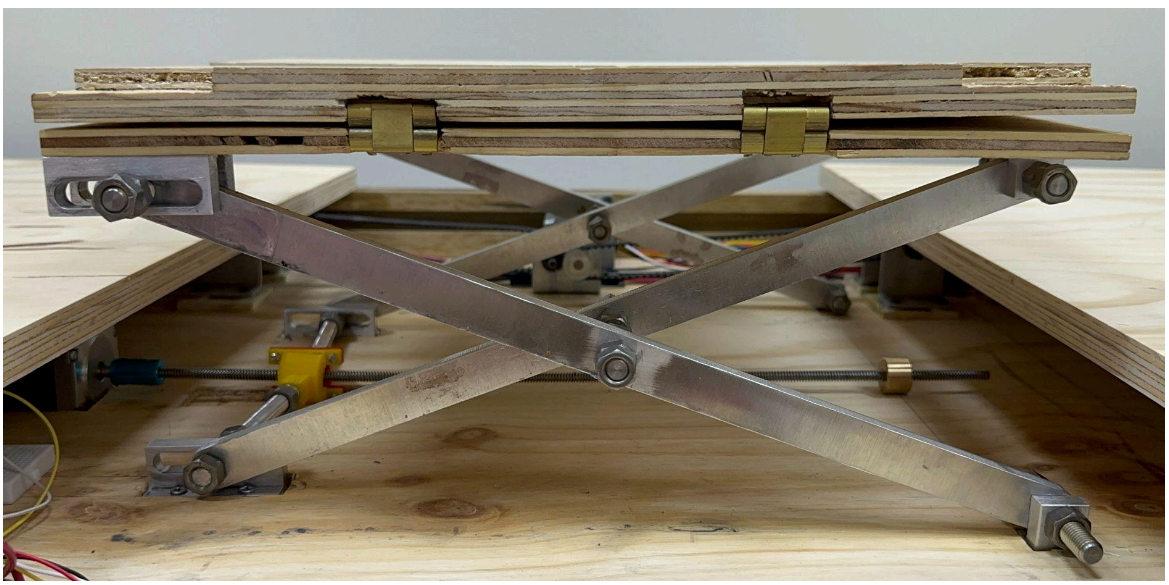

Figure 29: Prototype, scissor Lift sub mechanism

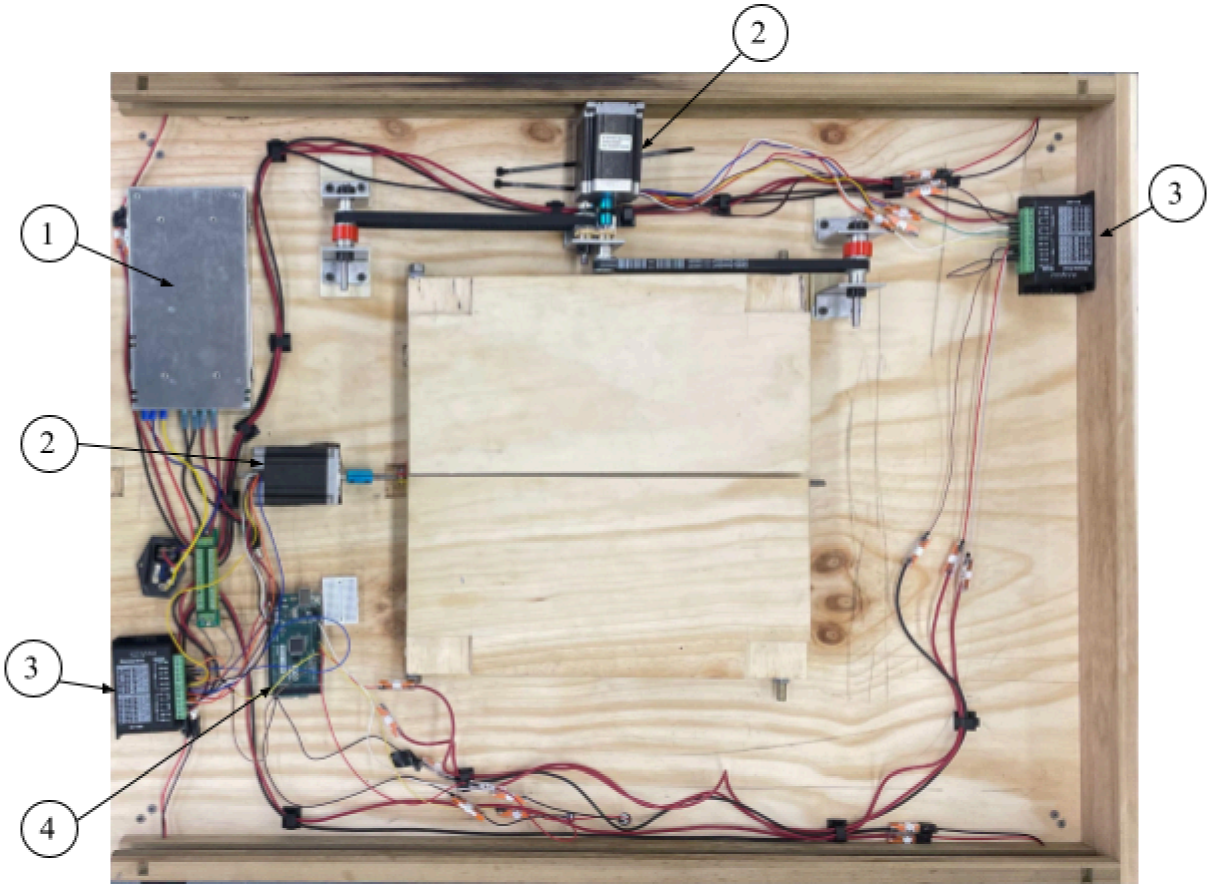

Figure 30: Prototype electrical wiring: 1. Power supply, 2. Motors for scissor lift (left) and table extending (right), 3. Motor controllers, 4. Arduino

4.3. Electrical

For the electrical parts of the table, we had a sea of choices. Figuring out exactly which parts were suitable for us, in addition to ensuring system compatibility, allowed our team to select a series of parts to power the table's mechanisms. In Table 2 below, there is a breakdown of the parts we used, the quantities, and the cost of each part.

Part Name	Part Description	Quantity	Cost
MEAN WELL LRS-350-12	Power Supply	x1	$32
Arduino Mega 2560 Rev3	Microcontroller	x1	$49
TB6600	Stepper Motor Controller	x3	$30
USB/Type-C Outlet	Outlets	x4	$20
Black/Red 16 AWG 25ft	Wires	x2	$24
OONO 16 Amp 2x12 Position	Terminal Block	x1	$10
Nema 23 Stepper Motor	Motor	x2	$80
Nema 34 Stepper Motor	Motor	x1	$48
Momentary Push Button	Button	x4	$13
AS5600 Magnetic Encoder	Rotary Encoder	x3	$17

Table 2: Bill of materials for the electrical components of the table

For the power supply, we chose the MEAN WELL LRS-350-12. This is a 12 V, 350 W power supply. We chose a 12 V power supply because we were initially planning to use 12 V DC motors for our systems, but it was also easier to find power supplies at good prices, considering our budget. After we chose to switch to stepper motors, we re-evaluated the Vage that we might need and decided to stick with 12 V, since we didn't need the motors to do continuous steps therefore the Vage was enough.

As for our microcontroller, we used the Arduino Mega 2560 Rev3. The reason we chose this specific microcontroller is because the code was simple and it would be easier and doable with an Arduino because the C++ based Arduino IDE coding language is straightforward, and the power consumption of the microcontroller is minimal. Moreover, this controller has enough

Pulse Width Modulation (PMW) pins for the motors and the buttons, and also has an input of up to 20 V. The microcontroller was connected directly to the power supply.

The stepper drivers we used are the TB6600. These drivers have an input of 9-42 V DC and allow us to use the motors in both unipolar and bipolar configuration.

We had four USB and Type-C outlets around the table to charge personal devices. These outlets operate at 12 V and each require approximately 15 W of power because of their fast charging capabilities.

To increase the number of V+ and V- slots, we added a terminal block, in which we connected our outlets and the motors. This terminal block was connected to our power supply which only has 3 V+ and V- slots which was not enough for all our devices. To connect all the parts together, we used 16 gauge wires, which are capable of transferring up to 13 Amperes, therefore are suitable to transfer the power we need.

For the Scissor lift and Extending mechanisms, we used two Nema 23 Stepper motors which can handle up to 2.83 N.m of force at 4 Amperes, enough to move the weight we need them to. For the leg mechanism, we are using a bigger motor, the Nema 34 Stepper motor. According to our calculations, the legs will require a motor that can handle more force and this one can handle up to 4.5 N.m of force.

To measure the motor shaft angle for feedback control, magnetic rotary encoders were used. A magnet was placed on the motor shaft,with the chip contained within the table. The encoder chips were powered by Arduino 5 Vs of power output and reported the motor shaft angle to the Arduino.

The Power that our system would require would be the addition of the power of all the components. The power that the four outlets require is 15 W each, the two Nema 23 motors require 21.1 W each, and the Nema 34 motor requires 12.1 W. Therefore, the total Power of the system will be:

$$P_{Total} = 15 \times 4 + 21.1 \times 2 + 12.1 = 114.3W$$

Which is less than what our power supply can provide and left us enough space to make any new additions in the future.

Thermal Analysis

The table's interior houses all of the electrical components, including the power supply. We wanted to ensure that the maximum output from the power supply would not damage or interfere with any other parts. To do so, a thermal analysis was conducted using the FEA software SOLIDWORKS (Figure 31). The analysis yielded a maximum temperature of 3.117e+02 K, or 38.55 degrees Celsius at the center of the power supply when running with a load of 114.3 W. This is below the allowable operating temperature of the power supply. By calculating the Power Dissipation, Thermal Rise, and Estimated temperature, we get:

$$\text{Dissipation} = \text{Load} \times (1\text{- Efficiency}) = 114.3\text{W} \times (1\text{-}0.9) = 11.43\text{W}.$$

$$\text{Temperature Rise} = \text{Power Dissipation} \times \text{Thermal Resistance} = 11.43\text{W} \times 1.2°\text{C/W} = 13.72°\text{C}$$

$$\text{Estimated Temperature} = \text{Ambient Temperature} + \text{Temperature Rise} = 25°\text{C} + 13.72°\text{C} = 38.72°\text{C}$$

The Estimated Temperature we calculated was similar to our simulated results, leaving us an error margin of 0.44%. Running the power supply at 114.3 W for an extended period of time will not occur due to the mechanisms opening sequentially, as programmed. Additionally, the analysis assumes that the motors and outlets run simultaneously and a solid power supply which does not account for the power supply's fan, nor the vents for the fan. This means the actual maximum temperature should not be reached. During our testing, we were testing the table for around 2 hours, using the motors and the outlets. The built-in fan of the power supply did not turn on during this time, meaning the power supply never exceeded 50 degrees Celsius, as this is the temperature point where the fan starts working.

