Adaptable Classroom and Workspace Table
Final Design Report (FDR)

Team Adapt-Table
Mechanical Engineering Department
California Polytechnic State University, San Luis Obispo

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Statement of Disclaimer

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Executive Summary

Within this document, team "Adapt-Table" shall describe the process in which the project of creating an adaptable table will be executed. The introduction section contains details on the problem, the customer, and the goals of the project. The background section contains research the team conducted, including information from an interview with Mr. Brennan, patent research, and industry standards the team is aiming to comply with. The objectives section contains the scope of the problem described through a problem statement, boundary diagram, and Quality Function Deployment (QFD) table. The concept design section illustrates the thought process used to arrive at the current table design as well as acknowledges current concerns regarding safety and implementation. The final design, manufacturing, and design verification sections outline the final design, manufacturing process, and testing procedures to evaluate the effectiveness of the verification prototype. The project management section outlines the overall design process, including a Gantt chart that displays a tentative schedule of key deliverables and expected completion dates. The conclusion section summarizes the final design report and discusses recommendations for the next project steps beyond the Senior Design class.

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1.0 Introduction

Mr. Michael Brennan, entrepreneur and founder of Co-Act Furniture, presented the problem of a classroom and workspace table that can be quickly, easily, and safely reconfigured to accommodate different types of collaboration and learning within a limited space. Current classroom and workspace furniture lacks modularity, which limits the usability of the space. Different groups use the same room to learn in different ways; adjustable furniture would benefit their learning and productivity. Mr. Brennan has developed several prototype tables with varying features, including adjustable angle, height, and tabletop surface area. Our team, composed of three mechanical engineering students, has a project goal to design and build an adaptable table that meets our sponsor's requirements and improves the modularity of classroom and work spaces. This document includes background research, establishes project objectives, illustrates the design process, and explains the manufacturing steps and project implementation.

2.0 Background

In order to develop our understanding of the scope of the project, we conducted initial background research in three categories: sponsor interviews, existing products and patents research, and technical literature. We conducted a sponsor interview to develop a list of customer requirements and the required functions of the end product. We researched existing products to find competitive current products and the associated patents. Lastly, we researched technical literature to evaluate future applications and industry standards relevant to the product.

2.1 Sponsor Interview

A meeting was conducted with our sponsor, Mr. Michael Brennan, on January 17, 2020 to gain a better understanding of the scope of the project. Mr. Brennan is the CEO and founder of Co-Act Furniture, a company he founded as he was pursuing his MBA in Entrepreneurship. Mr. Brennan formerly worked closely with faculty at Cal Poly selecting collaborative furniture for classrooms and improving overall classroom layout and functionality. Through this work, Mr. Brennan noticed that existing collaborative furniture meets a single function, while professors use classroom spaces in different ways. Professors requested teaching in specific rooms because the furniture met their teaching style. Mr. Brennan realized that classrooms needed adaptable furniture that could quickly be reconfigured from collaborative to lecture style teaching to accommodate all professors. He constructed several prototypes of adaptable classroom furniture that could expand in size, raise to standing height, and be used as a whiteboard, but he needs help improving and further developing the design. Additional notes from this interview are included in Appendix A.

2.2 Additional Interviews

Additional interviews were conducted with Cal Poly faculty familiar with classroom design and furniture purchasing. Michele Reynolds works with professors and schedules classes and classrooms on campus. Ms. Reynolds pointed out that the majority of collaborative spaces on campus are round, which limits the functionality of the classroom. She emphasized that furniture must be the appropriate size for a classroom so that seats are not lost and spaces must be reconfigured quickly to limit disruption to teaching. Lastly, Ms. Reynolds noted that current lecture rooms have whiteboards on all four walls rather than movable whiteboards.

We also interviewed Dave Norton, who is responsible for selecting and purchasing new furniture for Cal Poly's classrooms. Mr. Norton pointed out that "modern" classrooms on campus have a more collaborative feel and show forward thinking. Currently, there are not any standing height desks in classrooms because the chair does not convert to a stool.

An interview was conducted with a fellow student, Adam Melamed, a junior Economics major who is involved on campus. Mr. Melamed explained that working as a group is often difficult when sitting in a row in classrooms in the business building here at Cal Poly. He often spends time moving desks out of the way to accommodate Delta Sigma Pi, a Professional Business Fraternity, weekly meetings. He thought modesty panel table extensions would be great and thought there could be whiteboard marker and eraser storage. He sees a future where many desks in classrooms are standing desks because people are beginning to understand how our sitting posture is detrimental to health.

Interview notes from our meetings with Michele Reynolds, Dave Norton, and Adam Melamed are included in Appendix A.

2.3 Technical Research

Research was conducted to examine the advantages of an adaptable table in classroom settings. The main advantage of adjustable furniture is that it can accommodate a variety of teaching styles or classroom needs. According to a research paper by Robert Sommer, a professor in the Department of Psychology at the University of California, Davis, classroom layout nonverbally communicates teacher authority (Sommer). Students "read" the environment as soon as they walk into a room. In a lecture style, "sit-and-listen," class, teachers prefer straight rows of desks. Straight rows direct attention to the teacher at the front of the room and discourage conversations with peers. However, in group discussion and collaboration style classes, the straight row setup is not effective. According to a 2007 study by Brigitte Burgess and Naz Kaya, students prefer "cluster seating" for collaboration, because this setup does not require physical maneuvering to interact with peers (Burgess). If a teacher wants to alternate between lecture and group work, and maximize the effectiveness of each teaching style, classroom furniture must be rearranged. Zheng Yang concluded, in a 2013 study on student perceptions of higher education classrooms, that spatial attributes in classrooms have the greatest effect on student perceptions of learning and overall student success, ahead of factors like room temperature, acoustics, and technology. Additionally, Yang discovered that student perceptions were impacted more by the functionality and comfort of the furniture than by the amount of furniture (Yang). The findings in these studies indicate that the quality, adjustability, and layout of classroom furniture can greatly impact classroom atmosphere and benefit student learning.

Additional research was conducted to determine the industry and government standards relevant to the project. The relevant standards are from the American National Standards Institute (ANSI) and Business and Institutional Furniture Manufacturer's Association (BIFMA) organizations. Our final product should meet ANSI/BIFMA X5.5-2014 Standard for quality, durable office desk and table products.

ANSI/BIFMA X5.5-2014 provides a common basis for evaluating safety, durability, and structural performance of desk/table products intended for commercial office and educational environments. This standard provides test methods for leg strength, vertical load, proof load, locking mechanism fatigue, and other key components. ANSI/BIFMA X5.5-2014 specifies the acceptance levels to help ensure reasonable safety and performance independent of construction materials, manufacturing processes, mechanical designs, and aesthetic designs. The tests were developed with an estimated product life of ten years.

In addition to meeting the performance and safety requirements outlined in ANSI/BIFMA X5.5-2014, our final design must meet ergonomic requirements. BIFMA's G1 Ergonomic Guidelines recommend that standing desks be adjustable from a minimum height of 22" to a maximum height of 46.5". This accommodates 90% of the US population, from the 5th percentile of women to the 95th percentile of men. However, it should be noted that the European standard is 3" higher than the American, so for our design, we will have a target maximum height of 50". In addition, the product must meet ADA requirements, per the Americans with Disabilities Act. To comply with ADA requirements, the product must meet specific toe and knee clearance requirements. These specifications include a minimum of 30 inches of toe and knee clearance width, 8 inches of knee clearance depth, and 27 inches of knee clearance height above the floor (United States, Department of Justice).

2.4 Current Products

The current products research conducted consisted of a comparison of products already on the market and their ability to satisfy the customer's specifications. The target customers for the adaptable table are students, teachers, and business professionals. The scoring of current market products ranged from 1(poor) to 9(excellent) and can be found in our team's QFD, Figure B-1 in Appendix B, on the right hand section labelled "Benchmarks." The examination of current products on the market helped us determine the level of satisfaction current products provide our customers. The team is aiming to create a product that exceeds the level of satisfaction seen in current products. The current products examined by the team can be found in the figures in Appendix B.

The Steelcase Verb, depicted in Figure B-1, excelled in the basic functions of a nesting table but lacked in the custom desires of electrical access, height adjustment, modesty panels, and angle adjustment. It incorporates multiple detachable white boards per table. These white boards can be placed on a separate eisel to create an array of individual white boards. The company offers various table shapes, two types of legs, and claims to use sustainable practices.

The KI Pirouette, shown in Figure B-2, had many of the same strengths as the Steelcase Verb, but lacked whiteboard functionality. In exchange, the Pirouette offered various height options and the option of a modesty panel. However, the height of the tables are not adjustable.

The Allsteel Aware, depicted in Figure B-3, is similar to the Verb and Pirouette mentioned above, but lacks storage, electrical power, and white board functionality.

The Boss's Cabin Mantis, shown in Figure B-4, offers the nesting table features of the Verb, Pirouette, and Aware, but does not include electrical power, height adjustability, or white board functionality.

The Virco standard rectangular table, depicted in Figure B-5, was a wooden long-table commonly found in classroom settings. The table was extremely durable but very lacking in adjustability and additional features.

2.5 Patents

Background research also included a patent search for mechanisms that may prove to be helpful in the design and manufacturing of an adaptable table. The patent search provided promising mechanisms that could be used or modified to build an adaptable table capable of meeting the customer's specifications. The creation of an adaptable table is open-ended and should not be constrained to the attributes found within our patent search, but the ideas from the patents displayed in Table 1.

Table 1. Patent Search Relating to Nesting Tables

Patent Name	Patent Number	Key Characteristics
Learning Suite Furniture System	9,066,589	● Rolling table ● Nesting Feature ● Attached Whiteboard that can be mounted on the table
Foldable Table	CN201020624915U 20101125	● Adjustable table height ● Table folds out to extend
Nesting table with controlled pivoting movement	US20050252426A1	● Nesting top ● Staggered legs for storage
Nesting and folding table	EP1958537A1	● Staggered legs for compact storage ● Flexible transmission cables allow for nesting and locking of tabletop
Folding and tilting table	US6845723B2	● Nesting feature ● Legs completely fold up for storage

The patent search was conducted using Google Patent Search as well as directly searching on USPTO.gov. Despite many similarities in key characteristics of each patented product, the design process is open and should not be limited to what is already on the market. There are many potential systems that are yet to be used and shall hopefully arise during the brainstorming phase of the project.

3.0 Objectives

The requirements outlined by our sponsor and customers defined the challenge of the adaptable table and the scope of the project. From these requirements, our team developed a boundary diagram depicting the project's scope. The Quality Function Deployment (QFD) process was used to evaluate the most important specifications of the end product and the necessary engineering tests and tolerances to meet each specification.

3.1 Problem Statement

The problem statement for this project is defined as follows: Students, educators, and professionals need a way to quickly, easily, and safely reconfigure furniture to accommodate different types of collaboration and learning within a limited space. Current classroom and workspace furniture lacks modularity, which limits the usability of the space. Different groups use the same room to learn in different ways; adjustable furniture would benefit their learning and productivity.

3.2 Boundary Diagram

The boundary diagram shown in Figure 1 illustrates the scope of the adaptable table project. The scope of the project is boxed in red. Everything not within the red box is not within the team's control. The main components our team is able to control include the design and construction of an extension, rotation, and height adjustment mechanism to allow for reconfiguration of the table, a support structure, a table surface capable of becoming a whiteboard, and a mechanism to aid in transportation of the entire table. The variables outside of our team's control are the environment the table is applied to, the seats used to complement our table, and the objects the user places on the table.

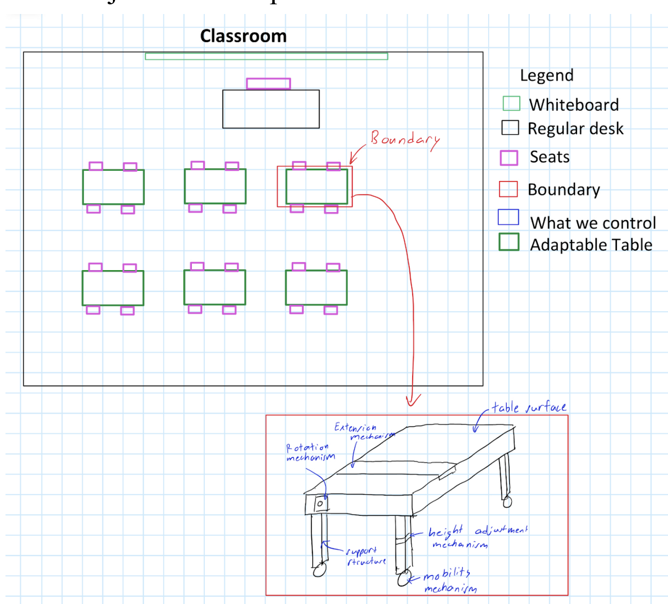


Figure 1. Adaptable Table Boundary Diagram

3.3 Quality Function Deployment (QFD)

The Quality Function Deployment process was used to determine and rank the specifications for the adaptable table. Customer needs were listed and ranked in terms of importance from 1-5 (i.e. 1 - not important, 5 - extremely important). A full list of customer wants and needs is included in Appendix A. Current products were evaluated by how well they meet the customer specifications from 1-9 (i.e. 1 - does not meet specification, 9 - meets specification extremely well). The customer specifications were paired with engineering requirements to determine how the specification will be evaluated (i.e. blank - engineering requirement does not measure customer specification, 9 - engineering requirement evaluates specification extremely well). This process ensures maximum customer satisfaction with the end product and determines the most important engineering requirements for the design. The full QFD, in its "House of Quality" is included in Appendix C.

The most important specifications for our project, as determined by the QFD, are movable, safe, durable, and size-changing functionality. These are closely followed by easy to configure, white-board functionality, and height adjustability. There are currently many classroom tables on the market, so these specifications play major roles in ensuring the product is proprietary and functional.

Table 2 displays a list of the specifications and targets for this project. The specifications are ranked in order of importance, as determined by the QFD.

Table 2. Engineering Specifications Table for the Adaptable Table

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Movable	1 person	Max	L	T
2	Reconfigure Time	60 sec	Max	H	A, I, S, T
3	Safe to use (Meets ANSI Safety Standards)	Pass	N/A	M	A, I, S
4	Table Surface Area Adjustability	8-16 ft^2	+4/-2 ft^2	L	A, T
5	Deformation Force	500 lbf	Min	H	A
6	Ratio of Purchased to Manufactured Parts	3:1	Min	M	I
7	Weight	50 lbf	Max	H	T, I
~~8~~	~~Nesting Width~~	~~6 in~~	~~Max~~	~~M~~	~~A, I~~
9	Modesty Panel Height	10 in	Min	L	A, I
10	Cost	$800	Max	M	A, S
~~11~~	~~Quantity of Storage Solutions~~	~~2~~	~~Min~~	~~L~~	~~I, S~~

Risk: L = Low
M = Medium
H = High

Compliance: A = Analysis
I = Inspection
S = Similarity
T = Test

Each specification in Table 2 has an assigned target, tolerance, risk, and compliance. The target is the goal value for the final design. The tolerance is the acceptable range of deviation from the nominal target in the final design. The risk criteria were assigned as High (H), Medium (M), or Low (L) based on the presumed difficulty of meeting each specification. Lastly, compliance is the way we will evaluate the specification to determine if the design meets the target and falls within the specified tolerance. The compliance methods included are Analysis (A), Inspection (I), Similarity to Existing Designs (S), and Test (T). For testing and analysis, our team will need to build a functional prototype to determine whether the design meets the specifications.

Each specification is explained in further detail:

1. The ability for the table to be moved by a single person is essential to overall product function because it affects ease of reconfiguring, portability, ease of storage, and adjustability of the product. It is essential that a single person can move, store, and reconfigure the table for it to be feasible in classroom and professional environments.
2. Usability was another of our customer's requirements. For the table to be easy to use, the time to reconfigure the product between two settings (i.e. sitting to white board) must be less than 60 seconds to minimize the disruption to productivity.
3. It is imperative that the product be safe to use in classroom environments. As a result, the device must meet the relevant ANSI, BIFMA, and ADA standards (specified in Section 2.3) and limit the number of pinch points.
4. Another essential customer requirement related to the original intent of the product is table surface area adjustability. The goal range of surface areas is from 8 ft^2 to 16ft^2.
5. Stiffness and deformation are strength and rigidity requirements that our team deemed necessary to ensure the durability of the product. The table will be used in classrooms, where it could be subject to students standing or sitting on the tabletop, so it is important that the top be able to support a 500 lb load.
6. Our sponsor indicated that the ratio of purchased to manufactured parts was important for him to be able to scale the product. Co-Act Furniture is a startup company with limited manufacturing resources. Purchasing many of the components could greatly reduce the final product cost and ease scaling. Our team has a goal ratio of purchased to manufactured parts of at least 3 to 1.
7. Our client would like the product to be portable and lifted if it needs to be transported between locations. The products should have a maximum weight of 50 lb.
8. The nesting width of the product is important for easing storage and minimizing the floor space necessary for storage. The nesting width should be no greater than 6 inches, which is comparable to other tables on the market.
9. Our customer would like the product to include a modesty panel to provide privacy for a person seated at the table and shield their upper legs. The modesty panel should have a height of at least 10 inches to maximize the effectiveness of the feature.
10. Our sponsor indicated that cost is not a huge factor on the product. Companies and universities currently spend at least $800 for a single basic table. Our product will have additional features, so the target sale price will be approximately $1600. To have 50% margins, the target cost for materials and manufacturing is $800.
11. The quantity of unique storage solutions is another selling feature of the product. The device should have at least two storage solutions for items such as pens and backpacks.

The high-risk specifications for our project are time to reconfigure, deformation force, and weight. These specifications are highly dependent on the materials and components used to build the product and will be more difficult to meet.

4.0 Concept Design Development

The ideation process and proposed design solution are discussed in this section.

4.1 Ideation Process

To begin the ideation process, the team conducted a functional decomposition of the project, breaking down the table into its most basic functions. Process ideation was done through a brainstorm session by asking "how might we?" questions for some of the basic functions of the design. In our brainstorm session, we explored how we might change tabletop surface area, as well as how we might provide nesting storage solutions. The session was conducted free of regard to implementation viability. By recording all ideas and disregarding feasibility during brainstorming, one impractical solution can spark an idea for the best solution. Throughout the brainstorm session, rough sketches were done to further understand the theoretical mechanisms being proposed. The ideas generated during our brainstorm session are attached in Figures D-1 and D-2 in Appendix D.

4.2 Concept Sketches

Next, we compiled our ideas for the separate basic functions and sketched our top overall designs. Sketches and descriptions of our top concepts are included in Figures 2 through 6.

Figure 2 depicts the modesty panel extension design. In lecture environments, the modesty panel hangs down; for collaboration, the panel swings up to expand the table surface. This design does not incorporate a sliding or hinging extension for lecture classes.

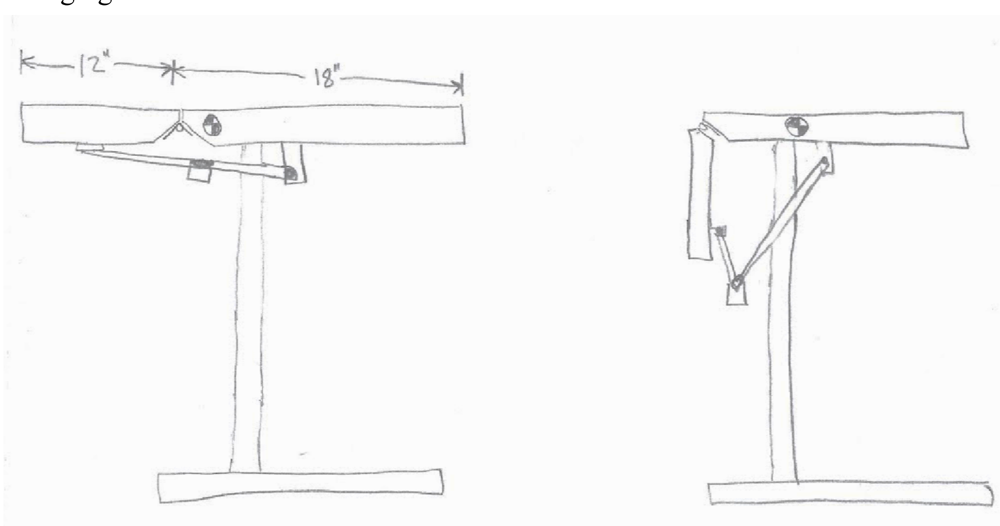


Figure 2. Modesty Panel Only

Figure 3, the two-way slide concept highlights a concept that changes tabletop shape rather than surface area. Two identical rectangular surfaces are attached with a single link. The tables are initially set up with the short ends connected for a lecture class. One table slides along the sides of the other table to align the long ends and form a square table for collaboration.