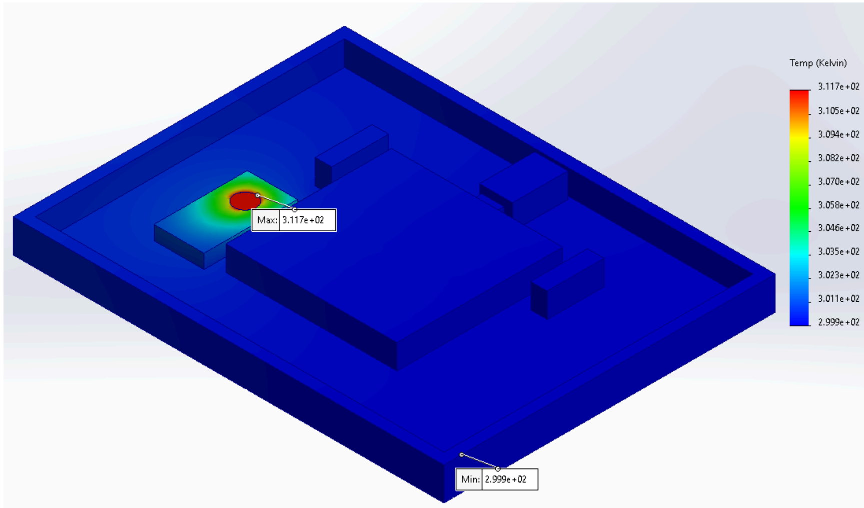

Figure 31: Thermal analysis of power supply at 114.3W

Code

The Arduino microcontroller was instructed with code written in the Arduino IDE language. A code sample is shown in Figure 32 with the full code provided in appendix C. The code seeked to control the buttons, all three stepper motors, and three rotary encoders. The programming includes the distance the motors must rotate to accomplish each function in each subsystem, as well as feedback control from the rotary encoders.

```
#define dirPin1 2
#define stepPin1 3
#define dirPin2 4  // Direction pin for the second motor
#define stepPin2 5  // Step pin for the second motor
#define dirPin3 7  // Direction pin for the third motor
#define stepPin3 8  // Step pin for the third motor
#define buttonPin 6  // Push button pin for start rotation
#define resetButtonPin 9  // Push button pin for reset to original position
#define stepsPerRevolution 200

void setup() {
  // Declare pins as output:
  pinMode(stepPin1, OUTPUT);
  pinMode(dirPin1, OUTPUT);
  pinMode(stepPin2, OUTPUT);
  pinMode(dirPin2, OUTPUT);
  pinMode(stepPin3, OUTPUT);
  pinMode(dirPin3, OUTPUT);
  pinMode(buttonPin, INPUT_PULLUP);  // Set the button pin as input with pull-up resistor
  pinMode(resetButtonPin, INPUT_PULLUP);
  

void loop() {
  // Check if start rotation button is pressed
  if (digitalRead(buttonPin) == LOW) {
    delay(50);  // Debounce the button
    if (digitalRead(buttonPin) == LOW) {
```

Figure 32: Arduino IDE code example

The Arduino code begins by initializing the encoders to match the steps of the motors. Pressing the corresponding button begins the coded cycle, allowing the system to change states accordingly. For example, if the tabletop is in the closed position, the cycle would end with the tabletop in its open configuration. If the mechanism was obstructed, say by a hand, then the motor would skip a step, triggering the safety protocol wherein the motor stops where it is.

The safety step is made possible by the rotary encoders, which continuously compare the expected step count with the angular displacement. In this case, pressing the button again will reset the motor to the state when the button was pressed the first time.

In the event that the table becomes unplugged or otherwise loses power mid-operation, there is a reset button that can be utilized once power has been reinstated. In this case, all motors will be restored to the closed position simultaneously. The closed state is detected by the motors skipping due to the end of mechanical travel for the individual system. Once all motors have stopped, meaning that the closed position has been reached, the code resets the encoders' counter. Figure 33 shows the block diagram of the structure and flow of the Arduino code.

The other consideration when designing the electrical components to the table was user experience. To achieve this we implemented fast-charging USB Type A and C outlets on the sides of the table. This way gamers can charge their devices while playing conveniently right at the table. To optimize usability, an outlet was placed at each corner of the design for a total of 4 outlets. Since each outlet has one of each type of USB plug, even with 8 people playing games at once, each could charge a device. Typically, a dorm room does not contain enough outlets to accommodate charging 8 devices simultaneously.

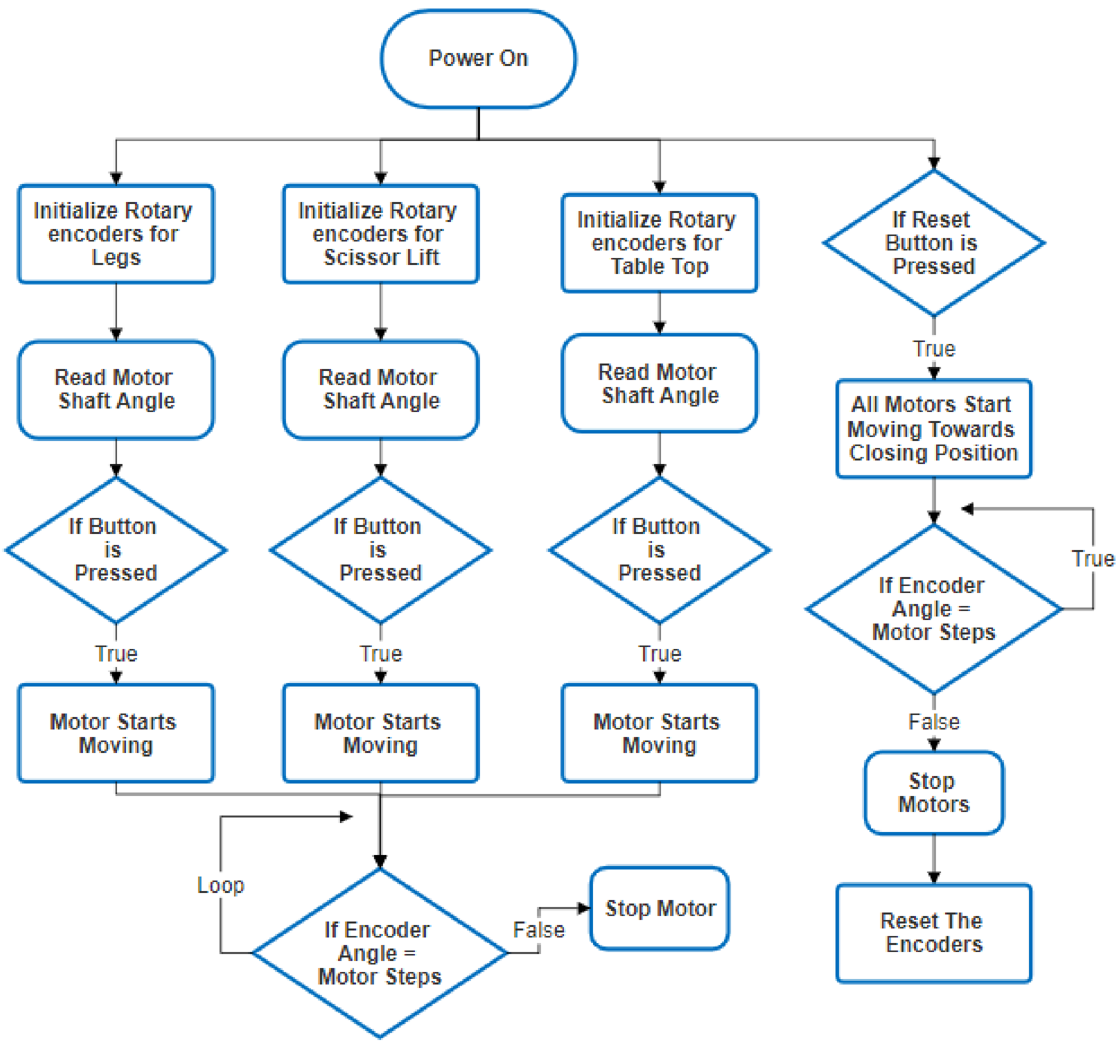

Figure 33: Code block diagram

4.4. Ergonomics

The ideal table height plays a pivotal role in ensuring comfort, functionality, and ergonomic efficiency in both residential and professional settings. Research in ergonomics suggested that the optimal table height varies according to the specific activity being performed, as well as the physical characteristics of the user, such as height and seated posture. A universally recognized standard for desk or working table height is approximately 74 cm, which caters to the average adult's seated height and allows for a comfortable arm angle when typing or writing (Woo, 2016).

The significance of selecting an ideal table height extends beyond mere comfort; it is crucial for preventing musculoskeletal disorders associated with prolonged periods of sitting, such as lower back pain, neck strain, and shoulder discomfort. Allowing each person seated enough clearance to move freely is key to ensuring comfort when playing. A study by Chandra, shows the ideal permissible width per person for a table as approximately 61 cm. These values helped validate the dimensions chosen for the table.

4.5. Marketability

Based on our research there is a definite gap in the market for an inexpensive and compact gaming table. There are many gaming tables on the market for a much higher price point starting on the low end at $2000. Additionally, we did not find any tables specifically marketed to college students, meaning our product would be the first of its kind. However, as we learned through our research and conversation with Professor Wang, a significant amount of work would be needed. Therefore, pursuing the development of our design for a mass market would not be feasible for this project.

Our research began by exploring the options available to us for securing funding. A common option would have been loans or grants from the government, both state and federal, that are established to help startup businesses. The main benefit to this option would have been that it allows the business to retain 100% of its equity. The other options would be gaining investors, either angel investors or Venture Capital firms. Among the two investing options, angel investors are the most preferable, because they are more likely to take risks and invest in companies that might not have as obvious a potential. Venture Capital firms are not taking such risks and also want to be part of the operation of the company. Another viable option is crowdfunding. Through websites, like Kickstarter.com, companies advertise their ideas and gather money from individuals who want to help.

Based on our conversation with Professor Wang, his initial recommendation was that we needed to determine the market size, as this would also be the first question that investors ask. A small market size would make investors less interested and thus it would be more difficult for us to market the product. This is because it is not worth their time to invest if there is not enough room for them to gain profit. In addition, he provided some steps we should take, like deciding on a business model to present to investors and filing a patent for our design. Another recommendation was finding an angel investor. Professor Wang informed us of a program that WPI has to help students with ideas, the I-Corps Site Program. However, to apply for the program, the group must be fully committed, and if the market size is too small, then it is not worth pursuing.

To determine the market size we needed to know how many people were in the market. Unfortunately there was very little data on the number of college students who play RPGs. Looking just at the most popular, DND, in 2020 it was reported that over 50 million people had played up to that point (Wieland, 2021). According to Wizards of the Coast 24% of players fall between 20-24 years old. Additionally, Dungeon Vault estimates 13.7 million annual users, however there is no reference for what the numbers are based on (Camp, 2022). Since this data could not be verified, the calculations are not necessarily accurate. Given the estimates available we calculated the market size to be 3.3 million users.

4.6. Survey

At the conclusion of the survey, there were 54 respondents and 3 invalid responses. This was a poor sample size, as there were only 51 responses out of approximately 5,246 students at WPI (U.S. News, 2022), and the variety of students who responded was well distributed. However, this group only consists of one college's opinion, which means the data could only be used for the sampled population and was not generalizable.

The portability of the table was important to college students. With 40 responses saying they would expect to transport the table with 1-2 people (Figure 34), it can be concluded that the table should not weigh more than the average person can carry. Which was established earlier as 23 kg, thus the table would have to be 23 - 45 kg. Another measure of this was how long respondents thought a "portable enough to play anywhere table" would take to set up. The vast majority said it would take under 20 minutes with the maximum responses saying it would take 5-10 minutes (Figure 35). This backs up our original assumption of college students desiring a portable table. While this was not one of the most important criteria of our table, we did use mechanisms that would lead to a more compact design to fit in an average person's car to improve portability.

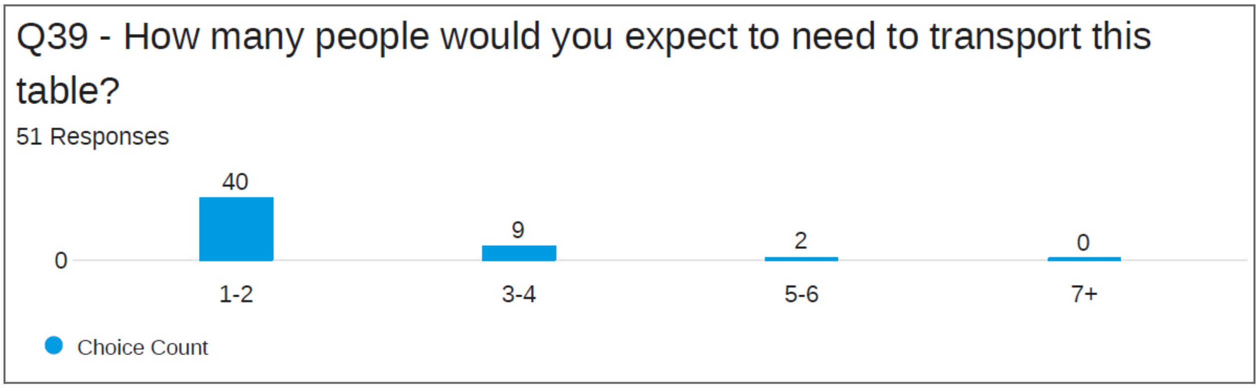

Figure 34: Charted data of student preferences for how many people are needed to transport a table

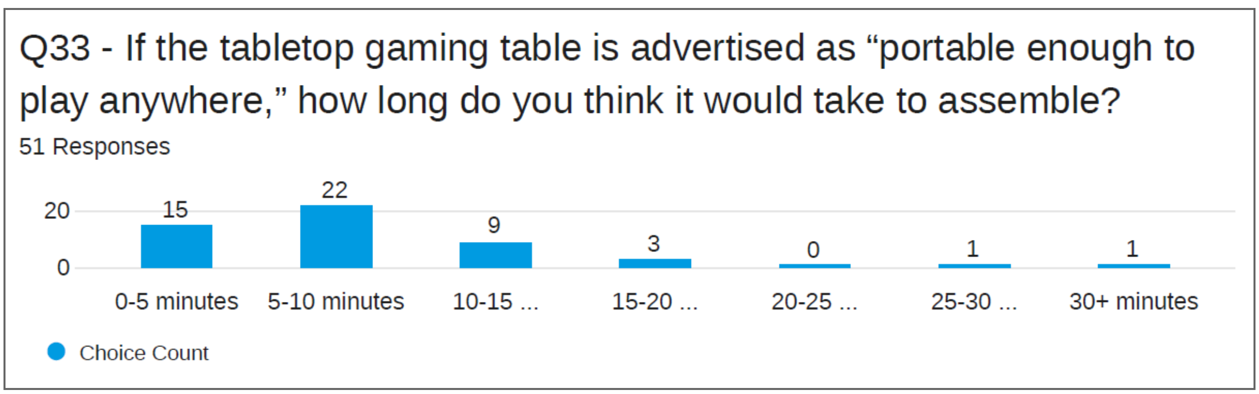

Figure 35: Charted data of student preferences for how long a portable table should take to assemble

The mean desired number of players at the table was 2-4, which would indicate the need for a table sitting 2-4 people. There were also 11 people who said they play with 5-7 people (Figure 36). This data shows we may not need to make the table as big as we initially planned. However, our table seating 4-6 people was a good compromise based on the responses.

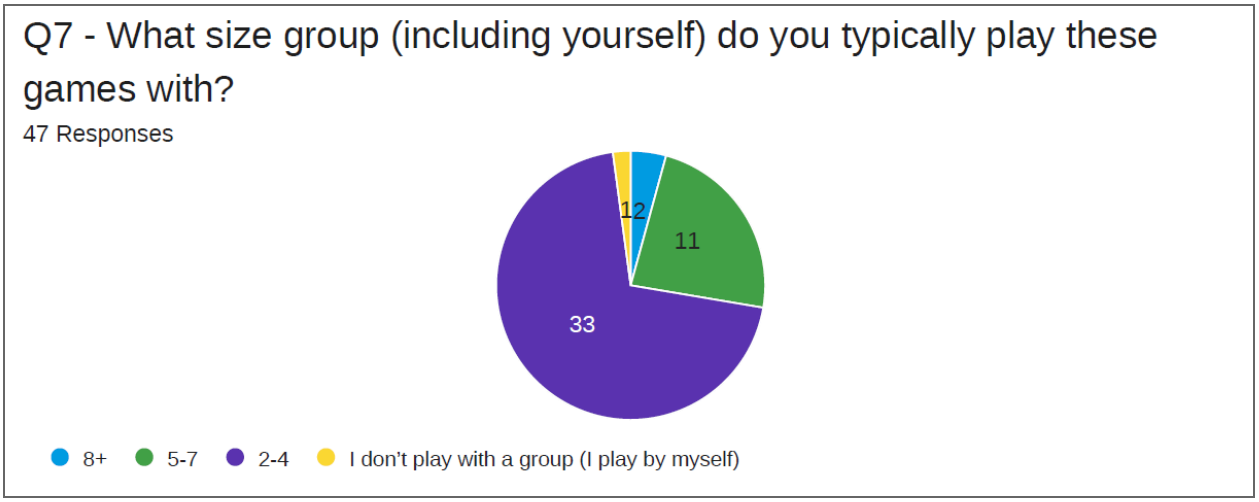

Figure 36: Charted data of student preferences for how many people play a tabletop game at one time

One of the important criteria for our table design was cost. The survey agreed with this claim, having a majority of the students wanting a table to cost under $500 (Figure 37).

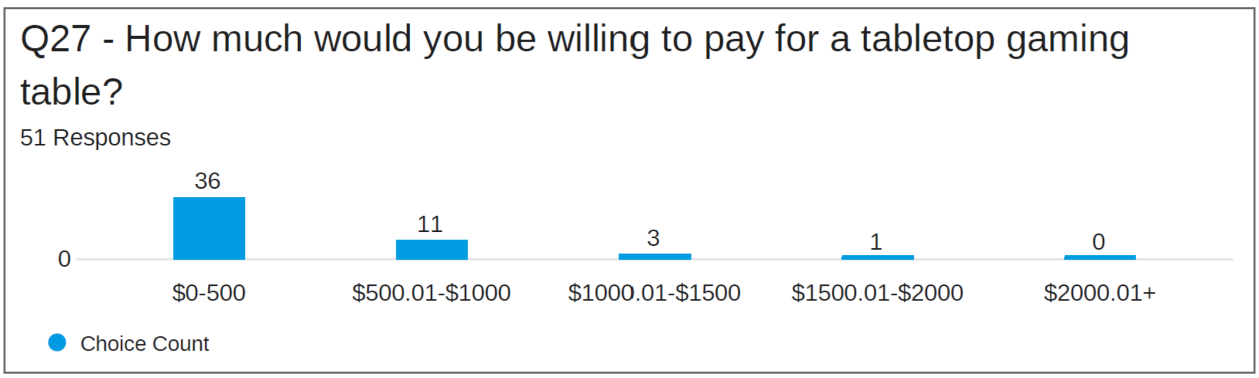

Figure 37: Charted data for student preferences of the cost for a tabletop gaming table

As mentioned previously, the data collected cannot be generalized, but it was informative to review in whole. There are also supplementary data points that go along with the claims made above in Appendix C. Lastly, the student answers both reinforced our criteria for cost being a priority for a tabletop gaming table, and displayed reasoning for our design choices.