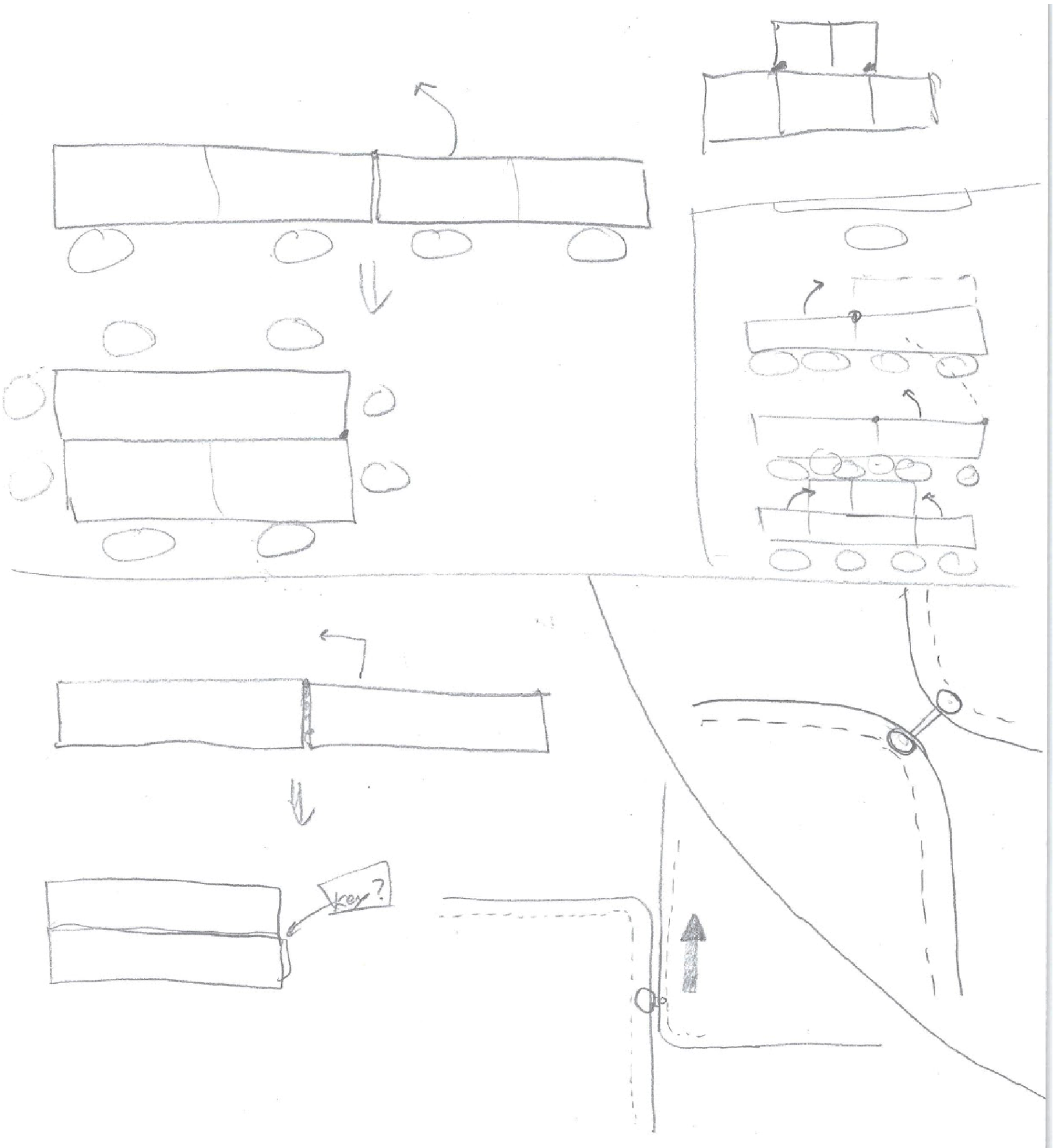


Figure 3. Two Way Slide

Figure 4, the sliding leg storage concept, depicts an alternate nesting solution. The outer leg slides in and reduces the necessary width for storage. The table surface rotates to sit perpendicular to the ground for storage or potential white board use.

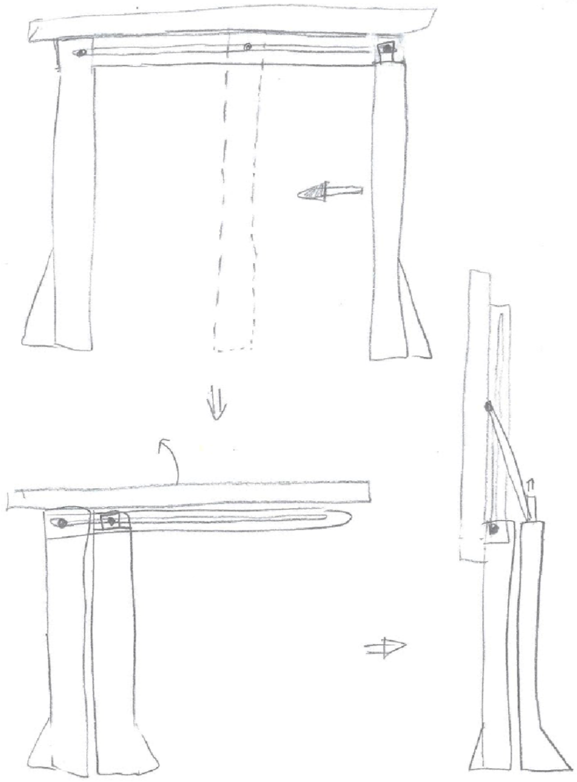


Figure 4. Sliding Leg Storage

Figure 5, the four bar linkage concept, shows two identical table surfaces connected on the sides by four bar linkage mechanisms. The mechanism ensures the second table surface remains parallel to the original surface the entire time. The second table surface includes an additional leg for support. The table surface rotates perpendicular to the ground for storage.

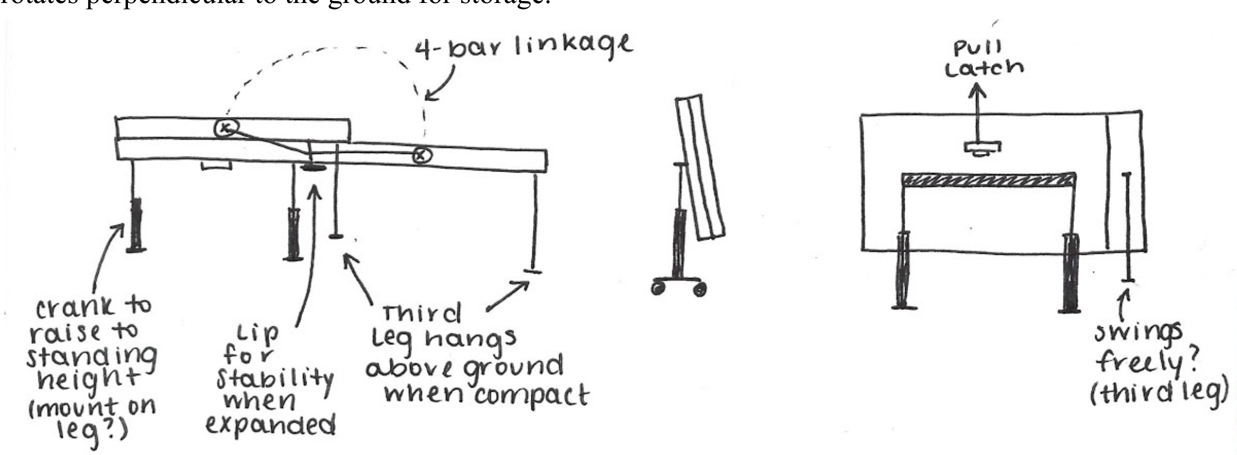


Figure 5. Four Bar Linkage Mechanism

Figure 6, the modesty panel slide concept, depicts two rectangular table surfaces that stack vertically for nesting. A modesty panel attached to the bottom table surface can flip up for collaboration, similar to the modesty panel only design in Figure D-3. For lecture, the top table surface slides parallel to the bottom table surface, then drops down by the thickness of the tabletop to create a level surface. The images show multiple components necessary for the sliding mechanism, including alignment rails, a spring-loaded bar mechanism, and a third support leg.

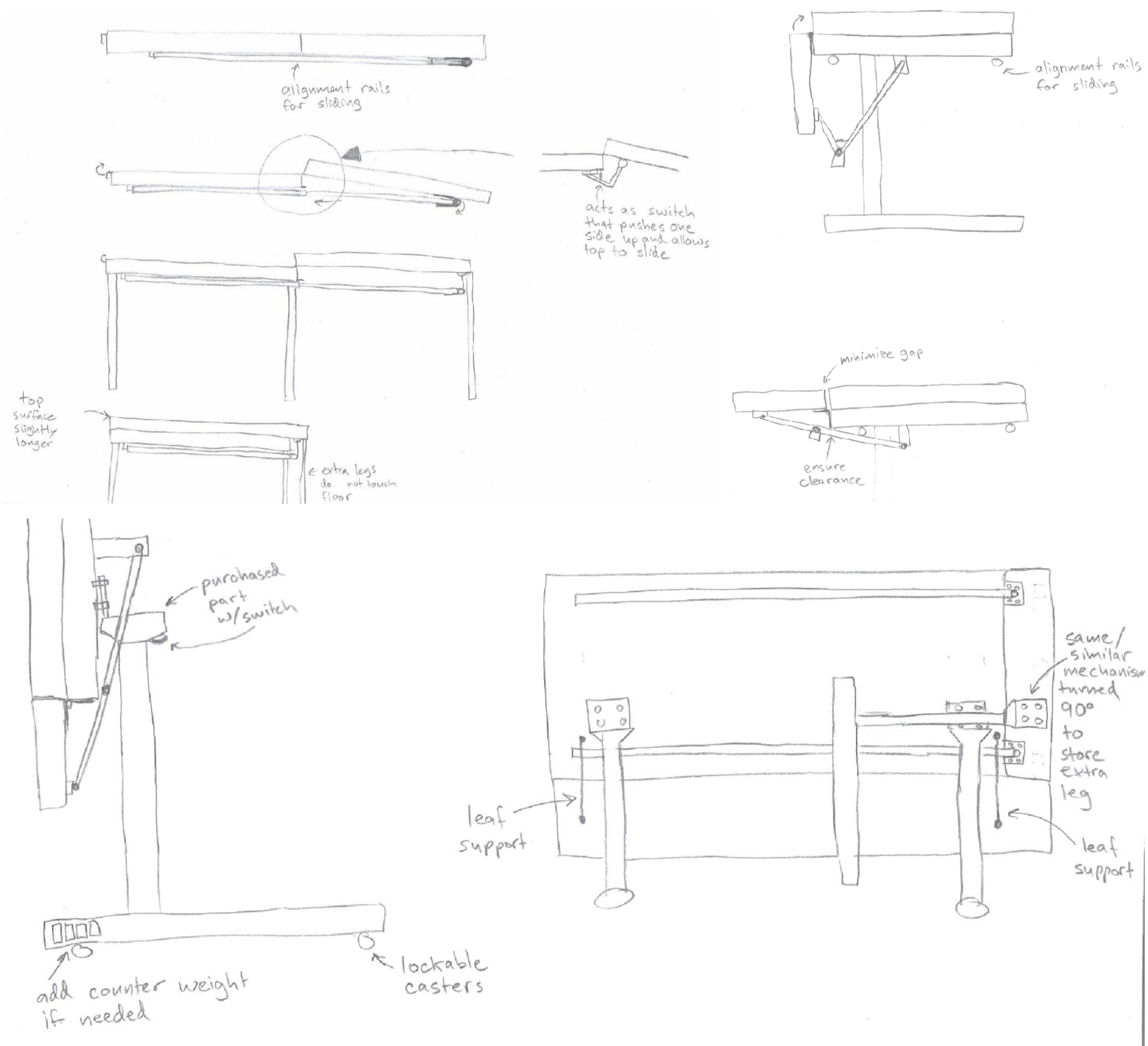


Figure 6. Modesty Panel Slider Design

4.3 Idea Refinement

The next step after functional decomposition and brainstorming was to further investigate the solutions through the creation of rough concept models. The concept models were tested to visualize geometric constraints as well as implementation problems such as interfering moving parts. Concept models also allowed for mental stimulation regarding the physical parts that would actually make the table (eg. legs, hinges, tabletop surfaces, etc.). The concept models we created were then narrowed down to the best three based on how effective they were at going from collaborative to lecture classroom environments and how easily they could be integrated with a table nesting mechanism. Images of three concept models are attached in Figure D-3 in Appendix D.

After deciding the top concepts, the next step was to create Pugh matrices evaluating how well the selected concepts for each basic function fulfill the customer's needs and wants. The concepts were each compared relative to a datum, which was Mr. Brennan's current design (+: better than datum, S: same as datum, -: worse than datum). The Pugh Matrices for tabletop surface area and nesting solutions are attached in Figures D-4 and D-5 in Appendix D.

Using the results of the Pugh matrices and general discussions, the top resulting concepts were combined into a morphological matrix. The morphological matrix consisted of all the combinations possible between the two subsystems of our project - the tabletop and the legs. The matrix was then narrowed down by evaluating the most feasible full system concepts. For the tabletop, we narrowed the best solutions down to four options. We had a modesty panel hinge design, a modesty panel slide design, a two way slide design, and a three section rotation design. For the legs, we had two best options allowing for nesting storage. The two options were staggered and angled designs. Next, we moved the morphological matrix into a weighted decision matrix. Each full system concept was rated on a scale of 1(worst)-5(best) for each engineering specification. The engineering specifications were weighted on a scale of 1(least important)-5(most important), allowing for an algebraic equation to determine which design would theoretically provide the best results considering a perfect design with no complications. The chosen design was a modesty panel slide mechanism for the tabletop paired with an angled leg design for nesting. This design scored ~5% higher than the second highest rated design. The weighted decision matrix is attached in Figure D-6 in Appendix D.

4.4 Selected Concept Design

From the weighted decision matrix, the selected concept design was the modesty panel slide mechanism. In this design, two rectangular table surfaces stack vertically for collaboration. We will call the lower table surface the "primary table" and the upper table surface the "secondary table" in this document. A modesty panel is attached to the primary table and hinges to align with the secondary table surface. This expands the depth of the table for collaboration. The modesty panel will attach using Rockler's drop leaf supports. An image of the concept prototype for the proposed modesty panel support, using the proposed Rockler supports, is included in Figure D-7. The concept design in the collaboration configuration is shown in Figure 7.

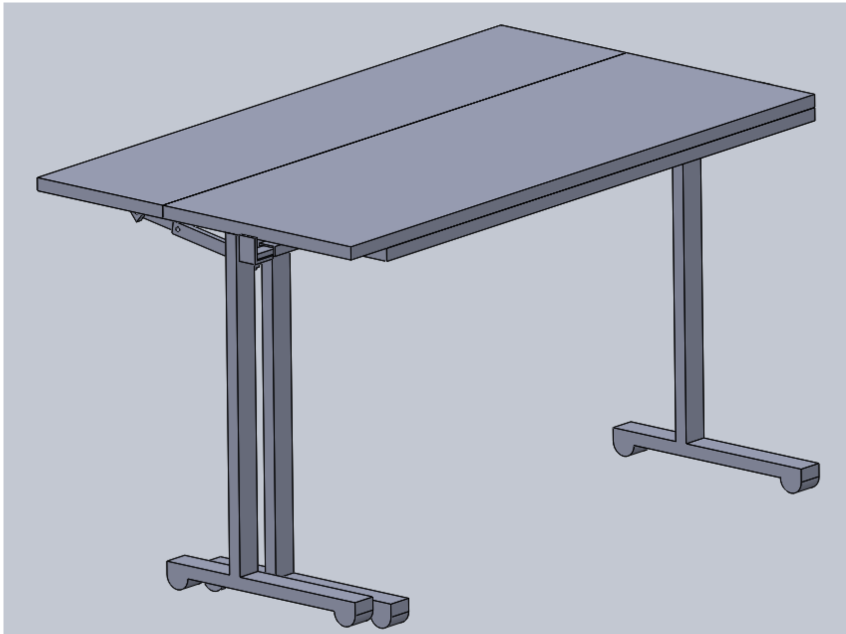


Figure 7. Concept Design in the Collaboration Configuration

For lecture, the modesty panel extension hinges down into the traditional modesty panel position. The secondary table surface slides parallel to the primary table surface using alignment rails, then drops down by the thickness of the tabletop to create a single, level, long table surface. The secondary table surface is supported by a third leg. The concept design in the lecture configuration is shown in Figure 8.

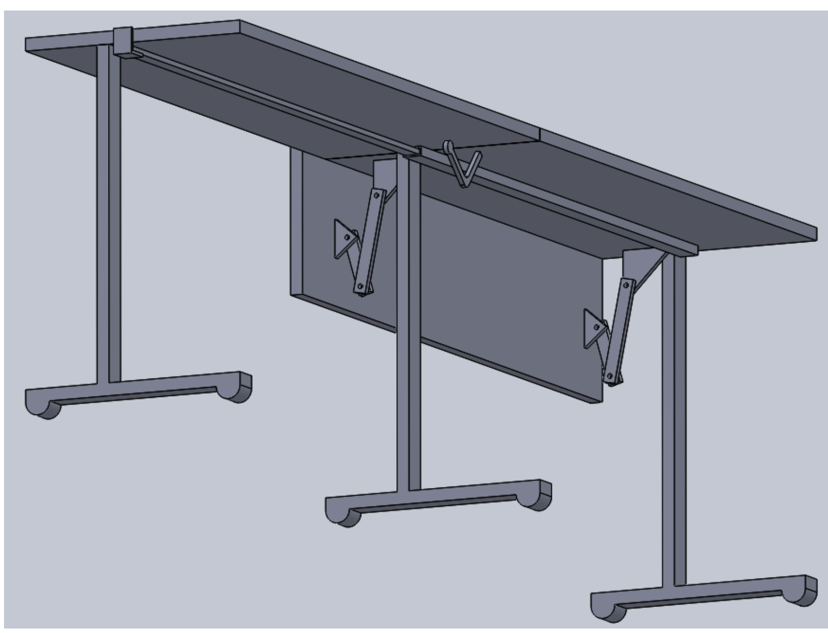


Figure 8. Concept Design in the Lecture Configuration

To return to the collaboration setup, a spring-loaded support bar lifts the secondary table surface above the primary table and extends the third leg by the thickness of the tabletop. The secondary table then slides back to its original position using the alignment rails. A labeled isometric view of the entire concept design is depicted in Figure 9.