5. Conclusion and Recommendations

5.1. Market Analysis

Because the group working on this design is composed of engineering majors, we came to the conclusion that the business side of creating a product was beyond the scope of our focus. Although we determined that it is not feasible for our team to continue marketing or securing funding to move forward with production of our design, we do believe mass production could be explored in the future. There is a clear gap in the market for a product similar to ours. Additionally, even though we were not fully able to pursue marketing our design, we believe this could be pursued in the future when the design is further evolved.

5.2. Construction

The construction of the prototype table, while complete, revealed potential design flaws and like all prototypes, left room to improve. For those who would like to improve upon or continue this project, we have compiled a set of recommendations to assist in this. Primarily, we recommend making the table at its full scale with its intended parts. While we are proud of our prototype, it is a proof of concept. To fit within our budget, we scaled the prototype to 75%, due to the lack of availability of inch-thick pine plywood, and to better fit within the budget because more raw material would cost more money. We purchased inexpensive parts that were as similar to the CAD model as possible. For example, the scissor lift rods were purchased to be completely threaded, as it was cheaper than rods that are partially threaded. Additionally, for large plates of wood, we used plywood instead of solid wood. This led to the wood warping, resulting in an uneven tabletop surface. The second recommendation is to decrease the bottom plate's thickness. A drawback to our design we noticed in making the prototype was the weight, removing material from the thickness of the table sections would help decrease the overall weight of the table, while keeping the integrity intact. Third, we suggest using power tools instead of hand tools, such as chisels, when possible for mass production. Additionally, to facilitate mass production, we recommend taking another glance at possible stock substitutes for custom parts. While we were able to improve our skill at chiseling wood, it was not going to be as precise as something cut by a mill. For the scissor lift, we recommend altering the design of the upper hinges and rails. In order to fit within the table, their foundations were forced to be thinner than the bottom hinges and rails. Unlike the lower hinges and rails, we cannot chisel into the wood it's attached to, as it was already thinner than the other tabletops. As they are, the thinness of the lower hinges and rails resulted in visible manufacturing error, altering its structural integrity. Fourth, we recommend adding a mechanism to keep the legs locked and attached to the bottom plate of the table.

5.3. Electrical

In a full scale table, a compartment in the middle, inside the scissor lift mechanism can be implemented to fit a tablet or a small screen, which would display information for everyone playing to see. Additionally, in a full scale table, heavier material might be used, and therefore the motors may need to be upgraded to stronger ones. With that change, more Vage would also be required, so a 24V or higher power supply should also be a good upgrade. Another addition would be speakers around the table. These speakers could be used with a bluetooth connection, for which the implementation of a bluetooth wireless module is possible with the Arduino. The speakers can be used to play music, or a creative tabletop game player could use them to play sound effects that coincide with events during the game.

5.4. Survey

Due to the project's time constraints, and not lining up the construction timeline with the survey, we had to design the table from our research instead of the survey results. This meant it was based on collected information from existing products and reasoning. The survey, however, was still conducted under the assumption it would back up our decisions, or be a valuable starting point for other researchers continuing the design, which it did. Based on the responses we would suggest: a more portable table by decreasing the weight of materials used, and a lower priced table as the prototype built was well above the desired cost for a tabletop gaming table.

5.5. Conclusion

The ultimate design demonstrates a solid proof of concept for a table that meets the initial requirements. Although our team was not able to fully realize all aspects that we had hoped at the beginning of the year, we each gained valuable experience. This design is a work in progress, and recommendations have been discussed for future work to further enhance the final product.

There are also other applications we believe this research and development would be useful for. The automatic nature of the table top opening system is a great fit for people who cannot put strain on their muscles to open a leafed dining room table. For example, an elderly person with mobility issues can have an extended table when inviting family to their home without having to worry about hurting themselves. On the other hand, the folding leg mechanism is beneficial in houses with little space. It allows homeowners to have their dining room table while being able to pack it up and put a bed out, which saves them space without having to use a plastic folding table.

Although not perfect, the CAD models developed for the design show a solid foundation for an idea that can be refined into a marketable product. Both the CAD and the prototype demonstrate a working design that meets the general modularity requirements. Additionally, the code developed was able to accommodate the safety considerations, with a fail safe in case a foreign object got caught between mechanisms while in motion.

Overall, there was a lot to be learned from this project, but that does not negate the usefulness and success of the design. Further testing would be required to iterate the design closer to perfection, as well as significant market research before pursuing the business potential. Ultimately, the ideas created through this project could be used for many applications beyond improving the college gaming experience.

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Appendices

Appendix A. IRB Approval Letter

WORCESTER POLYTECHNIC INSTITUTE

100 INSTITUTE ROAD, WORCESTER MA 01609 USA

Institutional Review Board
FWA #00030698 - HHS #00007374

Notification of IRB Approval

Date: 15-Nov-2023

PI: Mehdi Mortazavi
Protocol Number: IRB-24-0192
Protocol Title: Tabletop Gaming Table Survey

Approved Study Personnel: Nollman, Emma P~Mortazavi, Mehdi~

Effective Date: 15-Nov-2023

Exemption Category: 2

Sponsor*:

The WPI Institutional Review Board (IRB) has reviewed the materials submitted with regard to the above-mentioned protocol.We have determined that this research is exempt from further IRB review under 45 CFR § 46.104 (d). For a detailed description of the categories of exempt research, please refer to the IRB website.

The study is approved indefinitely unless terminated sooner (in writing) by yourself or the WPI IRB. Amendments or changes to the research that might alter this specific approval must be submitted to the WPI IRB for review and may require a full IRB application in order for the research to continue. You are also required to report any adverse events with regard to your study subjects or their data.

Changes to the research which might affect its exempt status must be submitted to the WPI IRB for review and approval before such changes are put into practice. A full IRB application may be required in order for the research to continue.

Please contact the IRB at irb@wpi.edu if you have any questions.

*if blank, the IRB has not reviewed any funding proposal for this protocol

Appendix B. Survey Questionnaire

Target Audience: College students, Tabletop gamers

Survey Consent

This survey is being conducted by a WPI Major Qualifying Project Group to collect information to better design a tabletop gaming table. There are 6 sections in total and will take 5-10 minutes to complete. This survey is anonymous, so your answers will not be connected to you. There are no benefits or risks to taking the survey. Only the potential to help in the process of creating a better tabletop gaming table.

By answering the next question you consent to taking this survey.

- Are you a college student?
    - o Yes
    - o No
        - § If no: Thank you for your time, we are only looking to receive information on college students in particular. If you would please share this survey with someone in college that would be greatly appreciated.

Gaming information

- What tabletop games shown below do you play?
    - o RPGs
    - o Board Games
    - o Card games
    - o Puzzles
    - o I do not play tabletop games
        - § [If no skip the game specific information]
    - o Other
        - § Short answer
- Do you have any friends that play tabletop games?
    - o Yes
        - § Please share this survey with them if they are a college student: link
    - o No
- What size group (including yourself) do you typically play these games with?
    - o I don’t play with a group (I play by myself)
    - o 2-4
    - o 5-7
    - o 8+
- Do you prefer using physical or digital game components? (Game Components: books, notes, maps, etc.)

- o Physical
- o Digital
- o Both
  - § Short answer
- o N/A

- Do you regularly use game boards or maps from the internet?
  - o No
  - o Occasionally
  - o Sometimes
  - o Usually
  - o Always
- Do you play tabletop games more online or in person?
  - o All online
  - o Online friends with physical game components
  - o Both online and in person
  - o Online game components with friends in person
  - o All in person
  - o Other
    - § Short answer
- Have you heard of tabletop gaming tables?
  - o Yes
  - o Maybe
  - o No
  - o Other
    - § Short answer

Tables

- Have you purchased a table before?
  - o Yes
  - o Yes, but with other people
  - o No, but I was part of the decision process
  - o No

    [If No skip indented questions]

    § Did you order the table online or in person? (buying online and picking up in person still counts as online)
    - · Online (website, phone, social media)
    - · In Person (furniture store, garage sale, secondhand store)

§ What company/platform did you order from?

- If online
  - Amazon
  - Facebook Marketplace
  - Ebay
  - Other
    - § Short answer

- If In Person
  - Bob's Furniture
  - Savers
  - IKEA
  - Garage/Tag/Estate Sale
  - Other
    - § Short answer

§ How much did you pay for the table?

- $0-500
- $500.01-$1000
- $1000.01-$1500
- $1500.01-$2000
- $2000.01+

§ On a scale of 1 (not satisfied) to 5 (satisfied) how satisfied were you with the product's ____?

- Rank multiple things
  - o Safety
  - o Cost
  - o Functionality
  - o Durability
  - o Size limitations
  - o Portability
  - § Would you elaborate on why you choose _1_ for _above thing_ in the previous question?
    - § Long answer

§ How did you transport the table?

- Car
- It was delivered
- Movers

· Other

§ Short answer

- How many people would you want a tabletop gaming table to sit? (enter a number)

§ Short answer

- Please rank which materials you want a table surface to be constructed from.

  - o Wood
  - o Metal
  - o Plastic
  - o Glass
  - o Felt

- Have you tried to build your own tabletop gaming table?

  - o Yes
  - o No
  - o Other

§ Short answer

§ [If yes] Would you be willing to provide your email for us to reach out with questions about the process? If yes, please follow the link provided, so your answers will not be connected to your email.

Value

- Would you be more inclined to purchase a tabletop gaming table if it were multifunctional? (Multifunctional: having several functions such as: dining table, gaming, charging, etc.)

  - o Yes
  - o Maybe
  - o No

§ If you would like, please elaborate on your above choice.

· Long answer

- How much would you be willing to pay for a tabletop gaming table?

  - o $0-500
  - o $500.01-$1000
  - o $1000.01-$1500
  - o $1500.01-$2000
  - o $2000.01+

Specific Features

- Choose the top 3 features you would want in a tabletop gaming table.

  - o Speaker
  - o TV/Screen

§ What would you expect to be able to interface with this screen?

§ Short answer

- o Phone Charging
- o Outlets
- o Dice tower
- o Card holder
- o Cup holder
- o Dice holders
- o Heating or cooling spot
- o Other
  - § Short answer

- What accessories do you currently use to play tabletop games?
  - o Mats
  - o Dice holders
  - o Dice Towers
  - o Card Holders
  - o Trifold/paper stand/book rest
  - o Other
    - § Short answer
- Would having built in accessories (Accessories: dice tray, card holder, cup holder, etc.) make you more likely to buy a gaming table?
  - o Yes
  - o Maybe
  - o No
  - o Other
    - § Short answer

Portability/Ease of Use

Portability: How easy it is to transport an object, as well as, assemble and disassemble said object.

- If the tabletop gaming table is advertised as "portable enough to play anywhere," how long do you think it would take to assemble?
  - o 0-5 minutes
  - o 5-10 min
  - o 10-15 min
  - o 15-20 min
  - o 20-25 min
  - o 25-30 min
  - o 30+ min

- Would you rather have a tabletop gaming table that:
  - Folds or Has a Rigid table surface
  - Has Folding legs or Rigid table legs
  - Is made of least expensive material or Premium material
  - Has a leafed surface or Full Tabletop
- How far would you want the table to travel?
  - Within your living space
  - To a neighboring building/around campus
  - In a car
  - Shipped
- If you were to transport the table in a car which of the below would you use?
  - Micro
  - Hatch
  - Convertible
  - Coupe
  - Saloon
  - Small SUV
  - Large SUV
  - MPV
  - Pick-up Truck
- Would you prefer indoor or outdoor use?
  - Indoor
  - Outdoor
  - Both
- How many people would you expect to need to transport this table?
  - 1-2
  - 3-4
  - 5-6
  - 7+

General information(demographics)

- Which of the following devices do you have accessible? (TV, Projector, Tablet)
  - TV
  - Projector
  - Tablet
  - None of the above
- What year of college are you in?

- o Freshman
- o Sophomore
- o Junior
- o Senior
- o Graduate

- What is your major(s)? (Please write out the full title, and if you have multiple separate them with commas)
  - o Short answer
- What is your minor(s)? (Please write out the full title, if you have multiple separate them with commas, if you do not have a minor leave it blank)
  - o Short answer
- How old are you? (Number entry only)

o Short answer

End of Survey

Thank you for your time, we are only looking to receive information on college students in particular. If you would please share this survey with someone in college that would be greatly appreciated: https://wpi.qualtrics.com/jfe/form/SV_5jspVFsTXEKVjb8

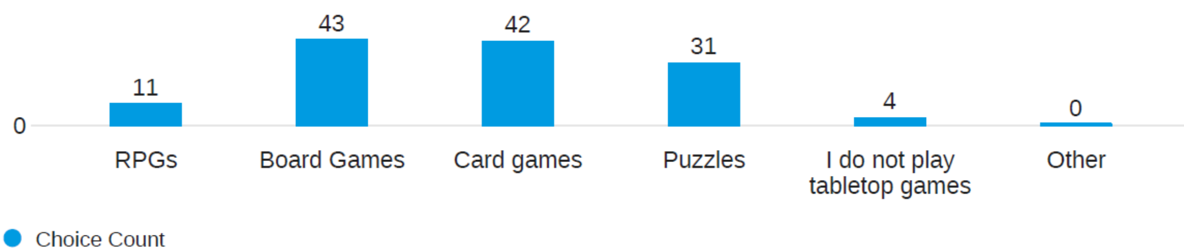
Appendix C. Survey Report

Q1 - Are you a college student?

54 Responses

Q4 - What tabletop games shown below do you play? - Selected Choice

52 Responses

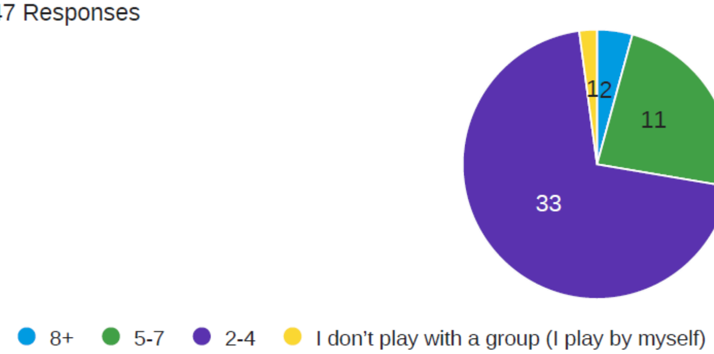


Q5 - Do you have any friends that play tabletop games?

48 Responses

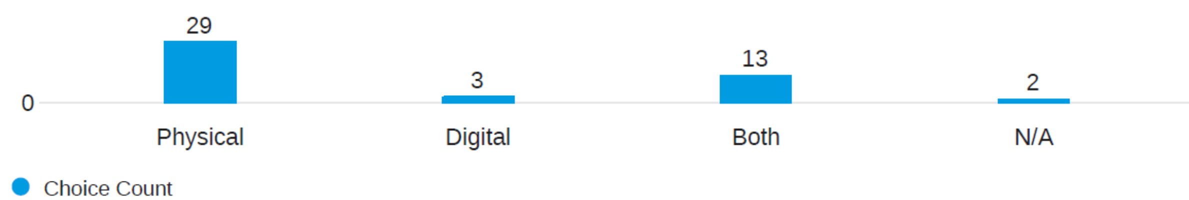
Q7 - What size group (including yourself) do you typically play these games with?

47 Responses



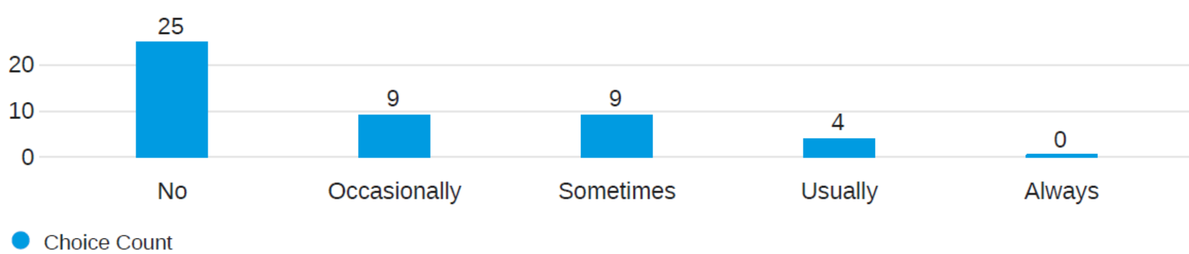
Q8 - Do you prefer using physical or digital game components? (Game Components: books, notes, maps, etc.) - Selected Choice

47 Responses



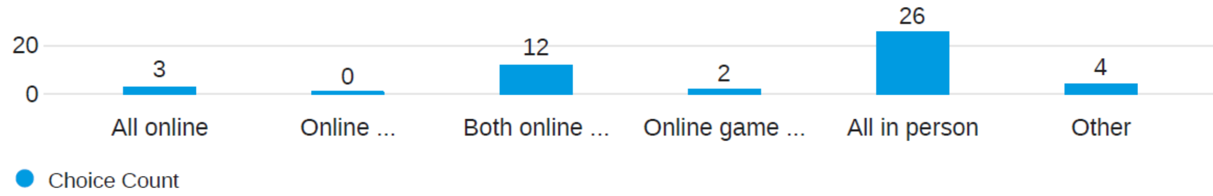
Q9 - Do you regularly use game boards or maps from the internet?

47 Responses



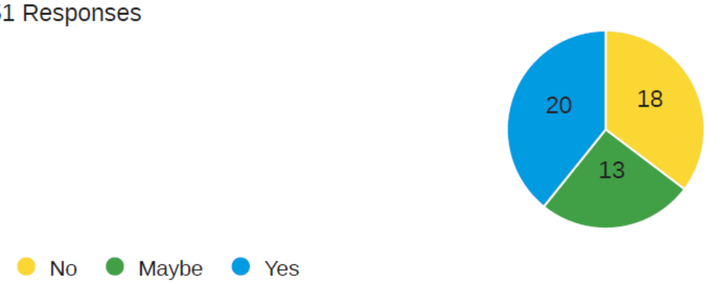
Q11 - Do you play tabletop games more online or in person? - Selected Choice

47 Responses



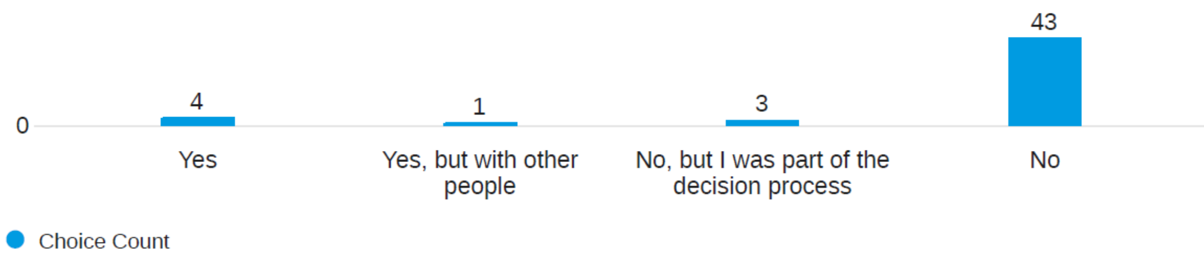
Q12 - Have you heard of tabletop gaming tables? - Selected Choice

51 Responses



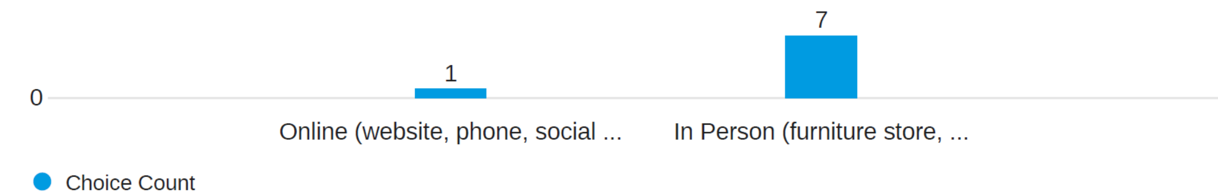
Q13 - Have you purchased a table before?