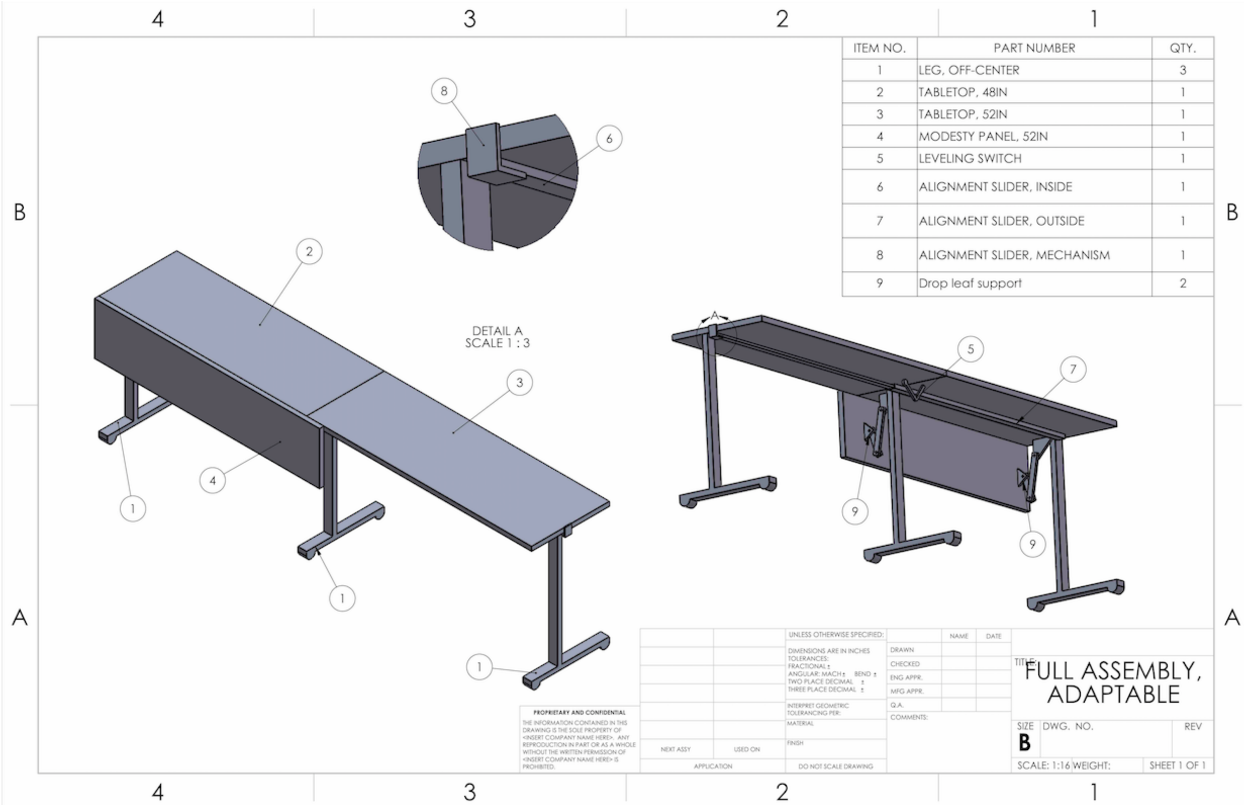


Figure 9. Labeled Isometric View

For nesting, the stacked primary and secondary tables hinge to sit perpendicular to the ground. The third support leg for the secondary table hinges downwards and out of the way. Multiple tables nest together by staggering the leg positions.

Engineering analyses we will have to consider as we refine the design include calculating the shift in center of gravity due to the addition of the modesty panel on one side of the table. We will offset the position of the legs and add counterweights as necessary to maintain the table's stability. We will also need to evaluate the strength of connections to the honeycomb tabletop material. Using the weight of the tabletop surface, we will calculate the required force of the spring loaded support bar to lift the secondary table surface and return to the collaboration configuration.

4.5 Risk Evaluation

Concerns with the current design include safety hazards as well as those regarding implementation, fabrication, and/or operation of the table. Safety hazards can be seen in Appendix E. In summary, the swinging motion of the modesty panel allows for a potential pinch point to be seen around the hinge. A disclaimer shall be used and instructions are to be placed into the manual in order to protect the user. The table may also collapse when put into a misuse case of too large of a load being placed on the table. The instruction manual shall state the allowed load. In terms of implementation, fabrication, and/or operation of the table, the final mechanism to allow for surface area expansion through a slider remains an area of interest and must be further investigated.

5.0 Final Design

In this section, we will discuss the final design of the Adaptable.

5.1 Overview

For the final design, we kept the main concept of three table tops that slide and rotate to meet collaboration and lecture classroom needs. We simplified the components and mechanisms to improve the transition between the configurations. For the final design, we decided to eliminate the nesting feature of the table. The nesting feature would allow the tabletops to rotate 90 degrees and reduce the space required to store the tables when not in use. We decided to eliminate this feature because in a classroom setting, there are few scenarios where the tables would need to be stored against the wall. Additionally, our sliding mechanism design, with 3 independent tabletops, makes a secure pivot motion difficult. The indented Bill of Materials for all parts required in the final design, including part numbers, is included in Appendix F.

5.2 Detailed Design

The final design of the Adapt-Table maintains the overall functionality of the concept design. There are three separate tabletops, referred to as the “Fixed Table,” “Sliding Table,” and “Modesty Panel” in this section of the report. The Adapt-Table functions in two main positions: lecture and collaboration. In the lecture configuration, the fixed table and sliding table are aligned, creating a single, long table surface. This setup is ideal for lecture style classes, where students sit in a row and all face the front of the classroom. The lecture configuration model is depicted in Figure 10.

Figure 10. Final Design in the Lecture Configuration

In the collaboration configuration, the sliding table slides longitudinally to rest on top of the fixed table. The modesty panel pivots upwards to increase the depth of the table surface. This configuration provides a short, deep table, ideal for a cluster of four students collaborating on an assignment. The collaboration configuration model is depicted in Figure 11.

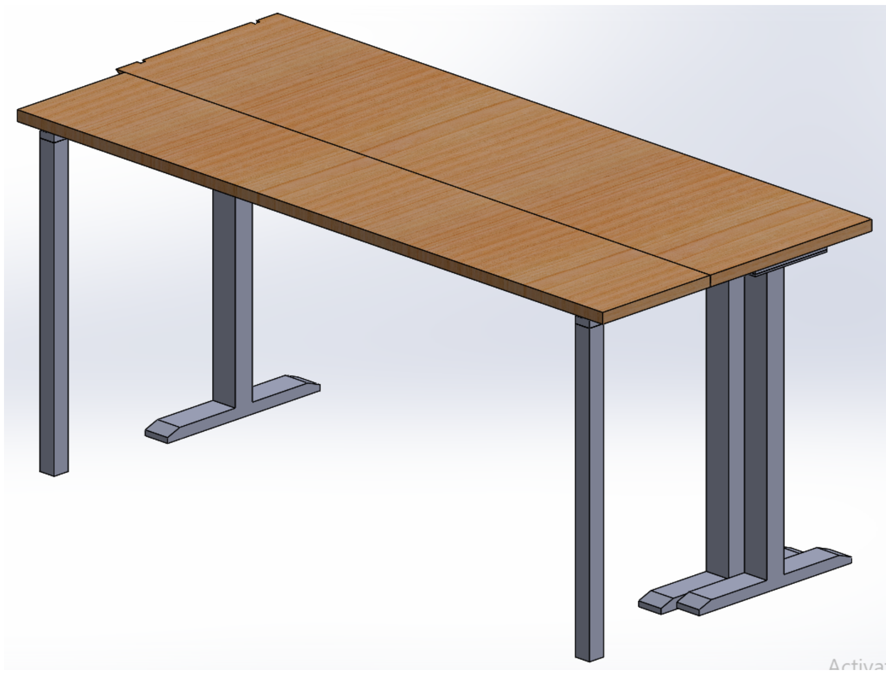


Figure 11. Final Design in the Collaboration Configuration

In the lecture configuration, the sliding table is supported on the left end with a T shaped table leg. On the right side, the table is supported by a sheet metal plate mounted between the fixed table and the left leg of the fixed table. The two tables could separate when a load is placed on the sliding table, or if the user pushes too hard on the sliding table while reconfiguring. Two angle brackets bolted to the sheet metal plate rest in a notch along the underside of the sliding table. The angle brackets prevent the sliding table from separating from the rest of the table and falling to the ground. The angle brackets, mounted to the plate, are shown in Figure 12.

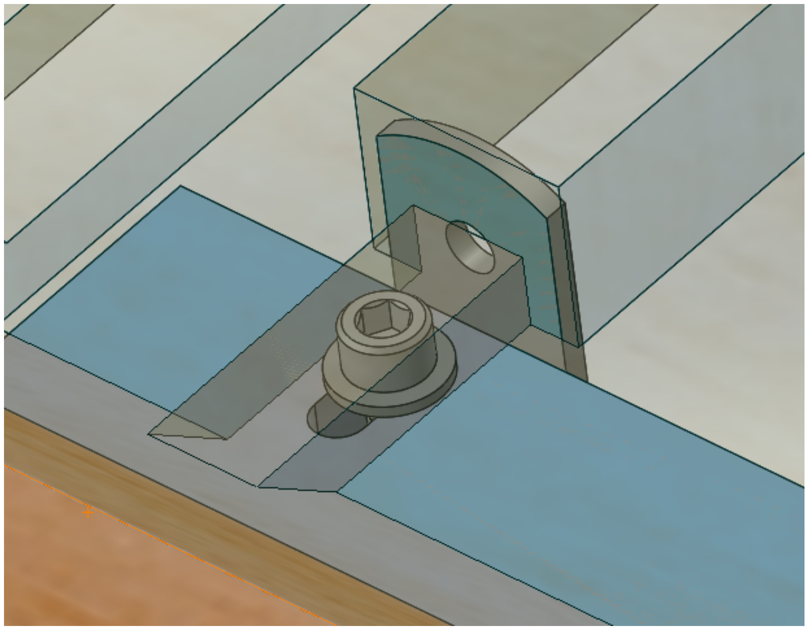


Figure 12. Angle Bracket Supports

The sliding mechanism is created by a system of four wheels, shown in Figure 13. Two wheels protrude from the top of the fixed table at the seam between the fixed table and sliding table in the lecture configuration. Two smaller wheels sit at the lower edge of the sliding table in the joint between the tables. The wheels will be 3D printed in two sections, to meet the specific dimensions and allow for more flexibility in tuning the final prototype. A steel spacer slots through the center of the wheels. A particle board screw from the side of the table acts as the axle through the center of the spacer.

The bottom edge of the sliding table and top edge of the fixed table are chamfered to hide the lower wheels and ease the sliding motion. The chamfers make it easier for the lower wheels to climb the height of the fixed table. When the user pushes horizontally on the end of the sliding table, the lower wheels climb the chamfered edge and the sliding table rolls parallel to the fixed table. The joint between the fixed table and sliding table, including the roller mechanism and chamfered table edges, is depicted in Figure 13.

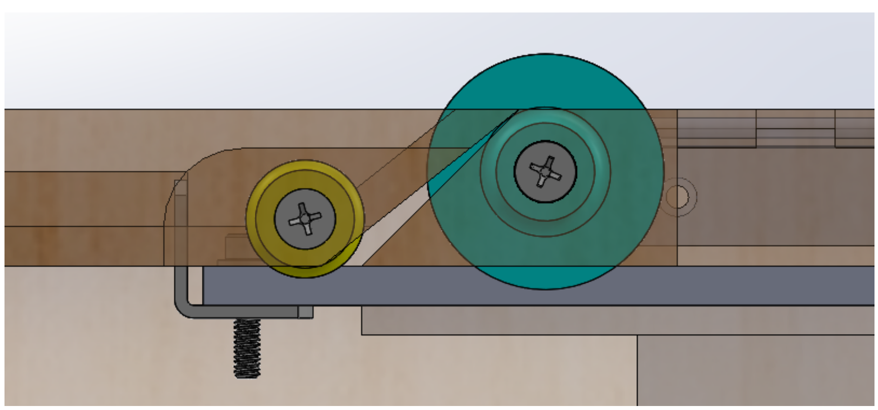


Figure 13. Roller Mechanism and Chamfer Design

The larger wheels, on the fixed table, ride in grooves along the underside of the sliding table, which maintains table alignment through the sliding process. When the sliding table reaches the collaboration position, both sets of wheels drop into grooves and the sliding table sits directly on the fixed table, as shown in Figure 14.

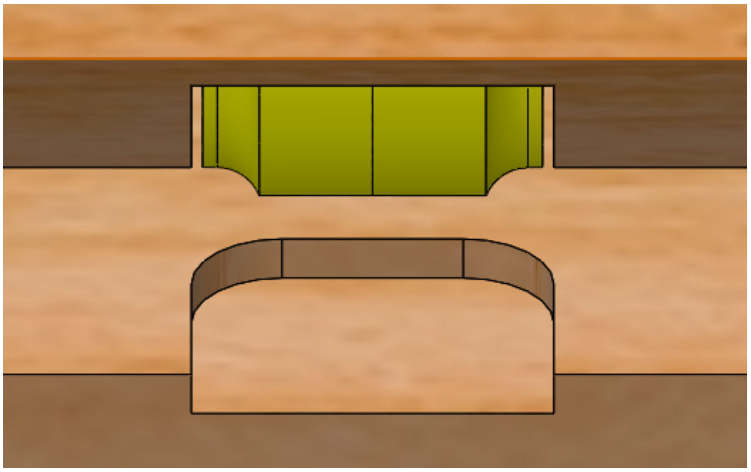


Figure 14. Grooves Lock Rollers in Place

The modesty panel pivots using a set of piano hinges. Two legs pivot down from the corners of the modesty panel to support the table surface. The modesty panel leg design is depicted in Figure 15.

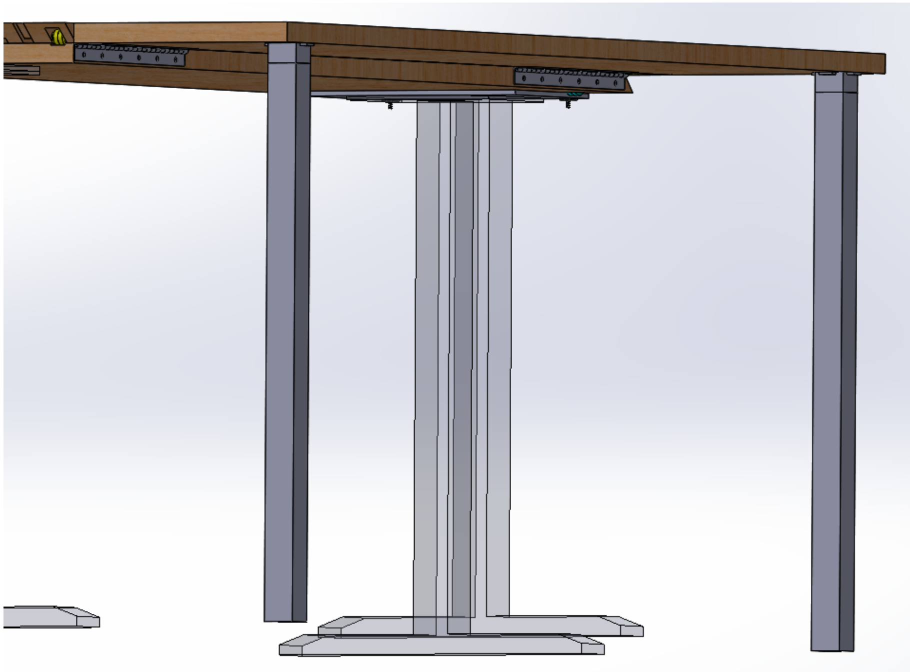


Figure 15. Modesty Panel Leg Design

The drawing package is attached in Appendix G. The drawing package includes dimensions and tolerances for all manufactured and modified parts and details for assembling the final product.

5.3 Detailed Analysis

Most of our engineering specifications centered around the user experience and usability of the product. As a result, we designed the table to meet geometric constraints, including table surface area, height off the ground, and modesty panel height. For the final design, we reduced the number of components and steps to reconfigure by simplifying the overall design. To reconfigure the final design, the user must push on the end of the sliding table, lift the modesty panel, and pivot the modesty panel legs into place. Our concept design required a complex switch system and locking mechanisms that require a lengthy reconfiguration time. The roller system is more durable, easier to install, and requires limited maintenance. The detailed failure modes and effects analysis is presented in Appendix H and includes explanations of potential failure modes and prevention and detection activities.

We conducted a numerical engineering analysis on the components most likely to fail. The results from the engineering analysis is attached in Appendix I. We focused our analysis on the manufactured parts. We calculated the maximum deflection of the sliding table, the longer tabletop, based on a 200 pound person standing in the center. For this calculation, we treated the table as a beam with a load in the center and fixed on both ends. We found that the maximum deflection under a 200 pound concentrated load is 1 inch. This deflection is reasonable given the 60 inch length of the table and the relatively low modulus of elasticity of medium density fiberboard. To reduce the deflection, we could install a metal support frame in the tabletop. We calculated the bending stress in the tabletop to determine whether the table would break under a 200 pound load and compared this value to the yield strength of medium density fiberboard. The calculated safety factor for the tabletop is 2.6, which meets our design criteria. The hand calculations completed for the tabletop strength analysis are attached in Figure I-1 in Appendix I.

Next, we analyzed the aluminum plate and angle brackets between the two tables. We verified the deflection of the aluminum plate under a 500 pound force, the design load for the joint. We treated the plate as a cantilever beam and determined the maximum deflection is 0.001 inches. Therefore, we do not expect the aluminum plate to fail under normal operating conditions. We calculated the bending stress in the plate, compared the value to the yield strength of 6061 aluminum, and found that the factor of safety for bending in the plate is 10. We do not expect the aluminum plate to fail under normal operating conditions. The hand calculations completed for the plate strength analysis are attached in Figure I-2 in Appendix I.

Next, we completed a strength analysis of the angle bracket. We calculated the deflection of one angle bracket under a 25 pound force. This meets our design condition of a 50 pound force separating the tables divided between the two brackets. We found that the maximum deflection of the angle bracket is 0.01 inches, a negligible amount. We calculated the bending stress in the bracket, compared the value to the yield strength of steel, and found that the factor of safety for bending in the bracket is 1.2. The factor of safety is greater than 1, so we do not expect the brackets to fail under normal operating conditions. The hand calculations completed for the angle bracket strength analysis are attached in Figure I-3 in Appendix I.

The last feature we examined is the minimum force required on the end of the sliding table to tip the tabletops. There is a gap between the end of the fixed tabletop and the end of the sliding tabletop in the collaboration configuration. If a person were to sit on the end of the sliding table and counteract the center of gravity of the table, the sliding table could act as a lever arm and cause the end of the table to pivot upwards. We calculated the maximum force the end of the sliding table can withstand without tipping the tabletop and found that the maximum force is 131 pounds. This force is less than the average weight of American adults, so the table will likely tip if someone sits on the end. The maximum force could be increased by reducing the distance between the ends of the two tables, but that distance cannot be altered due to plates. To solve the problem, we plan to install a rotating window latch on the far end of the tables. The latch will link the two tables and ensure that tipping does not occur. The tipping calculation is shown in Figure I-4 in Appendix I.

5.4 Safety, Maintenance, and Repair Considerations

Our final design has limited safety hazards, and ensures accessible, straightforward maintenance. The list of safety hazards can be seen in Appendix E. In summary, the swinging motion of the modesty panel creates a potential pinch point around the hinge. Additionally, the modesty panel is only supported when the modesty panel legs are in place. If the user were to lift the modesty panel without positioning the legs and step into the range of motion of the panel, the modesty panel could swing down onto the user. We plan to mitigate these hazards surrounding the modesty panel with disclaimer stickers warning of pinch points and the dangers of not positioning the modesty panel legs. The table may also collapse when put into a misuse case of too large of a load being placed on the table. The instruction manual shall state the allowed load. The table requires little maintenance besides periodic cleaning. The key maintenance procedures come from replacing components as they fail over time, such as the wheels. Our design allows for easy maintenance by removing the screw holding the wheel in place, replacing the wheel, and inserting the screw back into position.

5.5 Cost Analysis

A summary of the cost analysis is provided in Table 3. The table highlights the cost of the overall subsystems. As seen in the table, most of the cost of the project will be spent in the tabletops and legs. The full cost analysis, including a breakdown of the cost of each component is attached in Appendix J. Appendix J includes hyperlinks to the vendor web pages to purchase the components.