51 Responses



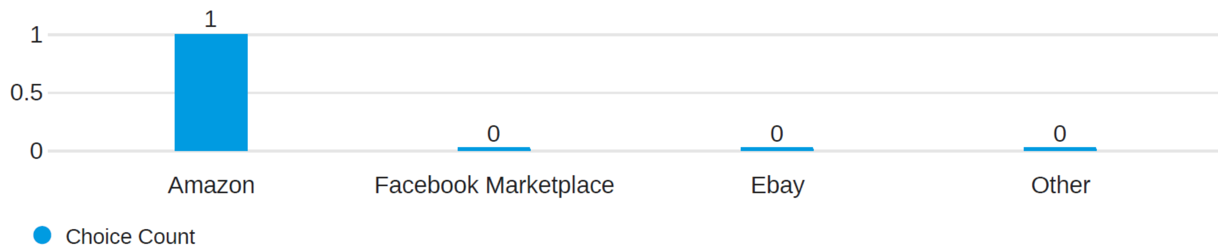
Q14 - Did you order the table online or in person? (buying online and picking up in person still counts as online)

8 Responses



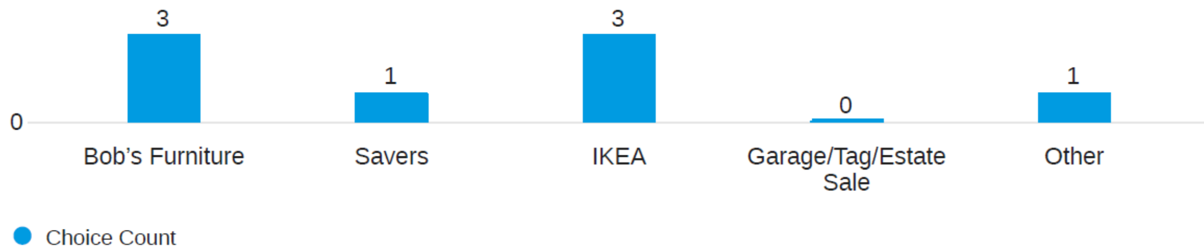
Q15 - What company/platform did you order from? - Selected Choice

1 Responses



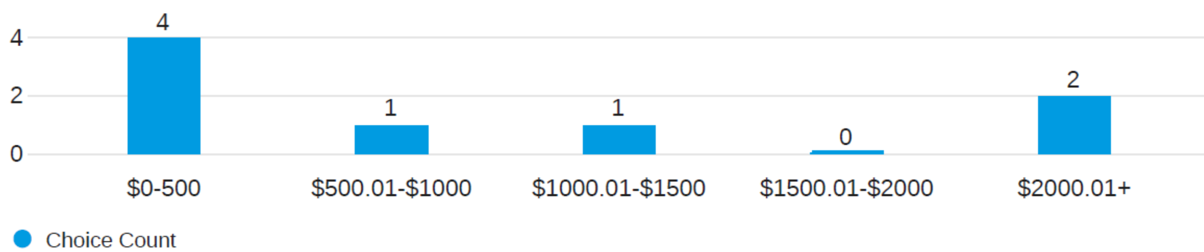
Q16 - What company/platform did you order from? - Selected Choice

7 Responses



Q18 - How much did you pay for the table?

8 Responses



Q19_1 - Safety

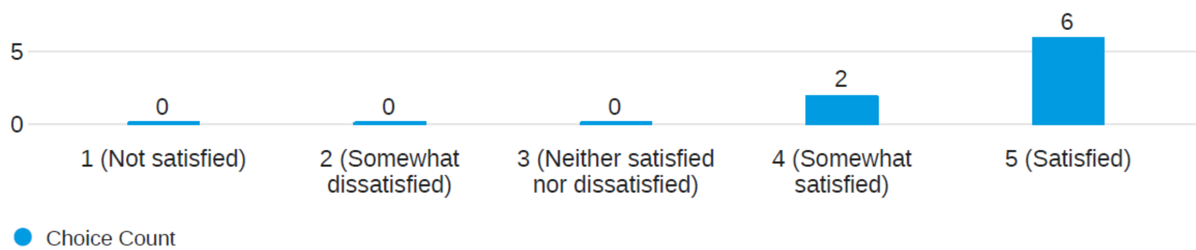
8 Responses

Q19_2 - Cost

8 Responses

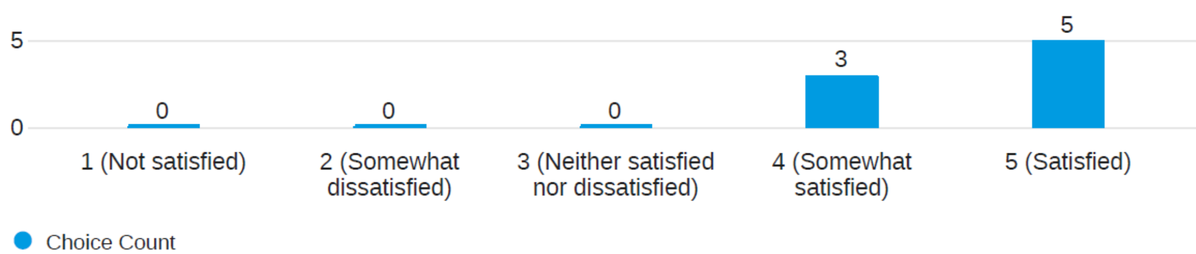
Q19_3 - Functionality

8 Responses



Q19_4 - Durability

8 Responses



Q19_5 - Size limitations

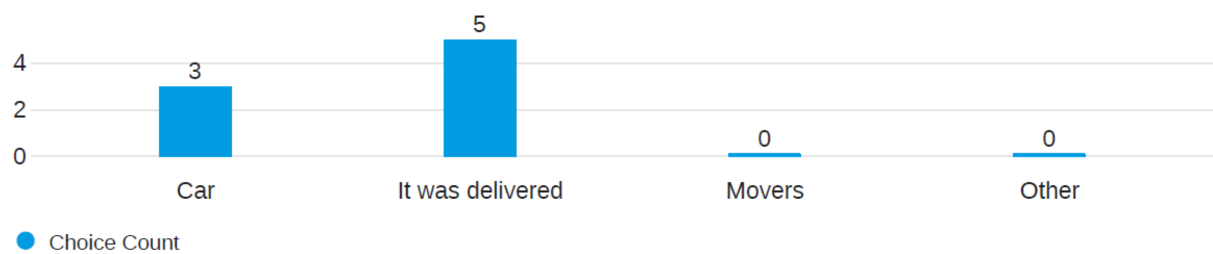
8 Responses

Q19_6 - Portability

8 Responses

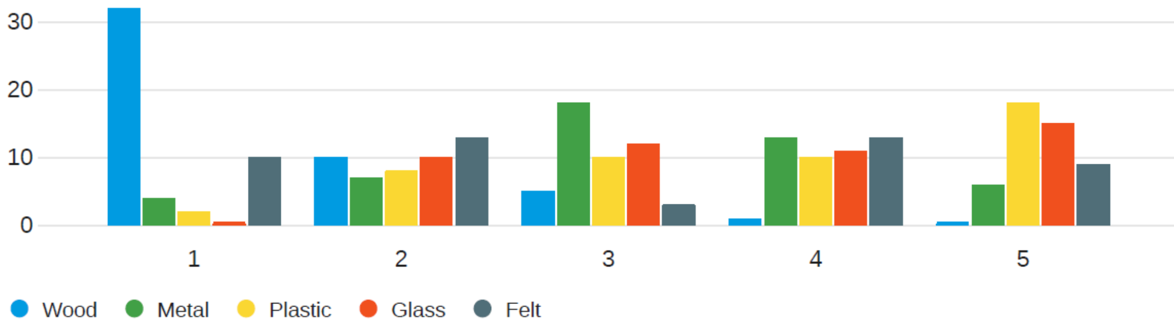
Q21 - How did you transport the table? - Selected Choice

8 Responses



Q22 - Please rank which materials you want a table surface to be constructed from...

48 Responses



Q23 - Have you tried to build your own tabletop gaming table? - Selected Choice

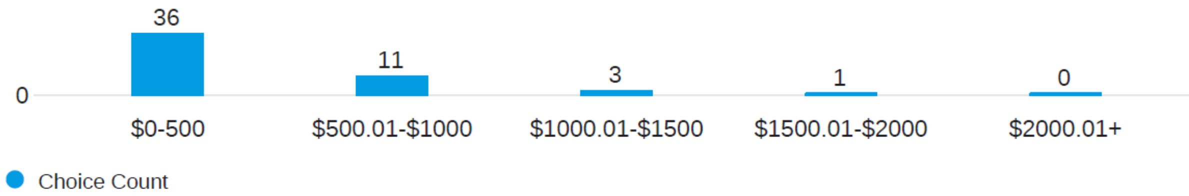
51 Responses

Q25 - Would you be more inclined to purchase a tabletop gaming table if it were multifunctional? (Multifunctional: having several functions such as: dining table, gaming, charging, etc.)

51 Responses

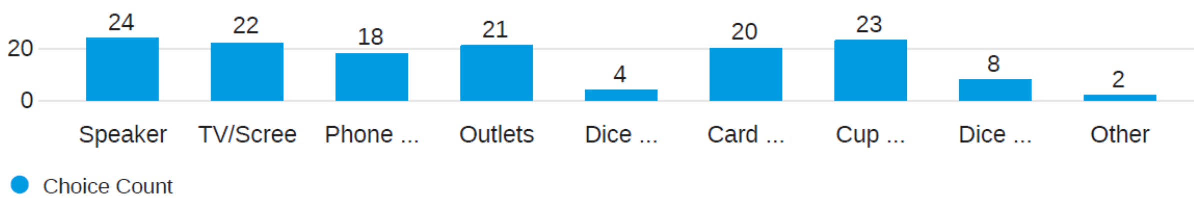
Q27 - How much would you be willing to pay for a tabletop gaming table?

51 Responses



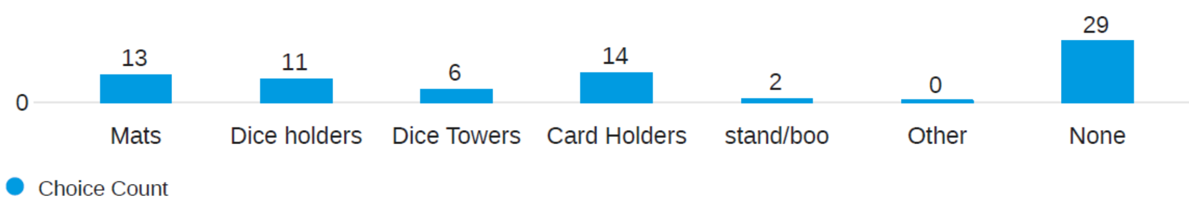
Q29 - Choose the top 3 features you would want in a tabletop gaming table. - Selected Choice

49 Responses



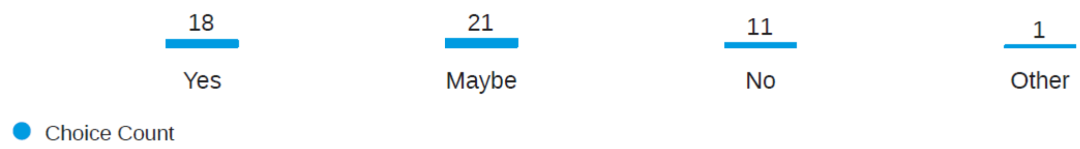
Q30 - What accessories do you currently use to play tabletop games? - Selected Choice

51 Responses



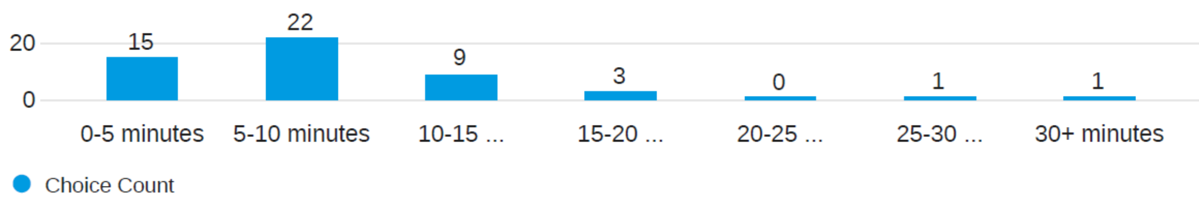
Q31 - Would having built in accessories (Accessories: dice tray, card holder, cup holder, etc.) make you more likely to buy a gaming table? - Selected Choice

51 Responses



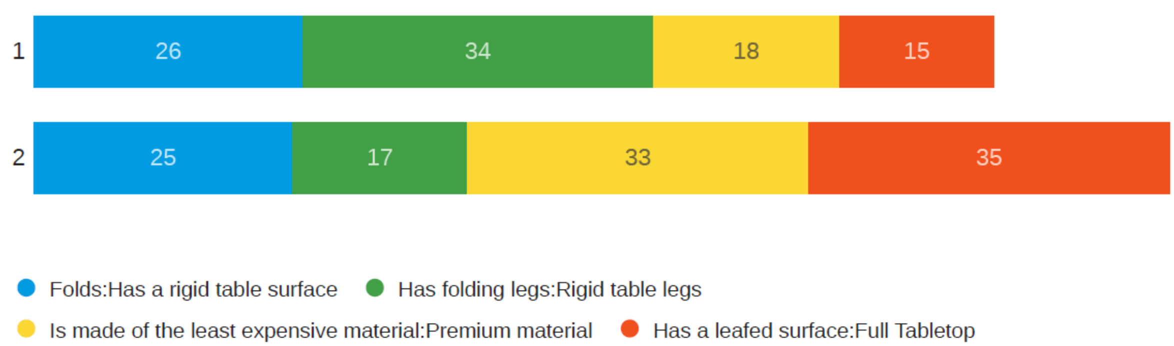
Q33 - If the tabletop gaming table is advertised as “portable enough to play anywhere,” how long do you think it would take to assemble?

51 Responses



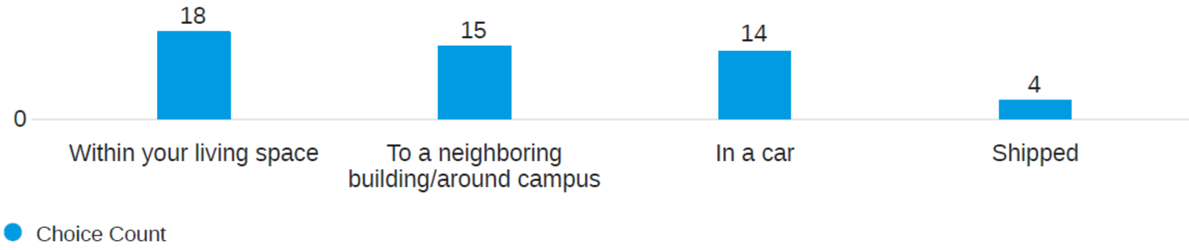
Q34 - Would you rather have a tabletop gaming table that:

51 Responses



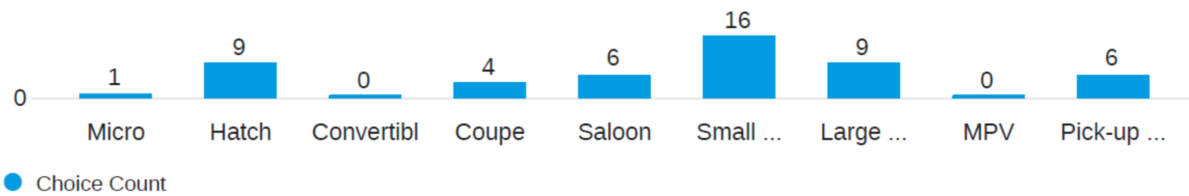
Q35 - How far would you want the table to travel?

51 Responses



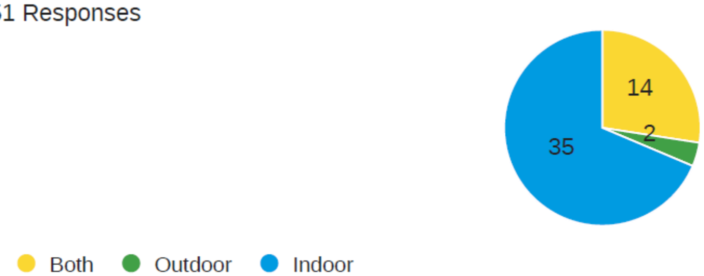
Q36 - If you were to transport the table in a car which of the above would you use?

51 Responses



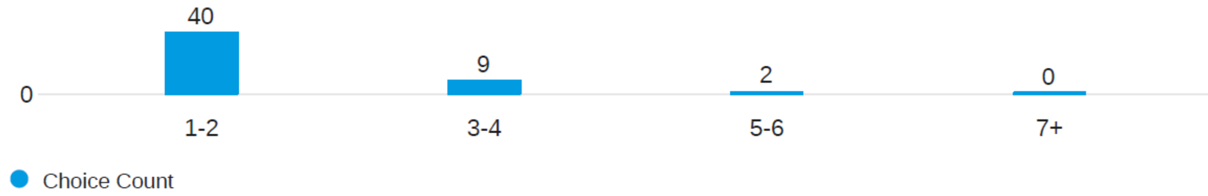
Q38 - Would you prefer indoor or outdoor use?

51 Responses



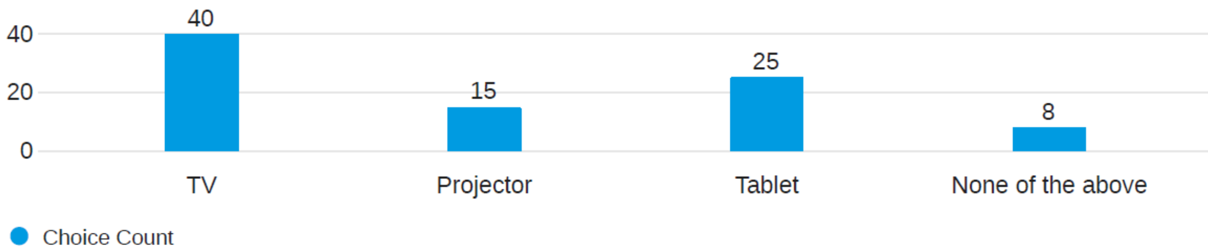
Q39 - How many people would you expect to need to transport this table?

51 Responses



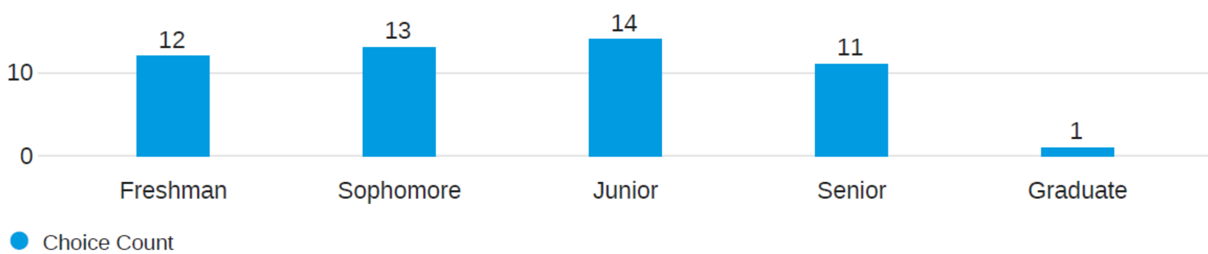
Q44 - Which of the following devices do you have accessible?

51 Responses



Q40 - What year of college are you in?