Table 3. Summary of Cost Breakdown

Component	**Cost ($)**
Tabletops	$129
Legs	$390
Plate Assembly	$39
Slider Assembly	$40
Fasteners & Other	$50
Total	$648

5.6 Design Changes

After the Critical Design Review, we made several design changes. The first change we made was to add more structural support under the tabletops. From our detailed analysis in Section 5.3, we determined that the maximum deflection of the MDF tabletop is 1 inch under a 200 pound concentrated load in the center of the table. This deflection exceeds our design requirements, so we chose to implement structural supports to minimize deflection. We added an aluminum C channel to the underside of the fixed table and the modesty panel. On the sliding tabletop, we added ⅛" thick by 1 inch wide aluminum bars to the long edges of the tabletop. We secured all of the aluminum structural supports with screws, as shown in Figure 16.

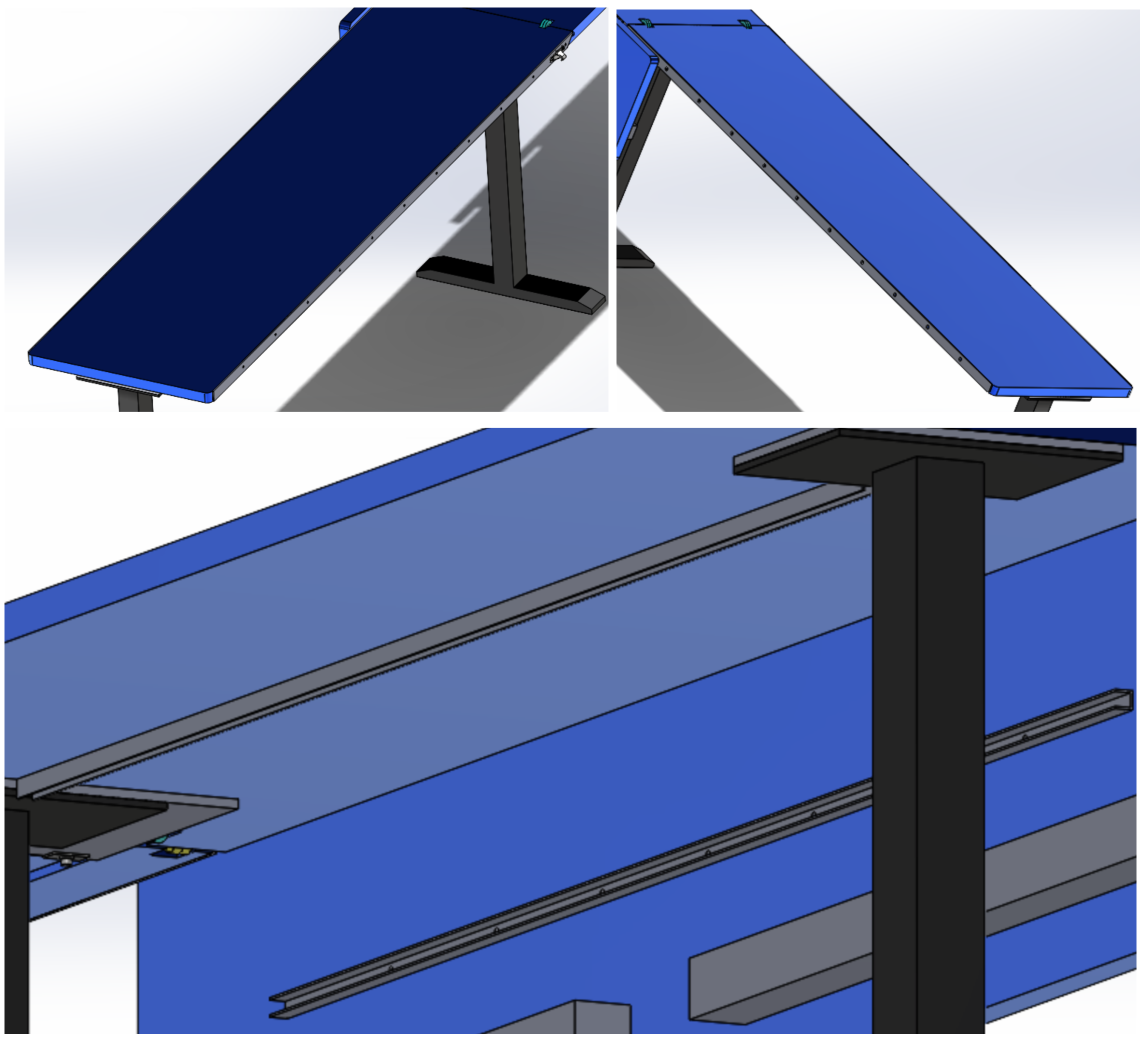


Figure 16. Aluminum Structural Supports

We eliminated the grooves that lock the rollers in place in Figure 14. We chose to leave a two millimeter gap between the tabletops in the collaboration configuration instead of adding a cutout to the fixed tabletop. This did not change table function, reduced a manufacturing step, and allowed us to maintain a uniform surface on the fixed tabletop.

6.0 Manufacturing

We designed the Adapt-Table with the goal of maximizing the number of off-the-shelf components to reduce manufacturing time and cost. We balanced cost with manufacturing time and decided to purchase some components, like the legs, and manufacture others ourselves, like the tabletops. We designed the Adapt-Table to reduce the assembly time for the product consumer once it arrives in a box. With these goals in mind, we created the following plans for part procurement and manufacturing.

6.1 Procurement

The table components are mainly commercial-off-the-shelf (COTS) parts from hardware and online vendors such as Home Depot, Gibraltar, Amazon, and McMaster-Carr. Home Depot is where we will purchase the MDF board for our tabletop and modesty panel, the window latch, and the aluminum structural supports. Gibraltar is the vendor for our table legs. Amazon will provide us the folding legs for our modesty panel. McMaster-Carr will provide us with aluminum plates, angle brackets, spacers, and fasteners. The full cost analysis, including a breakdown of the cost and source of each component is attached in Appendix J. Appendix J includes hyperlinks to the vendor web pages to purchase the components.

6.2 Manufacturing Steps

We purchased many of our components, including three table legs and two folding legs, because our design involves the implementation of standard table components in a novel product. As a result, the majority of our manufacturing steps are modifications to the tabletops.

We manufactured the tabletops from purchased MDF sheets. We purchased a standard ¾" thick sheet and a ¼" sheet and glued them together to create the 1 inch thick tables. We cut the sheets to size using a table saw, as shown in Figure 17. We created the grooves on the bottom surface of the sliding table by cutting thinner strips of the ¼" sheet.

Figure 17. Cutting the Tabletops to Size on the Table Saw

Next, we used a circular saw and a fence to cut the beveled edges, as shown in Figure 18. The beveled edges are located at the interface between the two while in lecture configuration.

Figure 18. Creating the Beveled Edges using the Circular Saw

Next, we used a hand router to create the remaining grooves and cutouts in our tabletops, as shown in Figure 19. We continued the long groove through the beveled edge, added pockets for the rollers on the fixed tabletop, and created cutouts for the angle brackets. We used the band saw to cut the pockets for the fixed tabletop rollers because that is a through feature. We finished the tabletops with a coat of water based industrial paint to improve the aesthetics and durability of the final product.

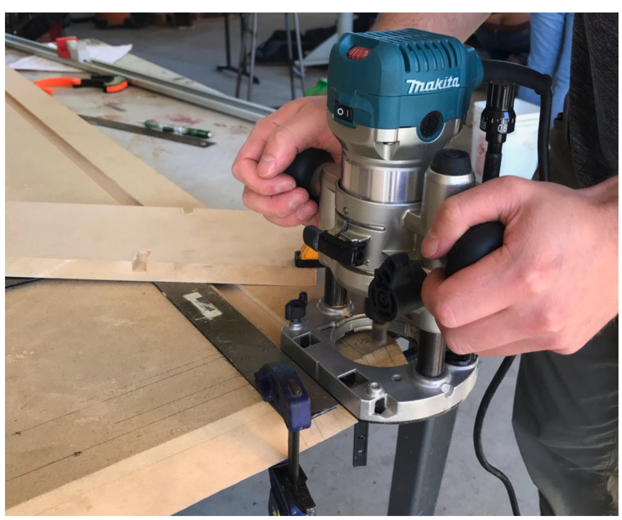


Figure 19. Creating Pockets, Cutouts, and Grooves using the Hand Router

We used a drill press to drill the pilot holes for the wheels. We used particle board screws to mount the wheels. We initially planned to make the wheels using 3D printing. 3D printing would allow us to make minor adjustments to the wheel dimensions on the prototype to meet the tight geometry constraints. We planned to print each wheel in two pieces, joined in the middle. However, we decided to make the wheels out of plastic washers instead to maximize our use of off-the-shelf parts. We purchased aluminum spacers that fit through the center hole of each wheel to protect the plastic from the screw threads.

We finished the tabletops with a painted surface finish. We used an industrial water-based alkyd urethane enamel paint, which is a premium paint formulated with resin to provide high performance, quality appearance, and durability. The professional, high performance paint will withstand wear from frequent use by students and the rolling of the wheels. We prepared the tabletops for paint by lightly sanding, wiping off any dust with a damp rag, and spraying a coat of primer. We applied two coats of paint with a roller, shown in Figure 20, and lightly sanded between coats for the optimal appearance.

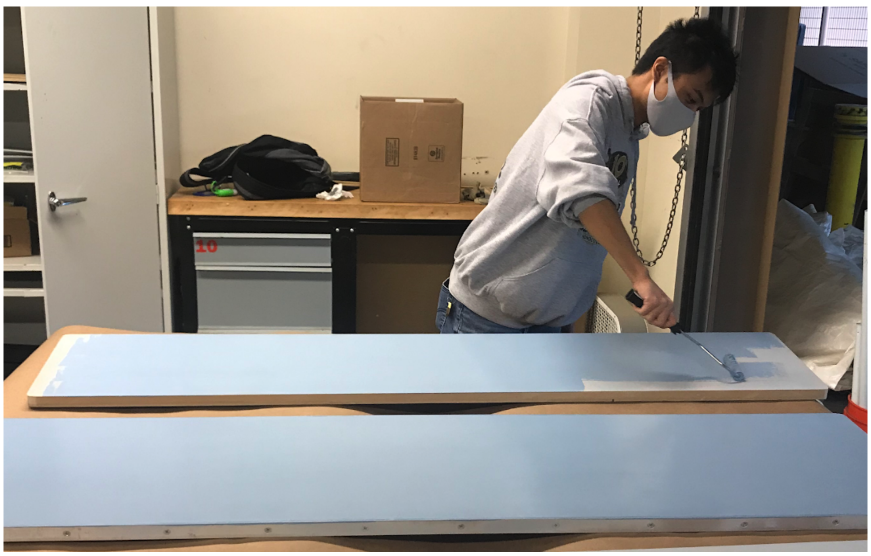


Figure 20. Painting the Tabletops with a Roller

We wrapped the edges of the tabletops with a melamine edge banding. The edge banding has an adhesive backing; we adhered it to the edge of the tabletops using a hot iron, shown in Figure 21. We trimmed the width using a utility knife and sandpaper to get a clean edge.

Figure 21. Adhering the Melamine Edge Banding

There is a plate between the two tabletops that supports the sliding tabletop and prevents the two tops from separating. The purchased plate already had the correct dimensions, so all we had to modify is adding the holes for the angle bracket mount using a drill press. We made the plate out of a 1/4” thick aluminum plate. We manufactured two additional plates that fit under the other two legs to keep all three legs level. We used a drill press on all three plates to match the leg’s existing hole pattern, as shown in Figure 22.

Figure 22. Adding the Hole Pattern to the Leg Spacer Plates using the Drill Press

We also used the drill press to add holes to mount the aluminum structural supports for the tabletops. We used a file to deburr the parts and ensure a close fit with the edge of the tabletop. We drilled countersunk holes in the aluminum bar and aluminum C-channel and mounted the supports with particle board screws.

A list of components categorized by the manufacturing scope is shown in Table 4. In the table, each component is categorized as a purchased/ready-to-install part, a purchased part with some modifications, or a component we manufactured from raw materials.

Table 4. List of Components

Component	Purchased	Modified from Purchase	Made from Raw Materials
Tabletop #1 (long)			X
Tabletop #2 (short)			X
Tabletop #3 (modesty panel)			X
Piano Hinge	X		
Aluminum Support Plate			X
Aluminum Structural Supports			X
Wheels	X		
Axle	X		
T Leg	X		
Folding Post Leg with Bracket	X		
Casters	X		
Latch	X		
Fasteners	X		

6.3 Assembly

In assembling the final product, we used squares, hand drills, clamps, and a tape measure to ensure accurate alignment and dimensions. We first attached the wheels using particle board screws as an axle, then mounted the legs, window latch, modesty panel, and modesty panel legs. Lastly, we lifted the sliding table and fit the fixed wheels into the grooves, then tested the assembled product. The fully assembled product is shown in the lecture configuration in Figure 23 and in the collaboration configuration in Figure 24.

Figure 23. Fully Assembled Prototype in the Lecture Configuration

Figure 24. Fully Assembled Prototype in the Collaboration Configuration

The Operator's Manual in Appendix K includes instructions for proper assembly, use, maintenance, and repair of the Adapt-Table.

6.4 Manufacturing Challenges

We encountered several minor challenges during manufacturing. The first challenge we encountered was cutting the tabletops to length using the table saw in the machine shop. The table was too long for the fence on the table saw in the machine shop, so we used the miter gauge to make those cuts. However, because the tabletop is significantly longer than the relatively short contact surface on the miter gauge, the final tabletop edges were not perfectly parallel.

We encountered a second challenge when mounting the rollers. The holes for the axles were located close to the edge of the tabletop, which resulted in splitting in the MDF when we mounted the screws. We resolved this problem by relocating the holes further from the edge, increasing the pilot hole diameter, and clamping the tabletop together as we secured the screws.

Our largest manufacturing challenge was time. The machine shops on campus opened midway through the quarter with limited hours. We created a schedule to ensure that we stayed on track and completed the project before the deadline, but we had to reduce our scope. We chose to paint the tabletops instead of installing Formica laminate as we planned. Formica is a more durable surface finish than paint, but installing it is a time consuming process. Because of the limited shop hours Fall Quarter and the lack of prototyping during Spring Quarter, we had to allocate more time towards building a functional table mechanism, rather than replicating an industrial laminate finish.

6.5 Recommendations

For future manufacturing, we recommend ordering the tabletops from a professional tabletop manufacturer, rather than completing the tedious steps described above using the table saw, circular saw, and router. Manufacturing the tabletops ourselves was necessary at this stage of the project so we could test the design along the way and make minor design changes as needed. However, as the Adapt-Table is scaled to market, CNC machining from a professional tabletop manufacturer is a much more efficient and economic manufacturing method. The professional manufacturer could use 1 inch MDF, which is a standard table material, but not available at local hardware stores, rather than gluing ¾” and ¼” pieces together. Additionally, tabletop manufacturers have the tools required to properly finish the tabletops with Formica laminate and edge banding in order to provide an aesthetically appealing and durable final product.

7.0 Design Verification

In this section, we will discuss our testing on the verification prototype. These tests will help us evaluate whether the verification prototype meets all of our design specifications. Our complete Design Verification Plan is included in Appendix L and lists all of our planned tests to evaluate the functionality of the verification prototype.

7.1 Component Testing Plan

All of our planned testing will be conducted on the final assembly, rather than individual components. Before we build the verification prototype, we plan to construct a scaled model of some of the components, including the channels along the underside of the table, and the wheel mounts. We will apply a load and validate the strength of the wheels and check the clearance and alignment of the wheels.

7.2 Overall Testing Plan

We plan to conduct our official testing on the assembled verification prototype. Many of our specifications are user based, so we plan to observe how a user who is unfamiliar with the product interacts with the table. We will test the user's ability to move the table around the room by themselves, gather qualitative feedback from the user, and record the time it takes for the user to reconfigure the table from the lecture to collaboration setup. We plan to repeat this user study with at least five individuals and perform a data analysis to determine the average reconfigure time for new users of the product.

In addition to the user analysis, we plan to conduct tests to evaluate the safety and durability of the product. We plan to use the back of a pencil, representing a small finger, to evaluate the presence of pinch points. We will also place a 200 pound load on the table and record the maximum table deflection. We will repeat this measurement at several centralized locations of the 200 pound force to determine the maximum deflection under the design load.

7.3 Testing Results & Conclusions

Because of time constraints due to limited machine shop access during the COVID-19 pandemic, we scaled back our test plan to focus on completing the prototype build. Our test results are summarized in Table 5 below.

Table 5. Design Verification Results

Item No	Spec #	Test Description	Acceptance Criteria	Test Results		
				Test Result	Pass	Fail
1	1	Moving and relocating table	1 person	2 people		X
2	2	Time to reconfigure table	<60 seconds	30 sec	X	
3	3	Pinch point access, check whether pencil fits into pinch area	<10 pinch areas	3 pinch areas	X	
4	4	Table surface area adjustability	2295 in^2	2295 in^2	X	
5	5	Max deflection under a 200 lb load	0.5"	0	X	
6	6	Ratio of Purchased to Manufactured parts	3:1	3:1	X	
7	7	Weight of table	100 lb	~40 lb	X	
8	9	Modesty Panel height	<12 in	12 in	X	
9	10	Cost of table	<$800	$600	X	

We found that it takes 30 seconds to reconfigure the table from the lecture to collaboration configuration and vice versa. However, this time was recorded for someone that is familiar with the product. It is reasonable to expect that someone who has not used the table before might take up to 120 seconds to reconfigure the table on their first use.

We recorded three pinch point areas at the modesty panel hinge, between the sliding and fixed tabletops, and the modesty panel legs. These pinch areas are only concerns while the table is being reconfigured. The user stands with their hands several feet away from the pinch points as they reconfigure the table, so these pinch areas are of minimal concern.

The only test that did not meet our design specification was the movability test. We did not install the casters as planned, so the table currently requires two people lifting the table from either end to move the table across a room. However, if the casters are installed, the table will be able to be moved by one person pushing from a single end and the table will meet all of our design requirements.

8.0 Project Management

The entire design project will be carried out over the course of a year, with each quarter dedicated to a specific step in the engineering design process. Key project deliverables are due throughout each quarter, and design reviews will be conducted to evaluate progress on the project at the end of each quarter. The culmination of the project at the end of the year will be a senior project exposition and final design review, where the final prototype will be presented.

8.1 The Design Process and Deadlines

The design process can be broken down into three quarters (Winter, Spring, and Fall), or 30 weeks, of work. The estimated project completion is November 27, 2020.

<u>Winter Quarter</u>

After the Scope of Work and research phase of the project is completed, our team will perform a benchmark comparison, evaluate the current prototype, and begin concept ideation. We plan to seek out one or more of the competitor products and perform a series of tests on it in order to understand the mechanisms. This will determine the features our design should improve or implement to meet our sponsor's needs. A list of specific criteria and our QFD specifications will be used as the standard to determine the success of the product in meeting our sponsor's needs. The order in which the team will design functions of the table shall follow the ranking of engineering specifications from Table 2. The logic followed is to prioritize parameters n=1 through n=11 and checking whether parameter n's target is met. If parameter n is not met, the team must go back and ensure there are no limiting parameters. The logic for this design process can be seen in the project design flow chart, Figure M-1, in Appendix M.

Concept ideation will consist of using different brainstorming techniques to generate as many solutions to the problem as possible. The list of solutions will be narrowed down to the ones that meet all the project requirements. Of these solutions, a decision matrix will be used to further narrow down the options and we will begin to make small-scale concept prototypes and CAD models.

These design choices will be explained in the Preliminary Design Review (PDR) report and presentation. The presentation and report will provide an overview of the project's purpose and scope; they will also state our overall design direction with justifications and explanations for our design choices. Alternative design concepts that were considered will be mentioned, and any issues with the set design direction will be discussed.

Spring Quarter

The project focus for Spring Quarter will be on completing the design, as Cal Poly transitions to virtual learning. Our team will refine the CAD model, build working prototypes, and perform preliminary testing in order to analyze if the design meets our sponsor's specifications. The focus will be on refining the key mechanisms and adding other auxiliary features such as storage and power connection. The Critical Design Review (CDR) includes the information from the PDR, the complete final design with associated CAD models, and the manufacturing and testing plans.

Fall Quarter

The project focus for Fall Quarter will be on testing the final prototype in a classroom, fine-tuning the final design, and participating in the Senior Project Exposition. We will test our product and determine if it meets the targets from the Engineering Specifications Table. These tests will include weighing, timing reconfiguration, measuring nesting width, cost analysis, and durability tests to ensure our sponsor's needs are met. The Final Design Review (FDR) report documents the entire project process. It includes the information found in the CDR, descriptions of the prototype's manufacturing process, and the results of various testing on the final prototype.

8.2 Special Techniques for Solving the Problem

While our sponsor, Mr. Brennan, already has a significant amount of time put into his multiple prototypes, he has given our team license to explore all possibilities to meet his requirements. We will assess the pros and cons of his current prototypes and the other products already on the market. Then, we will take a step back and start from the most basic version of the problem, outlined in the problem statement. We will use various ideation techniques to find innovative ways to solve the problem. We will likely research other types of products that have similar mechanisms and assess the viability of those mechanisms for our table.

8.3 Gantt Chart and Project Deliverables

Table 6 outlines the major project deliverables and deadlines. The necessary steps to achieve these major deliverables are outlined in the Gantt chart, which is included in Appendix N. The Gantt chart highlights deliverables, key due dates, and project milestones for the year.

Table 6. Project Deliverable and Tentative Schedule

Date	Deliverable
2/3/20	Submit Scope of Work (SOW) to Sponsor
2/27/20	Preliminary Design Review (PDR) Presentation
3/2/20	Submit PDR to Sponsor
4/23/20	Interim Design Review in Lab
5/19/20	Critical Design Review (CDR) Presentation
5/20/20	Submit CDR to Sponsor
6/4/20	Manufacturing and Test Review in Lab
11/19/20	Expo Poster / Final Design Review (FDR)
11/27/20	Senior Project Expo

9.0 Conclusions & Recommendations

This document establishes the goals the Adapt-Table team must meet in order to satisfy the expectations of sponsor Mr. Michael Brennan of Co-Act Furniture. The requirements specifically relate to the table's ability to be reconfigured to allow for collaboration between individuals or lecture-style class setups. The background and initial research provide ideas behind the motive of the creation of an adaptable table as well as similar mechanisms proposed by other patent holders. The concept design section describes the design process used in order to arrive at the current design as well as acknowledge current concerns regarding safety and implementation. The final design section explains how the design works, expands on the manufacturing plan, and breaks down the projected costs.

Beyond the Senior Project class, the next steps for the Adapt-Table are to continue refining the design to bring the table to market. Our team discussed manufacturing with several industrial tabletop manufacturers over the summer, and we discovered that the complex grooves in the current design will be costly to manufacture using CNC machining. We recommend investigating alternative manufacturing methods to reduce tabletop cost. One alternative is constructing the ends of the fixed and sliding tabletops, the sections with the most grooves, out of injection molded or machined plastic. The plastic piece could bolt on to a standard rectangular tabletop and then the entire surface would be covered in laminate to hide the two separate pieces, thereby reducing manufacturing cost without affecting aesthetics.

Engineering design is an iterative process and there are elements of every design that can be improved. For our Adapt-Table prototype, the aspects that could be improved include the sliding motion and the durability. During the sliding motion, if the user angles the sliding table rather than pushing in a straight line, the table sometimes loses alignment. This process could be improved by increasing the depth of the grooves on the bottom of the sliding table or adding a mechanism to maintain table alignment. Another concern with the current prototype is durability. Because of time constraints due to limited machine shop access during the pandemic, we downsized our initial manufacturing scope and decided to paint the tabletops rather than installing laminate. Although we selected a heavy-duty industrial paint, it is still less durable than laminate. As a result, the paint is likely to show scratches and wear from the wheels. While we note these opportunities for improvement, we concluded that our Adapt-Table prototype successfully proves our concept and meets the engineering design intent of expanding the functionality of classroom furniture.

References

ANSI BIFMA X5.5. *American National Standard for Office Furnishings - Desk Products.* 2014.

"Aware." *Allsteel.* https://www.allsteeloffice.com/products/accessories/meeting-support/aware?path=Aware-Training

"Bibliographic Data: CN201894401 (U) — 2011-07-13." *Espacenet*, European Patent Office, worldwide.espacenet.com/publicationDetails/biblio?FT=D&date=20110713&DB=EPODOC&locale=&CC=CN&NR=201894401U.

BIFMA G1. *Ergonomics Guideline for Furniture Used in Office Work Spaces.* 2013.

Burgess, Brigitte, and Kaya, Naz. "Gender Differences in Student Attitude for Seating Layout in College Classrooms.(Report)." College Student Journal 41.4 (2007): 940-946. Web.

"Learning Suite Furniture System." *United States Patent: 9066589*, United States Patent and Trademark Office, 18 Dec. 2014, patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PALL&s1=9066589.PN.

"Mantis." *Boss's Cabin.* https://www.bossescabin.com/wp-content/uploads/2017/10/Mandis-Opt-Use-This.pdf

"Nesting and Folding Table." *Espacenet*, European Patent Office, worldwide.espacenet.com/patent/search/familyworldwide.espacenet.com/patent/search/family/038283302/publication/EP1958537A1?q=pn=EP1958537A1038283302/publication/EP1958537A1?q.

"Nesting Table with Controlled Pivoting Movement." *United States Patent Application: 0050252426*, US Patent and Trademark Office, 17 Nov. 2005, appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&d=PG01&s1=20050252426.PGNR.

"Pirouette." *KI*. https://www.ki.com/products/name/pirouette-table/

Rectangular Activity Table. *Vicro*. https://www.schooloutlet.com/482448_Classroom_Activity_Table_p/482448.htm?gclid=CjwKCAiA1L_xBRA2EiwAgcLKA0PR6XZhSUf8OAL1UpqTHNJYX5PDQPb1dS5FGHnVgLDGe0Mmq3kCoxoC1j0QAvD_BwE&utm_medium=cpc&utm_source=google&back=2&utm_campaign=SHOPPINGLOWKWTEST

"Drop Leaf Support for Tables Without Aprons." *Rockler.* https://www.rockler.com/drop-leaf-support-for-tables-without-aprons

Sommer, Robert. "Classroom Layout." Theory Into Practice 16.3 (1977): 174-75. Web.

"US6845723B2 - Folding and Tilting Table." *Google Patents*, Google, patents.google.com/patent/US6845723B2/en?q=table.

United States, Department of Justice. *ADA Title III Standards for Accessible Design.* United States Dept. of Justice. 2010. Web.

"Verb Classroom Furniture and Whiteboards." *Steelcase.* https://www.steelcase.com/products/conference-classroom-tables/verb/?drawer_main=images&drawer_sub=environments#sustainability_overview

Yang, Zheng, Burcin Becerik-Gerber, and Laura Mino. "A Study on Student Perceptions of Higher Education Classrooms: Impact of Classroom Attributes on Student Satisfaction and Performance." Building and Environment 70 (2013): 171-88. Web.

Appendix A: Interview Notes & Customer Requirements

Interview Notes

<u>Michael Brennan (Sponsor)</u>

- Studied Industrial Technology at Cal Poly, worked with the university for ten years evaluating classroom layouts and updating furniture and technology in the classrooms
    - Noticed as he purchased furniture for the university that collaborative furniture only worked for collaborative classes and lecture furniture only worked for lecture classes
    - Faculty complained about not being able to teach in certain spaces or having to change their teaching style to meet the format of the classroom
- Came up with the idea of the adaptable table while pursuing MBA in entrepreneurship
    - Built a prototype in his garage
    - Needs adjustable height, angle, tabletop size
    - White board
    - A method for power capability would be good, but not necessary
    - Has filed a patent, will share patent application and patent lawyer's report with us
- Potential markets: education, conference centers, workspaces, coffee shops
    - One modular design can be adapted with specific components to meet the need of the space (limit total number of SKUs)
    - Our goal will be to work on the higher education version
- Would like majority of parts to be prefabricated - less manufacturing decreases need for holding stock and parts can be ordered when needed
    - Ship a package of parts and an installer will assemble on site
- Target cost: $800 for labor, materials, and packaging, sell for about $1600

<u>Michele Reynolds (Cal Poly Classroom Organizer)</u>

- Responsible for scheduling classes and classrooms
- Majority of requests are about proximity and movable chairs
- Oftentimes collaborative spaces are round, which limits functionality
- Must have right size room for furniture to not lose seats
- Quickly reconfiguring the space is very important! Professors are told classrooms should be left in lecture setup
- Rooms are used for classes, clubs, and conferences
- 30/2500 requests are for movable desks (not super important)
- White boards
    - Not very many classrooms with whiteboard on all walls currently
    - No movable whiteboards in lecture rooms
    - 3 rooms on campus have smart whiteboards (10-124,125,126) - Leaves residue on board

<u>Dave Norton (Cal Poly Furniture Purchaser)</u>

- Selects and purchases new furniture for Cal Poly classrooms
- Chevron shape is a good layout for large classrooms

- Modern classroom style is a more collaborative feel
- Newer buildings on campus show forward thinking
- Currently no standing height desks in classrooms because the chair doesn't convert to a stool

Adam Melamed (Cal Poly Student)

- Working as a group is often difficult when sitting in a row in classrooms in the business building here at Cal Poly
- Often spends time moving desks out of the way to accommodate for Delta Sigma Pi (Professional Business Fraternity) weekly meetings
- Thought modesty panel table extensions would be great and thought there could be whiteboard marker and eraser storage
- Sees a future where many desks in classrooms are standing desk because people are beginning to understand how our sitting posture is detrimental to health

List of Customer Wants & Needs

Table A-1. List of Customer Wants & Needs

Needs	Wants	Nice to Have (Additional Features)
• Modular tabletop size or shape • Easy to use design • Product rolls and is easily movable while also having the ability to lock in place • Durable design • Safe product with limited pinch points • Nesting capabilities for storage • Maximize number of students per class	• Reduce overall cost (Material cost of ~$800) • Maximize number of purchased (premanufactured) parts over total parts • Minimize total number of parts • Easy to assemble	• Modesty panel • Adjustable height and standing desk capability • Angle adjustability • Vertical white board capability • Storage solutions within product • Sustainably sourced materials • Self-leveling capability • Electrical outlet

Appendix B: Existing Products

Figure B-1. Steelcase Verb Chevron Shape

Figure B-2. KI Pirouette

Figure B-3. Allsteel Aware

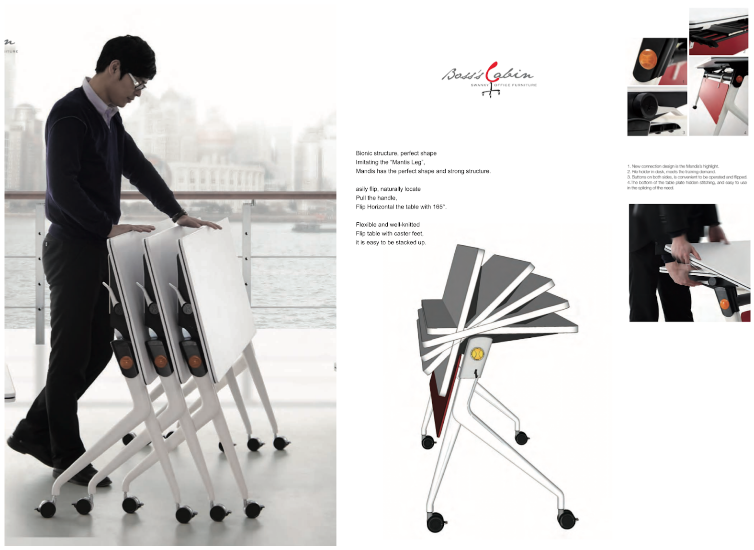


Figure B-4. Boss's Cabin Mantis

Figure B-5. Virco Rectangular Table

Appendix C: Quality Function Deployment

Adaptable Table		Engineering Requirements														Benchmarks		
	Students & Professionals Requirements	Weighting (1 to 5)	Weight	Cost	Table/whiteboard Surface Area	Move by 1 person	Deformation Force	Time to Reconfigure	Quantity of Storage Solutions	Ratio of Purchased to Manufactured	Meets ANSI Safety Standards	Nesting Width	Modesty Panel Height			Steelcase: Verb	KI Pirouette	Standard Rectangular Table
Customer Requirements	Light Weight	2	9													7	7	3
	Movable	5	2			9										9	9	1
	Easy to Configure	4				9		9								9	9	1
	Manufacturable	3								9						7	7	7
	Easily Stored	2				3		5				9				9	9	1
	Low Cost	2		9						2						4	4	9
	Safe	5					2				9					8	8	9
	Durable	3					9									7	7	9
	Size-changing Functionality	5			9	4		9								1	1	1
	Storage Space	2							9							9	1	1
	Self-leveling ability	1				6										1	7	3
	Modesty Panel	2											9			1	9	1
	Units		lb	$	in^2	y/n	lbf	s	#	unitless	y/n	in	in					
	Targets		<50	800	1440	yes	1000	<120	>=1	3:1	yes	<6	>10					
	Steelcase Verb		n/a	1000	828	yes	n/a	<120	0	3:1	yes	3.75	0					
	KI Pirouette		n/a	800	0	yes	n/a	<120	0	3:1	yes	6.04	10.14					
	Importance Scoring		28	18	45	113	37	91	18	31	45	18	18	0	0			
	Importance Rating (%)		25	16	40	100	33	81	16	27	40	16	16	0	0			