51 Responses



Q45 - What is your major(s)? (Please write out the full title, and if you have multiple separate them with commas)

49 Responses

What is your major(s)? (Please write out the full title, and if you have multiple separate them with commas)
Data Science

Data Science
Computer Science, Interactive Media and Game Development
Interactive Media & Game Design
Biotechnology
Biology and Biotechnology, Environmental and Sustainability Studies
Mechanical Engineering
Biomedical Engineering
Mechanical Engineering
Biomedical Engineering
Mechanical Engineering
Mechanical Engineering
robotics engineering
Aerospace Engineering
data science
Biomedical Engineers
Computer Science
humanities
Biomedical Engineering
Psychology
biomedical engineering
Mechanical Engineer
Computer Science
Biochemistry
Interdisciplinary Major - Acoustic Engineering
Business Analytics

Biology and Biotechnology, Environmental and Sustainability Studies
Computer Science, Music
mathematical sciences
mechanical engineering
Psychology
psychology
Data Science, Environmental and Sustainability Studies
Mechanical Engineering
Biomedical Engineering
Environmental and Sustainability Studies, Biology
Psychological and Cognitive Sciences
Aerospace Engineering; Psychological Sciences
Biology and biotechnology, Psychology
Computer Science
Computer science
Computer Science
Please ignore this survey entry - just testing
Robotics Engineering
Aerospace Engineering
Mechanical Engineering
Mechanical Engineering
Mechanical Engineering
Hustler

Q42 - What is your minor(s)? (Please write out the full title, if you have multiple separate them with commas, if you do not have a minor leave it blank)

17 Responses

What is your minor(s)? (Please write out the full title, if you have multiple separate them with commas, if you do not have a minor leave it blank)
Buisness
none
Creative Writing
Mechanical Engineering
Music
Creative Writing
Psychology
Information Management Systems
Psychology
none
Biochemistry
statistics and biology
none
Please ignore this survey entry - just testing
Computer Science
Fire Protection Engineering
small hustler

Q43 - How old are you? (Number entry only)

49 Responses

How old are you? (Number entry only)

19	18
19	20
19	22
18	21
20	21
19	19
18	20
18	20
19	18
21	18
19	19
20	20
19	19
19	20
19	21
20	21
20	19
36	99
18	21
20(21 soon)	21
21	21
22	26
18	21
21	22
21	

Appendix D. Code

```
#include <Encoder.h>

// Define stepper motor connections:
#define dirPin1 2
#define stepPin1 3
#define dirPin2 4
#define stepPin2 5
#define buttonPin1 6
#define buttonPin2 7
#define buttonPin3 8

// Define encoder connections:
#define encoderPinA1 10
#define encoderPinB1 11
#define encoderPinA2 12
#define encoderPinB2 13

// Encoder objects
Encoder motorEncoder1(encoderPinA1, encoderPinB1);
Encoder motorEncoder2(encoderPinA2, encoderPinB2);

// Constants for step calculation and threshold for stopping
const float stepAngle = 1.8; // degrees per step
const float discrepancyThreshold = 5.0; // degrees of allowable discrepancy

// Position tracking variables
long stepsMotor1 = 0;
long stepsMotor2 = 0;
long oldPosition1 = -999;
long oldPosition2 = -999;

void setup() {
  pinMode(stepPin1, OUTPUT);
```

```
  pinMode(dirPin1, OUTPUT);
  pinMode(stepPin2, OUTPUT);
  pinMode(dirPin2, OUTPUT);
  pinMode(buttonPin1, INPUT_PULLUP);
  pinMode(buttonPin2, INPUT_PULLUP);
  pinMode(buttonPin3, INPUT_PULLUP);
  Serial.begin(9600);
}

void stopMotors() {
  // Function to stop both motors
  digitalWrite(stepPin1, LOW);
  digitalWrite(stepPin2, LOW);
  Serial.println("Discrepancy too high, motors stopped!");
}

void loop() {
  // Update the encoder readings and calculate the angles
  long newEncoderPosition1 = motorEncoder1.read();
  long newEncoderPosition2 = motorEncoder2.read();
  float calculatedAngle1 = stepsMotor1 * stepAngle;
  float calculatedAngle2 = stepsMotor2 * stepAngle;

  // Calculate discrepancies
  float discrepancy1 = abs(calculatedAngle1 - newEncoderPosition1);
  float discrepancy2 = abs(calculatedAngle2 - newEncoderPosition2);

  // Check for discrepancies and stop motors if necessary
  if (discrepancy1 > discrepancyThreshold || discrepancy2 > discrepancyThreshold) {
    stopMotors();
    return; // Exit the loop to prevent further motor commands
  }

  // Normal operation: move motors based on button presses
```

```
 if (digitalRead(buttonPin1) == LOW) {
   digitalWrite(dirPin1, HIGH);
   digitalWrite(stepPin1, HIGH);
   delayMicroseconds(500);
   digitalWrite(stepPin1, LOW);
   delayMicroseconds(500);
   stepsMotor1++; // Increment step counter for motor 1
 }

 if (digitalRead(buttonPin2) == LOW) {
   digitalWrite(dirPin2, HIGH);
   digitalWrite(stepPin2, HIGH);
   delayMicroseconds(500);
   digitalWrite(stepPin2, LOW);
   delayMicroseconds(500);
   stepsMotor2++; // Increment step counter for motor 2
 }
}
```

Appendix E. Supplemental Materials

BOM: BOM.xlsx

QR code used in presentation:

Appendix F. Torque Calculations

Required lead screw torque calculation based on load and lead screw parameters:

Lead Screw Torque Calculations

Constants

$L := 15in$

$\theta := 8.32deg$

$w := 15lbf$

Force and Moment Equations Bar AB

$$\sum M_B := \left[\left(\frac{w}{2}\right) \cdot 2L \cdot \cos(\theta)\right] - \left(F_y \cdot L \cdot \cos(\theta)\right) - \left(F_x \cdot L \cdot \sin(\theta)\right) = 0$$

$$\sum F_{xt} := F_x - R_{x1} = 0$$

$$\sum F_{yt} := -\left(\frac{\omega}{2}\right) + F_y - R_{y1} = 0$$

Force and Moment Equations Bar CD

$$\sum M_A := -\left[\left(\frac{w}{2}\right) \cdot 2L \cdot \cos(\theta)\right] - \left(F_y \cdot L \cdot \cos(\theta)\right) - \left(F_x \cdot L \cdot \sin(\theta)\right) = 0$$

$$\sum F_x := -F_x + R_{x2} = 0$$

$$\sum F_y := -\left(\frac{\omega}{2}\right) - F_y + R_{y2} = 0$$

Solving Moment Equations

M_B $$0 = \left[\left(\frac{w}{2}\right)\cdot 2L\cdot\cos(\theta)\right] - \left(F_y\cdot L\cdot\cos(\theta)\right) - \left(F_x\cdot L\cdot\sin(\theta)\right)$$

$$F_y := \left[\frac{-\left(\frac{w}{2}\right)\cdot 2\cdot L\cdot\cos(\theta)}{L\cdot\cos(\theta)}\right] + \left(\frac{F_x\cdot L\cdot\sin(\theta)}{L\cdot\cos(\theta)}\right)$$

$$F_y := -w + F_x\cdot\tan(\theta)$$

M_A $$0 = -\left[\left(\frac{w}{2}\right)\cdot 2L\cdot\cos(\theta)\right] - \left(F_y\cdot L\cdot\cos(\theta)\right) - \left(F_x\cdot L\cdot\sin(\theta)\right)$$

$$F_x := \left[\frac{\left(\frac{w}{2}\right)\cdot 2L\cdot\cos(\theta)}{L\cdot\sin(\theta)}\right] - \left(\frac{F_y\cdot L\cdot\cos(\theta)}{L\cdot\sin(\theta)}\right)$$

$$F_x := \left(\frac{w}{\tan(\theta)}\right) - \left(\frac{F_y}{\tan(\theta)}\right)$$ Substitute F.y into F.x

$$F_x := \left(\frac{w}{\tan(\theta)}\right) - \left(\frac{-w + F_x\cdot\tan(\theta)}{\tan(\theta)}\right)$$

$$F_x := \frac{w}{\tan(\theta)}$$

Solving Force Equations

F_{xt} $\quad 0 = -R_{x1} + F_x$ $\qquad$ Fx $\quad 0 = R_{x2} - F_x$

$R_{x1} := F_x$ $\qquad R_{x2} := F_x$

$$F_x = R_{x1} = R_{x2} = \frac{w}{\tan(\theta)}$$

Closed $\qquad$ Open

$$\frac{15\text{lbf}}{\tan(2.86\cdot\text{deg})} = 300.253\cdot\text{lbf} \qquad \frac{15\text{lbf}}{\tan(8.3\cdot\text{deg})} = 102.821\cdot\text{lbf}$$

Max Force Closed

$$F\cdot 4.45\frac{N}{\text{lbf}} = 1.336\cdot 10^3 N$$

Lead Screw Specifications

$r := 0.125\text{in} = 3.175\times 10^{-3}\,\text{m}$

$\text{Lead}_{\text{Pitch}} := 0.063\text{in} = 1.6\times 10^{-3}\,\text{m}$

$\mu := 0.15$

$\tan(\alpha) := \frac{\text{Lead}_{\text{Pitch}}}{2\pi\cdot r}$ $\qquad \tan(\phi) := \mu$

$\phi := \text{atan}(\mu) = 8.531\,\text{deg}$

$\alpha := \text{atan}\left(\frac{\text{Lead}_{\text{Pitch}}}{2\pi\cdot r}\right) = 4.586\,\text{deg}$

$$T := F\cdot r\cdot\left(\frac{\tan(\alpha+\phi)}{\cos(\phi)}\right)$$

$$T := 1336N\cdot 0.003175m\cdot\left(\frac{\tan(4.586+8.531)}{\cos(8.531)}\right)$$

$T = 1.016Nm$

Required motor torque calculation based on load and wheel mechanism parameters:

Wheel Torque Calculations

Constants

$\mu_{wheel} := 0.6$ $\mu_{wood} := 0.25$ $g = 9.807 \frac{m}{s^2}$ $\rho_{pine} := 382 \frac{kg}{m^3}$

$r_{wheel} := 0.0080899m = r_{pulley} = r_{gear}$

$w := 19.5in$ $l := 30in$ $h := 0.75in$

Weight of One Table Top

$\rho := \frac{m}{V}$ $V := w \cdot l \cdot h = 0.00718982m^3$ $m = 2.7465kg$

$w_g := m \cdot g = 26.94N$

Force and Moment Equations for One Table Top

$\sum F_x := F_{fR} + R_x - F_{fw} = 0$

$\sum F_z := N_R + N + N_w - w_g = 0$

$\sum M_N := N_w \cdot 0.00635 - N_R \cdot 0.24765 = 0$

$F_{fw} = \mu_{wheel} \cdot N_w$

$F_{fR} = \mu_{wood} \cdot N_R$

$R_x = \mu_{wood} \cdot N$

Solving System of Equations

M_N $N_w = 39N_R$

F_x $0.6N_w = 0.25N_R + 0.25N$

$Nw = 31.69N$

$F_{fw} = 0.6 \cdot 31.69$

$F_{fw} = 19.02N$

Torque from Wheel->Pulley->Gear->Motor

$T_{wheelshaft} := F \cdot r_{wheel}$ $T_{Pulley} := Fr_{pulley}$ $T_{gear} := Fr_{gear}$

$T = 0.1538Nm$

2 Table Tops and safety factor

$T_{motor} := 4Nw \cdot r_{wheel}$

$T_{motor} = 0.6152Nm$