Figure C-1 Full QFD

Appendix D: Concept Design

Ideation

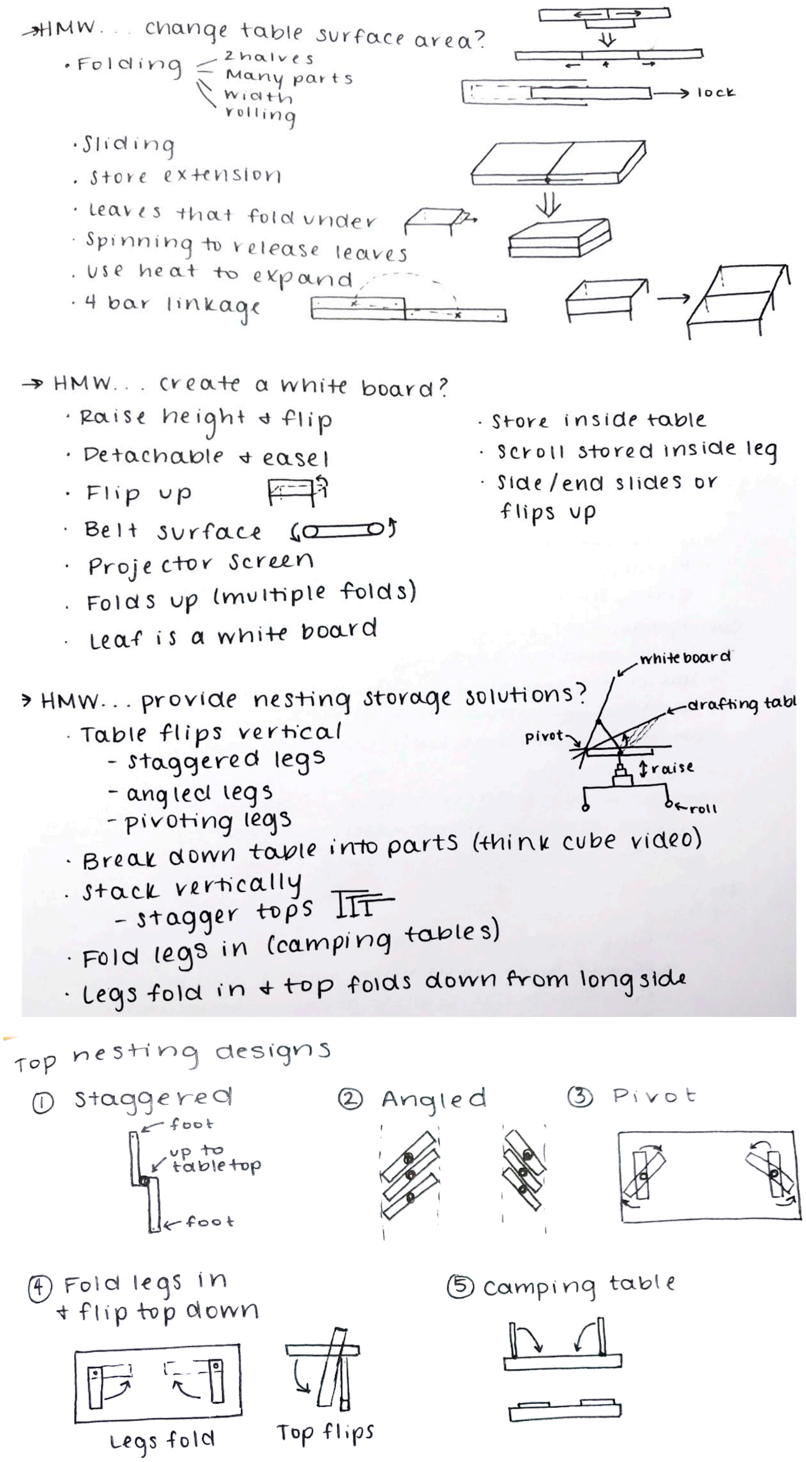


Figure D-1. Ideation Solutions

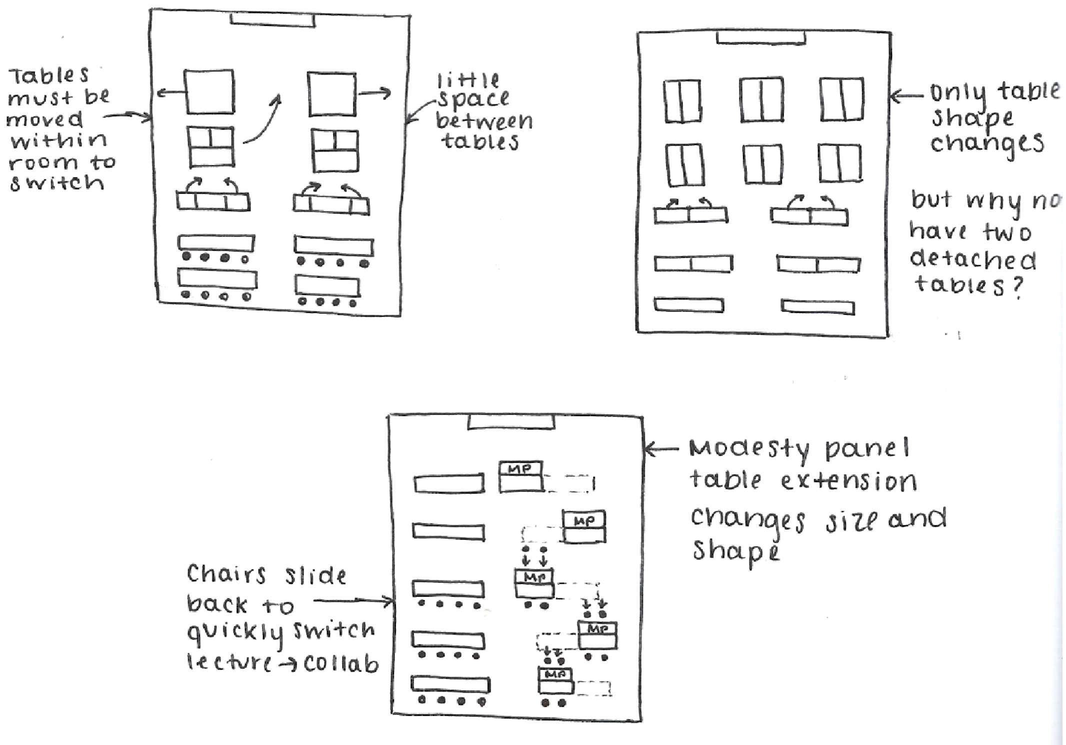


Figure D-2. Classroom Layout Configurations

Concept Models

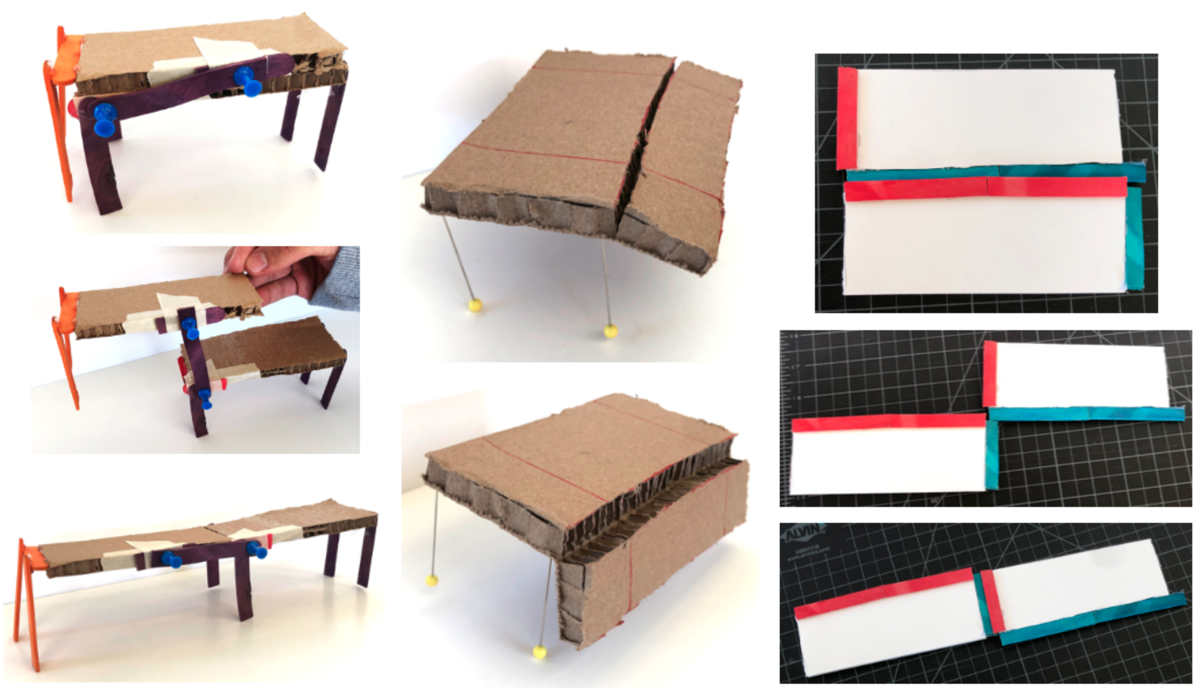
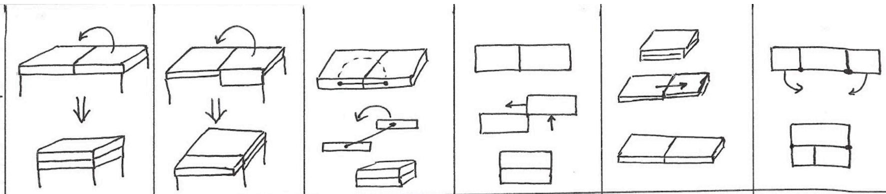


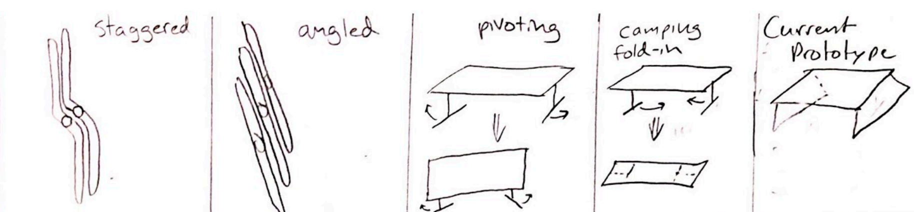
Figure D-3. Concept Models

Pugh Matrices



Criteria \ Concept	Current Design (Hinges)	Hinges with modesty panel extension	4 bar Linkage Pivot	One section slides and reattaches	Sliding extension	Two sections swivel and reattach
Easy to use		S	−	+	S	+
Durable	D	S	−	+	−	+
Limited Pinch Points	A	S	−	+	+	+
Maximize # students	T	+	S	+	S	+
Modular tabletop size or shape	U	S	S	S	S	S
Meets lecture needs	M	S	S	S	S	S
Meets collab needs		+	S	+	S	+

Figure D-4. Pugh Matrix for Tabletop Solutions



Criteria \ Concept	staggered	angled	pivoting	camping fold-in	Current Prototype
Light weight	+	+	+	+	D
movable	S	S	S	S	A
durable	S	S	−	−	T
safe	S	S	−	−	U
easy to use	+	+	S	-	M
low cost	−	−	−	−	
storage space	+	+	+	+	
Sum	3+ 1- 3S	3+ 1- 3S	2+ 3- 2S	2+ 4- 1S	

Figure D-5. Pugh Matrix for Nesting Solutions

Weighted Decision Matrix

Engineering Specifications		Movable	Reconfigure Time	Safe to Use	Deformation Force	Tabletop Shape Adjustability	Ratio of Purchased to Manufactured Parts	Weight	Nesting Width	Modesty Panel Height	Cost	Tabletop Surface Area Adjustability	**Total**
Weighting (1-5)		5	5	4	4	3	3	2	2	1	1	1	
Tabletops	**Legs**												
Modesty panel hinge	Staggered	3	3	1	3	4	5	1	2	5	4	5	93
Modesty panel hinge	Angled	3	3	1	3	4	5	1	5	5	4	5	99
Modesty panel slide	Staggered	3	5	5	3	4	3	1	2	5	2	5	111
Modesty panel slide	Angled	3	5	5	3	4	3	1	5	5	2	5	117
Two way slide	Staggered	3	3	4	3	4	3	5	1	0	1	1	93
Two way slide	Angled	3	3	4	3	4	3	5	3	0	1	1	97
Three section rotation	Staggered	3	4	3	3	5	5	5	1	0	5	1	107
Three section rotation	Angled	3	4	3	3	5	5	5	3	0	5	1	111

Figure D-6. Weighted Decision Matrix

Concept Prototype

Figure D-7. Concept Prototype for Proposed Modesty Panel Support

Appendix E: Design Hazard Checklist

Table E-1. Design Hazard Checklist

Y	N	
X		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	X	2. Can any part of the design undergo high accelerations/decelerations?
X		3. Will the system have any large moving masses or large forces?
	X	4. Will the system produce a projectile?
X		5. Would it be possible for the system to fall under gravity creating injury?
	X	6. Will a user be exposed to overhanging weights as part of the design?
	X	7. Will the system have any sharp edges?
	X	8. Will any part of the electrical systems not be grounded?
	X	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	X	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	X	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	X	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	X	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	X	14. Can the system generate high levels of noise?
	X	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
X		16. Is it possible for the system to be used in an unsafe manner?
	X	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:

(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

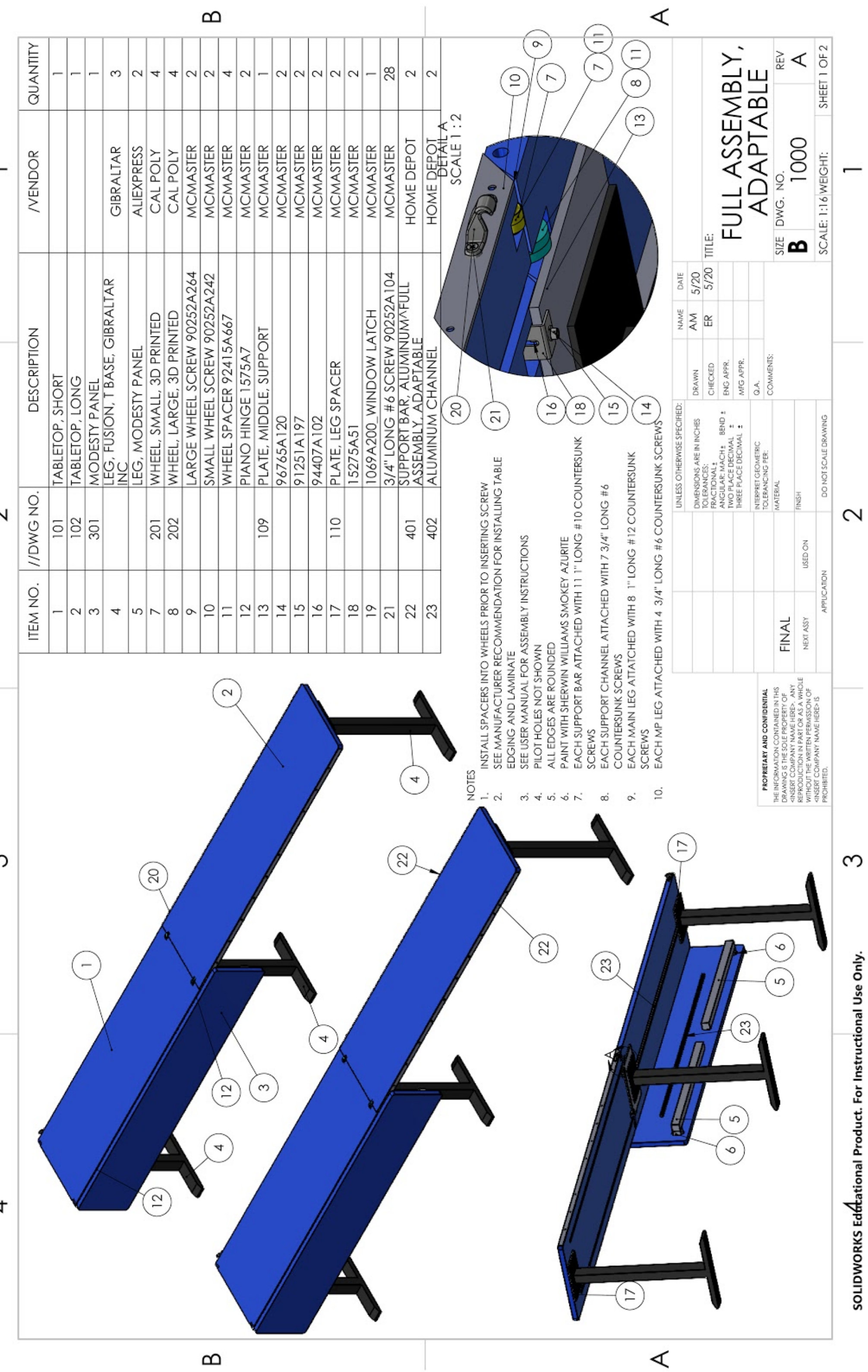
Table E-2. Planned Corrective Actions for Design Hazard Checklist

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Swinging motion of modesty panel on hinge connected to table top exposes user to potential pinch point.	The product user manual shall contain a disclaimer and warning about the potential pinch point. The physical table, when put into sale, shall also include stickers clearly marking the hinges as pinch points and to avoid sticking fingers into there when folding the modesty panel.	10-24-20	
The larger of the two table tops slides along a line. The weight of the table in conjunction with its legs can be deemed to be relatively substantial and may result in injury of a user should someone push the tabletop aggressively when swapping from collaboration to lecture mode.	The product user manual will state misuse cases such as shoving the table with excessive force. The rollers on the table shall also include high friction materials in order to increase the resistive friction force. The rollers may also incorporate thick lube in the bearings in order to increase the force needed to induce motion.	10-24-20	
When setting the table up for collaboration configuration, the modesty panel is only supported once the legs for the modesty panel are lowered. Meaning that the modesty panel may swing down onto a user if they were to go in the panel's range of motion before putting the modesty panel legs into position.	The product user manual shall include warnings about the swinging motion of the modesty panel. The user is not to go within the swinging range of motion of the modesty panel until the legs of the modesty panel are lowered, or if attempting to lower the modesty panel, until the panel is resting against the shorter table top (right tabletop).	10-24-20	
The system may potentially collapse when subject to a large enough weight such as putting bricks on the table or having too many people sitting on the table.	The product user manual shall display max load for a factor of safety 2. Based on finite element analysis for max load cases and misuse cases. The user manual shall also discuss what NOT to do with the table (ex. Stand on the table.)	10-24-20	

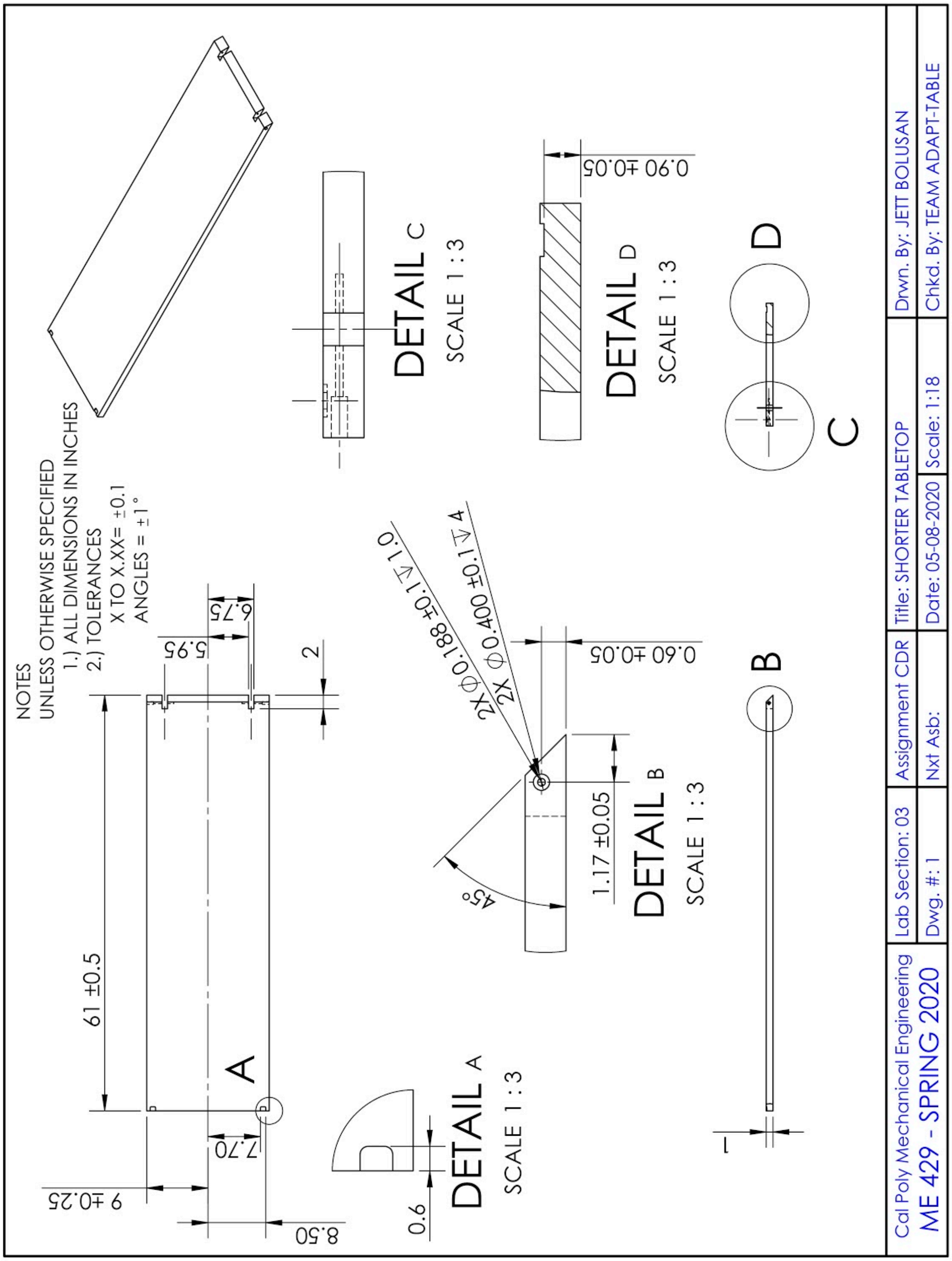
Appendix F: Indented Bill of Materials

	Part #	Description				Vendor	Qty	Cost	Total Cost
		Lvl0	Lvl1	Lvl2	Lvl3				
0	1000	Final Assy				------			
1	100		Table Assembly			------			
2	101			Fixed Tabletop		Home Depot	1	60	60
2	102			Sliding Tabletop		Home Depot	1	0	0
2	103			Fixed Tabletop Structural Support		Home Depot	2	15.73	31.46
2	104			Sliding Tabletop Structural Support		Home Depot	1	12.51	12.51
2	105			Paint		Sherwin-Williams	1	30	30
2	106			Table Edging		Home Depot	2	10	20
2	107			T-Leg		Gibraltar	3	60	180
2	108			Caster		Amazon	6	4	24
2	109			Latch		Home Depot	1	3.21	3.21
2	110			Plate Assembly		------			0
3	111				Support Plate	McMaster	1	18.66	18.66
3	112				Leg Spacer Plate	McMaster	1	18.66	18.66
3	113				Angle Bracket	McMaster	2	0.70	1.40
3	114				Fasteners	Home Depot	1	0.5	0.5
1	200		Sliding Assembly			------			0
2	201			Sliding Wheel		McMaster	2	0.70	1.40
2	202			Fixed Wheel		McMaster	12	0.56	6.72
2	203			Axle Assembly		------			0
3	204				Wood Screw	Home Depot	4	0.25	1
3	205				Small Spacer	McMaster	2	2.32	4.64
3	206				Large Spacer	McMaster	2	3.86	7.72
1	300		Modesty Panel Assembly			------			0
2	301			Modesty Panel Tabletop		Home Depot	1	0	0
2	302			Piano Hinge (1')		McMaster	3	3.46	10.38
2	303			Post Leg		AliExpress	2	30.22	60.44
2	304			Modesty Panel Structural Support		Home Depot	1	12.51	12.51
2	305			Fasteners (piano hinge)		Home Depot	24	0.015	0.36
1	900		Miscellaneous Fasteners			McMaster	20	0.1	2
							80		**507.57**

Appendix G: Drawing Package



ITEM NO.	//DWG NO.	DESCRIPTION	/VENDOR	QUANTITY
1	101	TABLETOP, SHORT		1
2	102	TABLETOP, LONG		1
3	301	MODESTY PANEL		1
4		LEG, FUSION, T BASE, GIBRALTAR INC	GIBRALTAR	3
5		LEG, MODESTY PANEL	ALIEXPRESS	2
7	201	WHEEL, SMALL, 3D PRINTED	CAL POLY	4
8	202	WHEEL, LARGE, 3D PRINTED	CAL POLY	4
9		LARGE WHEEL SCREW 90252A264	MCMASTER	2
10		SMALL WHEEL SCREW 90252A242	MCMASTER	2
11		WHEEL SPACER 92415A667	MCMASTER	4
12		PIANO HINGE 1575A7	MCMASTER	2
13	109	PLATE, MIDDLE, SUPPORT	MCMASTER	1
14		96765A120	MCMASTER	2
15		91251A197	MCMASTER	2
16		94407A102	MCMASTER	2
17	110	PLATE, LEG SPACER	MCMASTER	2
18		15275A51	MCMASTER	2
19		1069A200_WINDOW LATCH	MCMASTER	1
21		3/4" LONG #6 SCREW 90252A104	MCMASTER	28
22	401	SUPPORT BAR, ALUMINUM^FULL ASSEMBLY, ADAPTABLE	HOME DEPOT	2
23	402	ALUMINUM CHANNEL	HOME DEPOT	2



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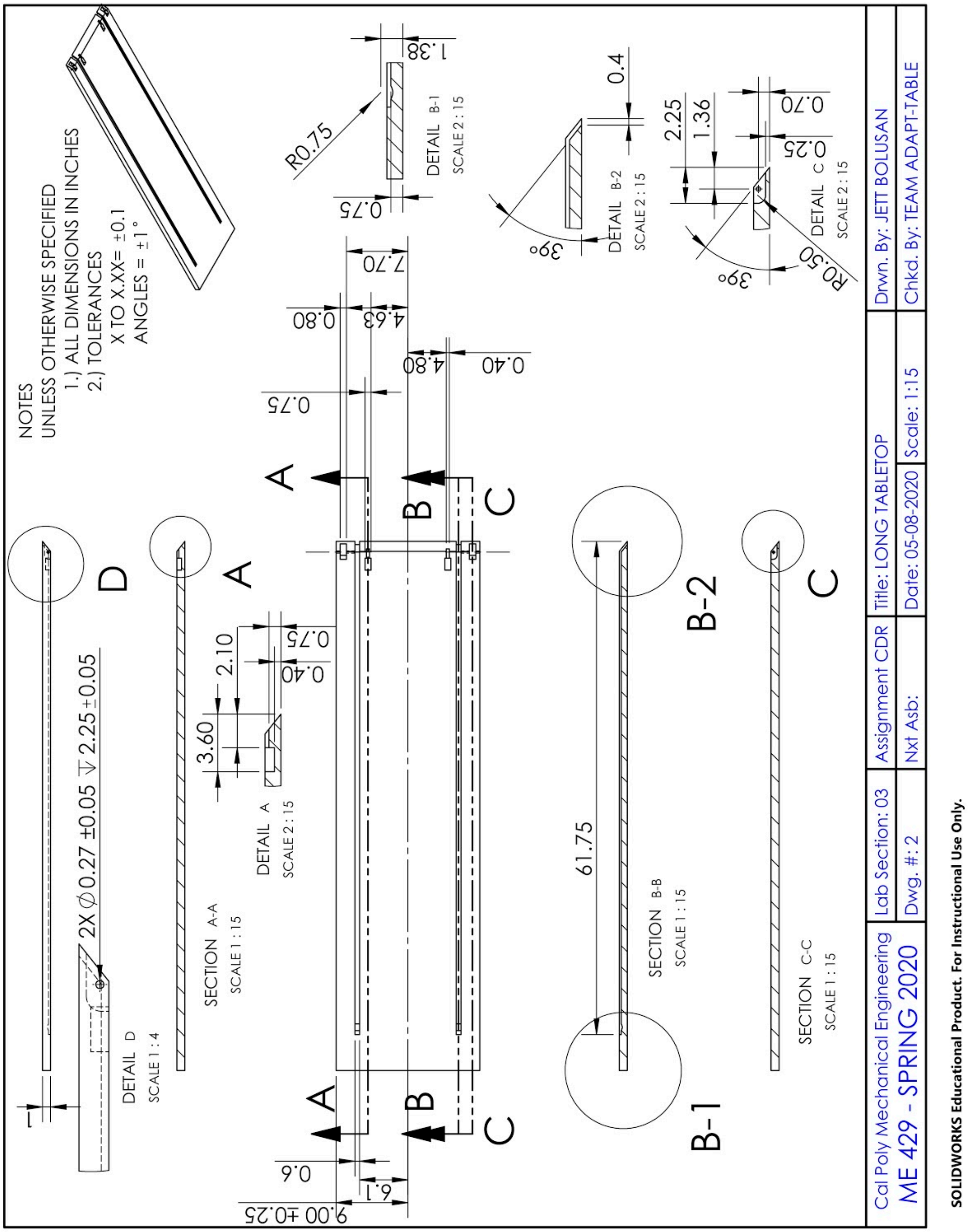
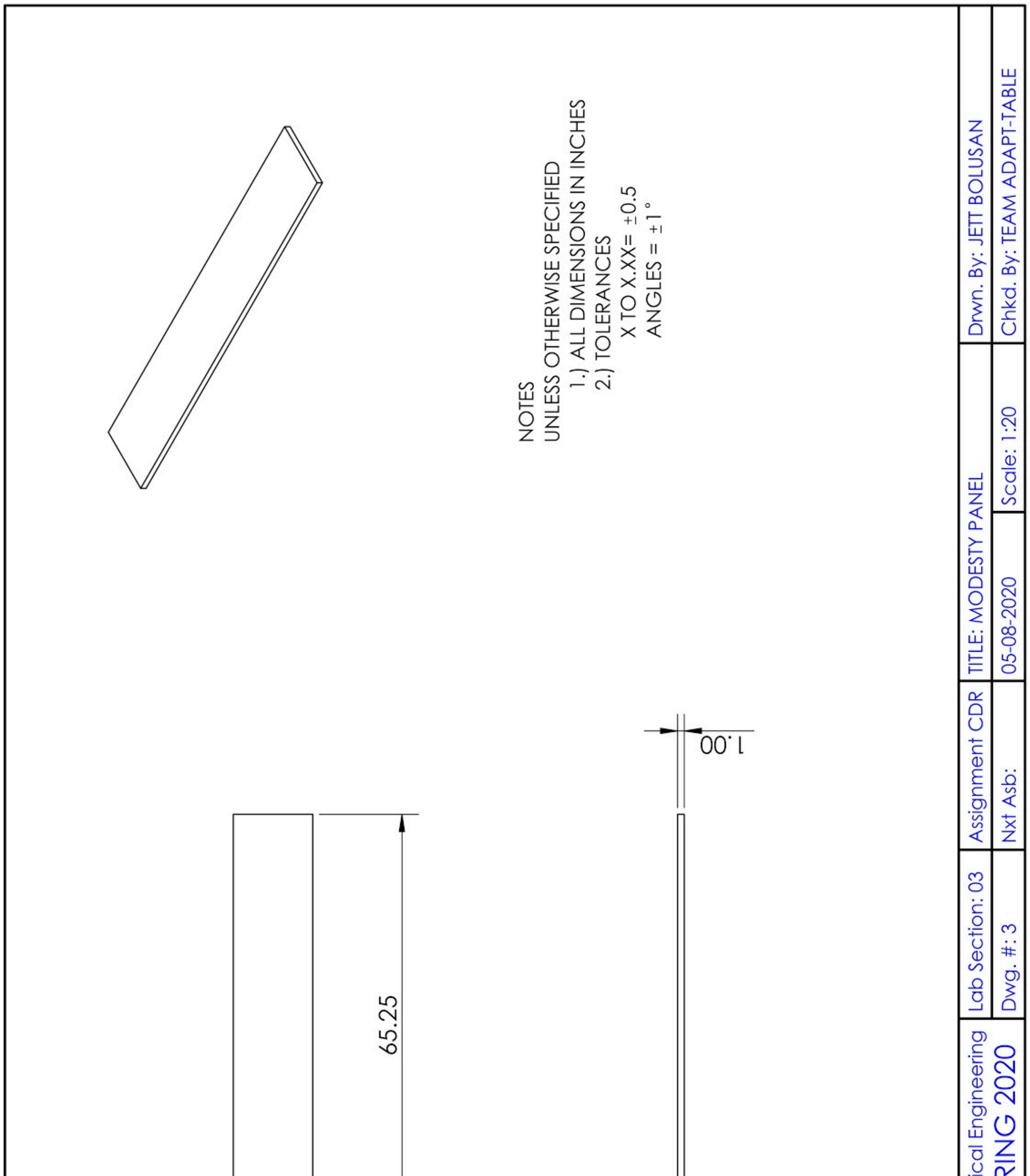
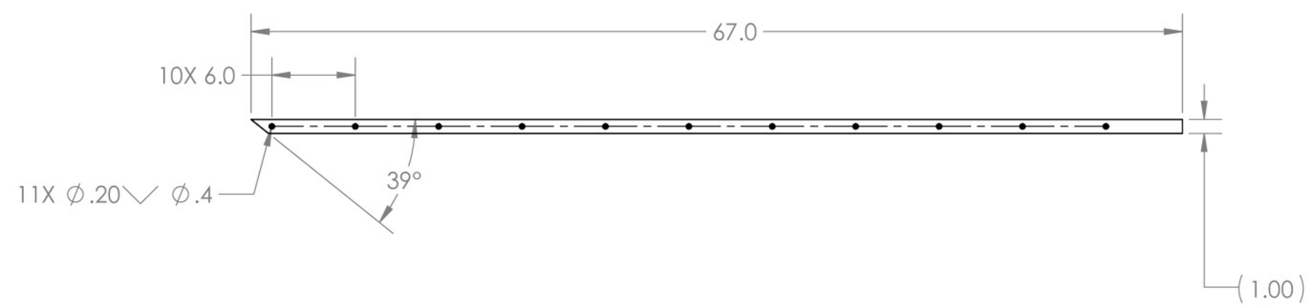

NOTES
UNLESS OTHERWISE SPECIFIED
1.) ALL DIMENSIONS IN INCHES
2.) TOLERANCES
X TO X.XX= ±0.1
ANGLES = ±1°
2X ⌀0.27 ±0.05 ↧ 2.25 ±0.05
DETAIL D
SCALE 1 : 4
SECTION A-A
SCALE 1 : 15
DETAIL A
SCALE 2 : 15
SECTION B-B
SCALE 1 : 15
SECTION C-C
SCALE 1 : 15
DETAIL B-1
SCALE 2 : 15
DETAIL B-2
SCALE 2 : 15
DETAIL C
SCALE 2 : 15
R0.75
R0.50
39°
61.75
9.00 ±0.25
Cal Poly Mechanical Engineering
ME 429 - SPRING 2020
Lab Section: 03
Dwg. #: 2
Assignment CDR
Nxt Asb:
Title: LONG TABLETOP
Date: 05-08-2020
Scale: 1:15
Drwn. By: JETT BOLUSAN
Chkd. By: TEAM ADAPT-TABLE
SOLIDWORKS Educational Product. For Instructional Use Only.


12.00
65.25
1.00
NOTES
UNLESS OTHERWISE SPECIFIED
1.) ALL DIMENSIONS IN INCHES
2.) TOLERANCES
X TO X.XX= ±0.5
ANGLES = ±1°
Cal Poly Mechanical Engineering
ME 429 - SPRING 2020
Lab Section: 03
Dwg. #: 3
Assignment CDR
Nxt Asb:
TITLE: MODESTY PANEL
05-08-2020
Scale: 1:20
Drwn. By: JETT BOLUSAN
Chkd. By: TEAM ADAPT-TABLE



NOTE:
1. USE 96" LONG, 1" WIDE, 1/8" THICK ALUMINUM BAR
2. DEBURR ALL EDGES

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APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	A. MCC	11/29/20
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

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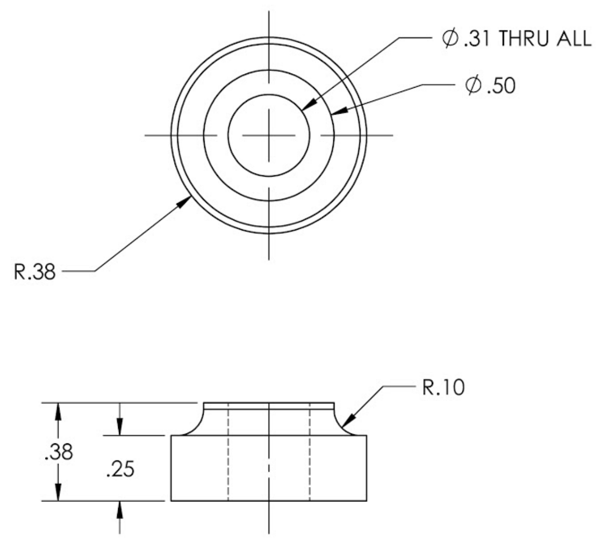
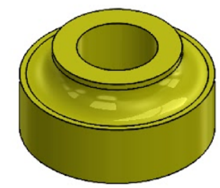
SUPPORT BAR, ALUMINUM

SIZE A | DWG. NO. 401 | REV

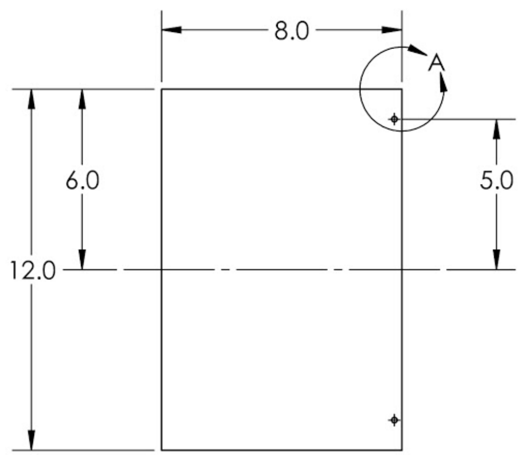
SCALE: 1:10 | WEIGHT: | SHEET 1 OF 1

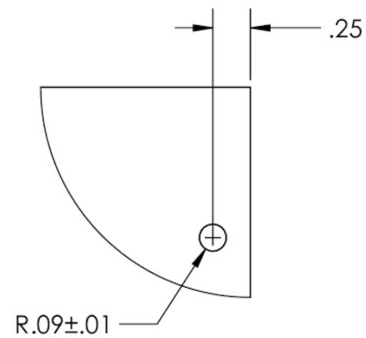




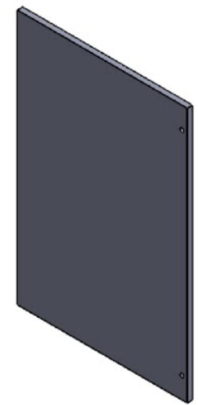
NOTES
UNLESS OTHERWISE SPECIFIED
1.) ALL DIMENSIONS IN INCHES
2.) TOLERANCES
X TO X.XX= ±0.01
ANGLES = ±1°
3.) 3D PRINT WITH ABS OR USE INJECTION MOLD WITH DELRIN.
4.) OPTION 2: USE MCMASTER P/N 92825A203

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment CDR	Title: SMALL 3D PRINT WHEEL		Drwn. By: JETT BOLUSAN
ME 429 - SPRING 2020	Dwg. #: 201	Nxt Asb: 1000	Date: 05-08-2020	Scale: 2:1	Chkd. By: AARON MCCALLISTER



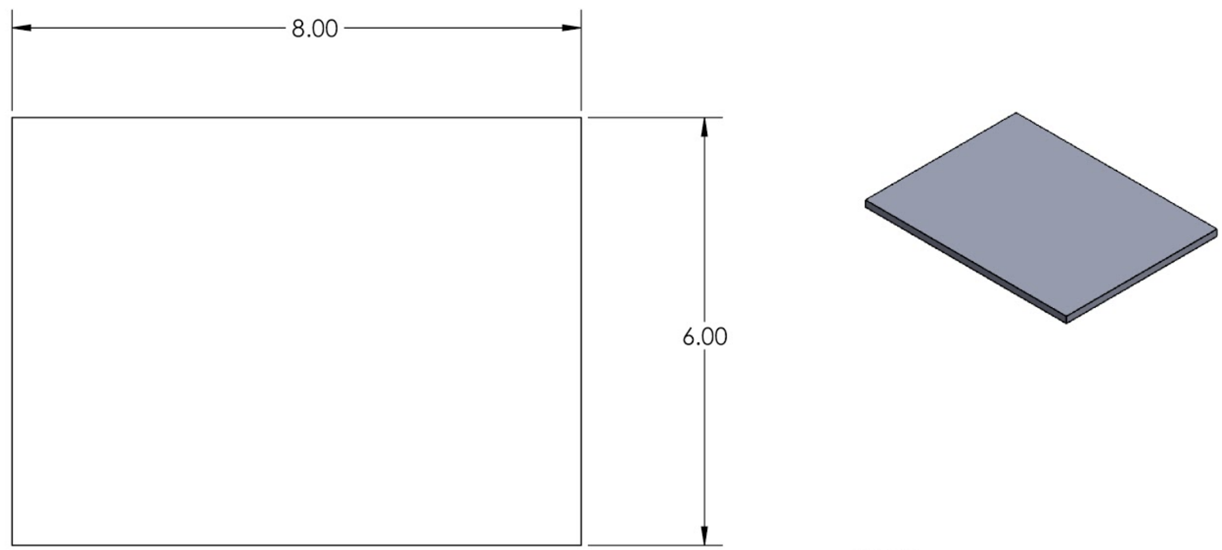


DETAIL A
SCALE 1 : 1



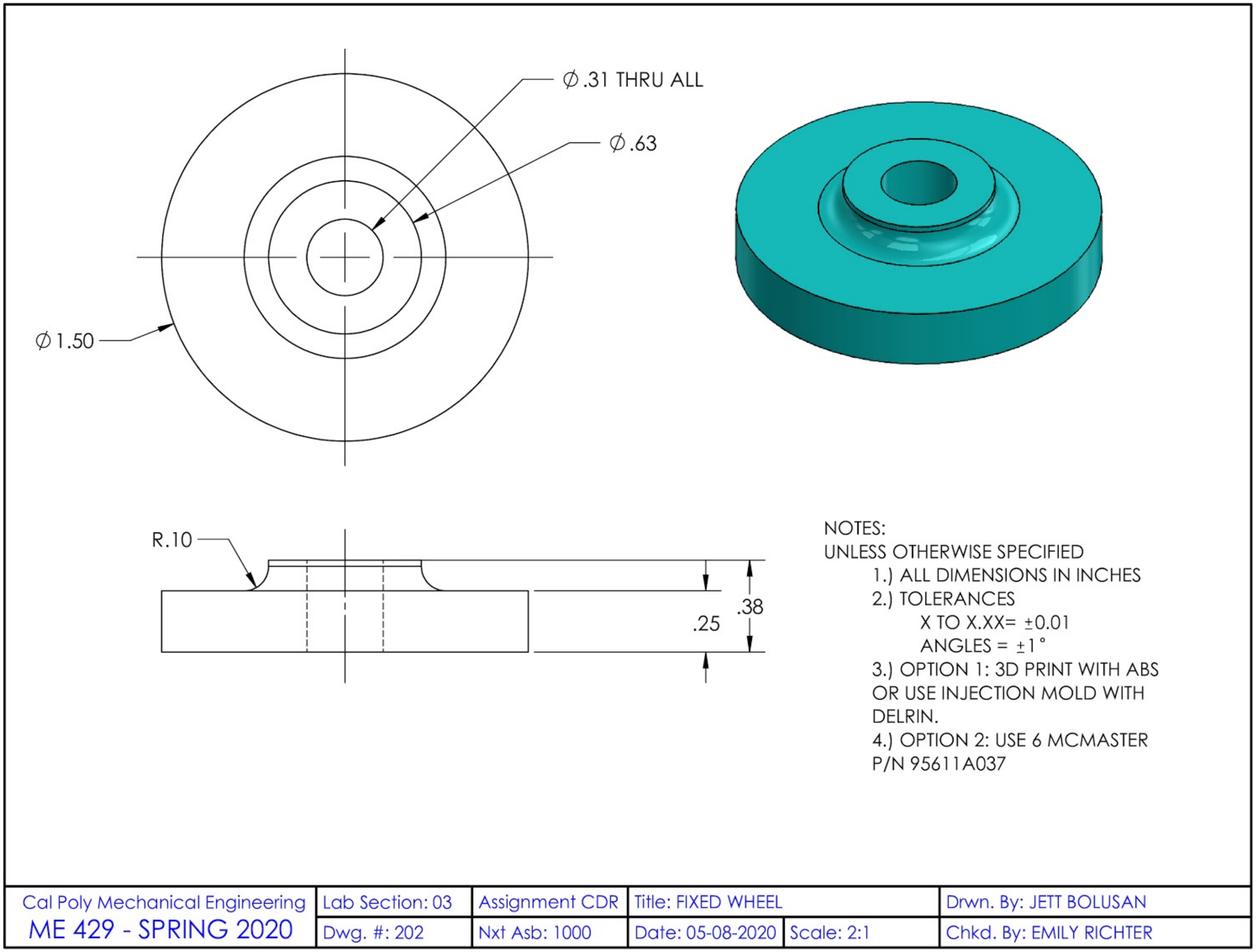
NOTES:
UNLESS OTHERWISE SPECIFIED
1.) ALL DIMENSIONS IN INCHES
2.) TOLERANCES
X TO X.XX= ±0.1
ANGLES = ±1°
3.) 6061 ALUMINUM PLATE, 0.25 THK
4.) USE GIBRALTAR LEG HOLE PATTERN WITH LONG SIDE OF LEG PLATE ALIGNED WITH EDGE OPPOSITE OF BRACKET HOLES AND CENTERED BETWEEN HOLES

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment CDR	Title: SUPPORT PLATE		Drwn. By: JETT BOLUSAN
ME 429 - SPRING 2020	Dwg. #: 109	Nxt Asb: 1000	Date: 05-08-2020	Scale: 1:5	Chkd. By: EMILY RICHTER

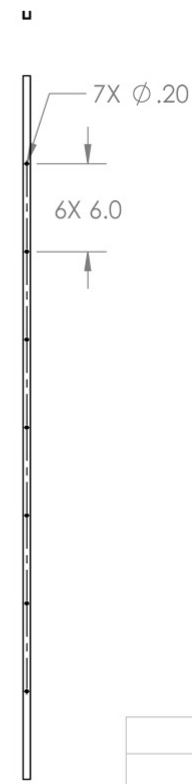


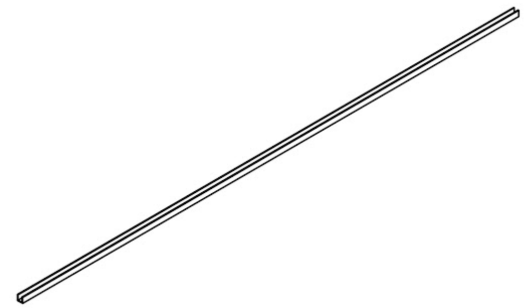
NOTES:
UNLESS OTHERWISE SPECIFIED
1.) ALL DIMENSIONS IN INCHES
2.) TOLERANCES
X TO X.XX= ±0.1
ANGLES = ±1°
3.) 6061 ALUMINUM PLATE, 0.25 THK
4.) USE GIBRALTAR LEG HOLE PATTERN WITH LONG SIDE OF LEG PLATE ALIGNED WITH EDGE OPPOSITE OF BRACKET HOLES AND CENTERED BETWEEN HOLES

Cal Poly Mechanical Engineering	Lab Section: 03	Assignment CDR	Title: LEG SPACER PLATE		Drwn. By: JETT BOLUSAN
ME 429 - SPRING 2020	Dwg. #: 110	Nxt Asb: 1000	Date: 05-08-2020	Scale: 1:2	Chkd. By: EMILY RICHTER



SOLIDWORKS Educational Product. For Instructional Use Only.





NOTE:
1. USE 48" LONG, 1/2" WIDE, 1/2" TALL, 1/16" THICK ALUMINUM CHANNEL
2. DEBURR ALL EDGES

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	A. MCC	11/29/20	TITLE: ALUMINUM CHANNEL
	CHECKED			
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A	DWG. NO. 402	REV
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10	WEIGHT:	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

Appendix H: Failure Modes & Effects Analysis

Table H-1. Failure Modes & Effects Analysis

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date
Tabletop / Provide a stable working surface	Tabletop is soft or rough	Pencil penetrates paper; Difficult to write on surface	7	Rough surface finish; inadequate material hardness	Smooth surfaces; Evaluate and test materials prior to building; Use industry standard materials	1	Test writing on surface	1	7		
Tabletop / Reconfigure surface area	tabletops are difficult to reconfigure	Rollers scratch table; slider binds; difficult to reconfigure table	6	Rollers are too hard for tabletop material; sliding system binds	use plastic rollers; use engineering analysis to evaluate durability over time; use standard industry materials	5	Customer clinic	4	120	Evaluate hardness of rollers and tabletops	Emily; 4/10/20
Modesty Panel / Expands table Surface Area	Too large of a seam that it hinders work; Seam is in a position that it hinders writing; Panel does not lock in the tabletop position	Things fall through gap/seam; Paper lies on top of seam making it difficult to write; Surface area does not increase	5	Hinge is too large; Panel is too small; Panel support hinge does not lock or support enough load	Use a smaller hinge or design to hide the hinge; Sizing is determined based on standard filler paper size; Get a large enough support hinge or put multiple support hinges	2	Measure how large the gap is and determine if common work objects fall in it; Test different paper positions to see if paper is on top of the seam and if the seam is too large to write comfortably over; Test misuse cases and/or calculate loads on the hinge and support beams	4	40		
Modesty Panel / Covers Upper Legs of User	Does not effectively cover the parts of the user that should be hidden for privacy reasons	User feels uncomfortable during use depending on attire	5	Panel is too small	Sizing is determined based on standard filler paper size and standard modesty panel dimensions	1	Sit across from the panel and see if things that should not be visible are visible	1	5		
Sliding System / Expands Surface Area	Mechanism doesn't allow table to lift and slide	Tables do not slide over each other	8	Both sides of table don't lift together; sliding rail has high friction	Design robust sliding mechanism	5	Customer clinic	4	160	Build a prototype of mechanism and adjust as necessary; multiple customer clinics	Jett; 4/22/20
Sliding System / Maintain Table Alignment	Sliding rail binds up	Sliding rail gets stuck or breaks	7	Lack of sufficient alignment mechanisms	Design in other slider/wheel for alignment	6	Customer clinic	4	168	Ensure design maintains vertical and horizontal alignment	Aaron; 4/20/20
General / Hold parts together	Joints separate	Parts disconnect from table	9	Hardware strips or shears	Use robust hardware/gussets	2	Measure play in joints	5	90		
Leg system / support all other systems	Lack of leg stability	Table collapses	9	Connection between leg and table is loose or weak	Use robust hardware/gussets	2	Measure angle of legs under abnormal use	3	54		
Leg system / minimizes space to store	Third leg doesn't fold in	Table requires more space for storage	4	Hinge gets stuck	Use robust hinge	5	Test hinge under worst working conditions	6	120	Test repetitive use	Jett; 5/17/20
Leg system / Eases transport	Casters break or get stuck	Table cannot slide on floor	4	Object gets stuck in caster	Use proven casters	5	Roll casters over a variety of objects	3	60		

Appendix I: Detailed Analysis

Strength of MDF Tabletop Analysis

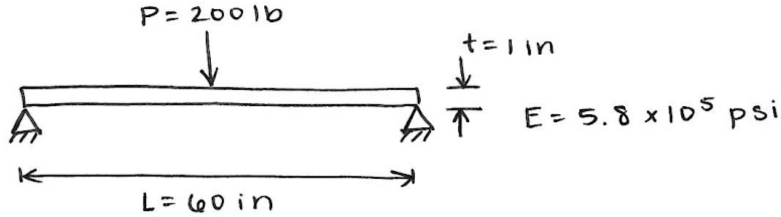


Table Stress

$$I = \frac{1}{12} bh^3 = \frac{1}{12}(18\ in)(1\ in)^3 = 1.5\ in^4$$

$$M_{max} = \frac{PL}{4} = \frac{(200\ lb)(60\ in)}{4} = 3000\ lb \cdot in$$

$$y = \frac{t}{2} = 0.5\ in \quad \text{(farthest distance from centroid)}$$

$$\sigma = \frac{My}{I} = \frac{(3000\ lb \cdot in)(0.5\ in)}{1.5\ in^4} = 1000\ psi$$

$$S_y = 2.6 \times 10^3\ psi \quad \text{(yield stress of MDF)}$$

$$\eta = \frac{S_y}{\sigma} = \frac{2.6 \times 10^3\ psi}{1000\ psi}$$

$$\eta = 2.6 \longrightarrow \text{factor of safety}$$

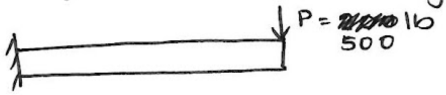
Table Max Deflection

$$\delta_{max} = -\frac{PL^3}{48EI} = -\frac{(200\ lb)(60\ in)^3}{48(5.802 \times 10^5\ psi)(1.5\ in^4)}$$

$$\delta_{max} = 1.03\ in \longleftarrow \text{max deflection of tabletop}$$

Figure I-1. Tabletop Deflection Analysis

Strength of Plate Analysis



$E = 10{,}000\,\text{ksi}$

$t = 0.25\,\text{in}$

$L = 1\,\text{in}$

$w = 12\,\text{in}$

treat as a cantilever beam

Plate Stress

$$I = \frac{1}{12}bh^3 = \frac{1}{12}(12\,\text{in})(0.25\,\text{in})^3 = 0.0156\,\text{in}^4$$

$$M_{max} = (500\,\text{lb})(1\,\text{in}) = 500\,\text{in}\cdot\text{lb}$$

$$y = \frac{1}{2}t = \frac{1}{2}(0.25\,\text{in}) = 0.125\,\text{in}$$

$$\sigma = \frac{My}{I} = \frac{(500\,\text{in-lb})(0.125\,\text{in})}{0.0156\,\text{in}^4} = 4000\,\text{psi}$$

$$\eta = \frac{S_y}{\sigma} = \frac{40030\,\text{psi}}{4000\,\text{psi}} = 10$$

$\eta = 10 \rightarrow$ factor of safety for bending

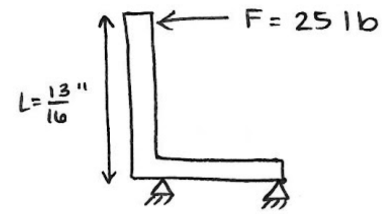
Plate deflection

$$\delta_{max} = \frac{PL^3}{3EI} = \frac{(500\,\text{lb})(1\,\text{in})^3}{3(10\times10^6\,\text{psi})(0.0156\,\text{in}^4)}$$

$\delta_{max} = 0.00107\,\text{in} \leftarrow$ max deflection of plate

Figure I-2. Plate Deflection Analysis

Strength of Angle bracket Analysis



$t = 0.06$ in

$W_{min} = 1'' - 0.18'' = 0.82''$

$E = 29 \times 10^6$ psi

Bracket stress

$$M = (25\ lb)(\tfrac{13}{16}\ in) = 20.3\ in\text{-}lb$$

$$y = \tfrac{1}{2}t = \tfrac{1}{2}(0.06\ in) = 0.03\ in$$

$$I = \tfrac{1}{12}bh^3 = \tfrac{1}{12}(0.82\ in)(0.06\ in)^3 = 1.476 \times 10^{-5}\ in^4$$

$$\sigma = \frac{My}{I} = \frac{(20.3\ in\text{-}lb)(0.03\ in)}{(1.476 \times 10^{-5}\ in^4)} = 41260\ psi$$

$$S_y = 50700\ psi$$

$$\eta = \frac{S_y}{\sigma} = \frac{50700\ psi}{41260\ psi}$$

$\eta = 1.2$ ← factor of safety for bending

Bracket deflection

$$\delta_{max} = \frac{PL^3}{3EI} = \frac{(25\ lb)(\tfrac{13}{16}\ in)^3}{3(29 \times 10^6\ psi)(1.476 \times 10^{-5}\ in^4)}$$

$\delta_{max} = 0.01$ in ← max deflection of bracket

Figure I-3. Angle Bracket Deflection Analysis

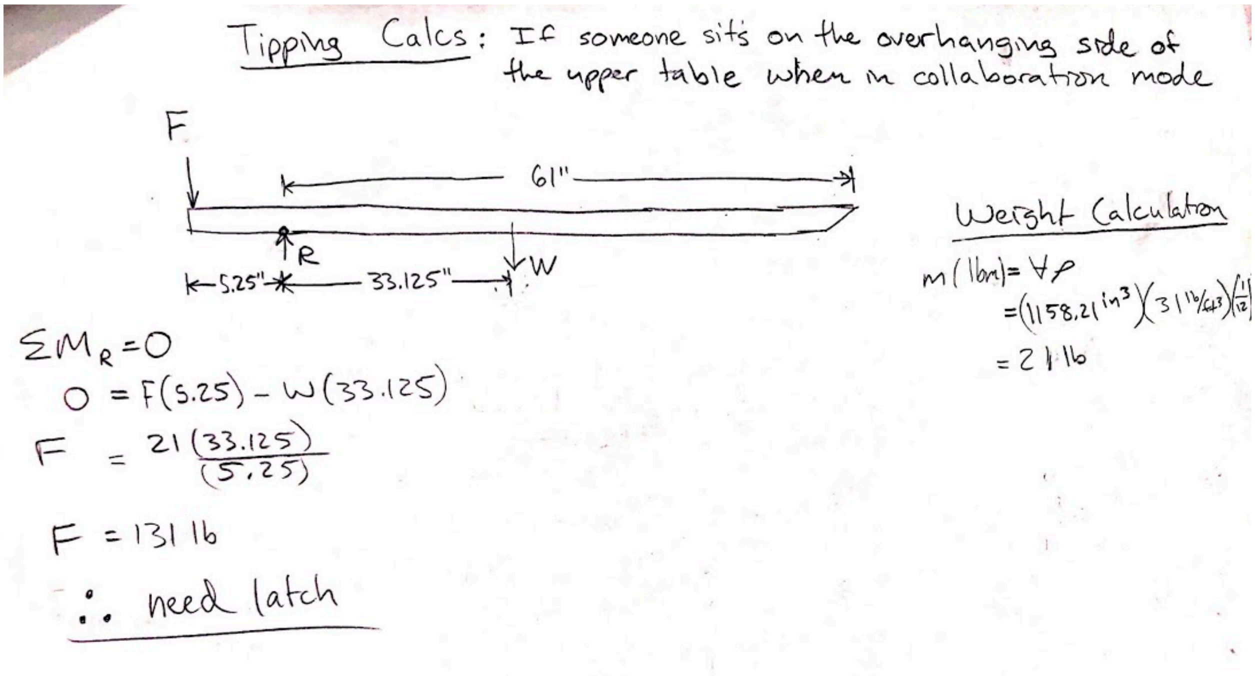


Figure I-4. Table Tipping Analysis

Appendix J: Project Budget and Purchases

Table J-1. Project Budget with Hyperlinks to Website

Component	Vendor	Quantity	Cost ($)	Total Cost ($)
Tabletops	Home Depot	1	58.92	58.92
T-Legs	Gibraltar	3	110	330.00
Latch	McMaster	1	3.21	3.21
Plate	McMaster	2	18.66	37.32
Bar Structural Support	Home Depot	2	15.73	31.46
C-Channel Structural Support	Home Depot	2	12.51	25.02
Angle Bracket	McMaster	2	0.70	1.40
Large Wheel	McMaster	2 (1 pack)	14.07	14.07
Small Wheel	McMaster	2 (1 pack)	13.85	13.85
Large Spacer	McMaster	2	3.86	7.72
Small Spacer	McMaster	2	2.32	4.64
Piano Hinge	McMaster	3	3.46	10.38
Post Leg	AliExpress	2	30.22	60.44
Miscellaneous Fasteners	McMaster	-	50	50.00
			Total	**$648.43**

Appendix K: Operator's Manual

This user's manual includes instructions for product use and important safety information. Read this section entirely including all safety warnings and cautions before using the product.

Using the Adapt-Table

Starting with the table in the Lecture configuration (see picture)

1. Go to the end of the side without the modesty panel.
2. Carefully push on the end of the table such that it rolls on top of the other table surface.
3. Keep the tabletop relatively level and slide across the bottom table until it falls into its slot.
4. Locate the locking safety latch and lock the tables into place on top of one and other.
5. Rotate the modesty panel up such that it is level with the top table.
6. Hold the modesty panel up and pull the leg release lever to allow the folding legs to come down.
7. Ensure both folding legs are vertical and locked into place.
8. Re-orient chairs such that the free chairs move to the modesty panel side of the table.

Starting with the table in the Collaboration configuration (see picture)

1. Go to the modesty panel side of the table.
2. Hold the modesty panel up and unlatch then fold up each folding leg.
3. Let the modesty panel down gently.
4. Unlock safety latch.
5. Go to the end of the table on the side with the third leg.
6. Gently pull the top table out of its notch.
7. Slowly walk backwards and slide the top table away from the rest of the table without turning or twisting until it drops into place.
8. Move the chairs back to the side with the other two chairs.

Assembly

Use the labeled bags of screws at the appropriate steps to attach the legs, rollers, and modesty panel. The tabletops will arrive in the box machined with pilot holes, grooves, and chamfers.

Maintenance

No active maintenance is required to keep the Adapt-Table operating correctly. Twice a year, check for loose screws and tighten as necessary. The table is intended for indoor use only. The coating on the top surface is water-resistant to spills, but warping and discoloration may occur if liquid remains on the surface for extended periods of time.

In order to keep the hinge in working condition, remove debris (such as eraser shavings) twice a year and avoid purposely pushing things into the gap between the modesty panel and tabletops.
Don't just drop the modesty panel, but rather, slowly lower it in order to avoid excessive force on the hinges. Excessive force may cause early wear and reduce table lifetime.

Replacing or Repairing Parts

To replace or repair a part, remove the part by following the associated assembly step in reverse order. Replacement components may be purchased from Co-Act Furniture Inc. Otherwise, components can be purchased from the vendors specified on the Bill of Materials section of this report.

Appendix L: Design Verification Plan & Report

Appendix L contains the test plan and test procedures to validate the prototype.

Test Plan & Results

The test plan in Table L-1 summarizes the test requirements, corresponding engineering specification, acceptance criteria, and results.

Table L-1. Test Plan for Verification Prototype

Item No	Spec #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	Quantity	Test Results			
							Test Result	Pass	Fail	Notes
1	1	Moving and relocating table	1 person	Aaron	FP	1	2 people		X	Should install casters (as planned)
2	2	Time to reconfigure table	<60 seconds	Jett	FP	1	30 sec	X		
3	3	Pinch point access, check whether pencil fits into pinch area	<10 pinch areas	Aaron	FP	1	3 pinch areas	X		Modesty panel, between two tables, modesty panel legs
4	4	Table surface area adjustability	2295 in^2	Jett	FP	1	2295 in^2	X		
5	5	Max deflection under a 500 lb load	0.5"	Emily	FP	1	0	X		No noticeable deflection
6	6	Ratio of Purchased to Manufactured parts	3:1	Aaron	FP	1	3:1	X		
7	7	Weight of table	100 lb	Aaron	FP	1	~40 lb	X		
8	9	Modesty Panel height	<12 in	Jett	FP	1	12 in	X		
9	10	Cost of table	<$800	Emily	FP	1	$600	X		

Test #1: Reconfiguration Time

Description of Test:
Determine if the Adapt-Table can be reconfigured in 60 seconds or less without rushing.

Location: Open classroom

Safety:
- Follow COVID guidelines
- Use caution with heavy weights
- Watch out for pinch points

Required Materials:
- Stop Watch
- Table
- Student & Faculty Test Subjects

Testing Protocol:
1. Start with the Adapt-Table in the "Lecture" configuration.
2. Using a stopwatch, time how long it takes for the test subject to fully reconfigure the Adapt-Table into the "Collaboration" configuration. The test subject should reconfigure the table at a casual pace, like they would in the middle of class time.
3. Repeat the test for how long it takes the test subject to reconfigure the table from the "Collaboration" configuration to the "Lecture" configuration.
4. Gather qualitative feedback from the test subject about the experience, any difficulties, etc.
5. Repeat the test with four additional test subjects.

Data:

Test Number	Lecture -> Collaboration Time (s)	Collaboration -> Lecture Time (s)	Observations
1			
2			
3			
4			
5			

Test #2: Tabletop Deflection Tests

Description of Test:
Determine the deflection of the table while under full load at different locations along the table. Locations include the middle of the table and interfaces between tabletops. Deflection should not exceed 1 inch.

Location: Open classroom

Safety:
- Follow COVID guidelines
- Use caution with heavy weights
- Watch out for pinch points

Required Materials:
- Fully assembled adapt-table
- Weights of varying sizes

Testing Protocol:
1. Start with the adapt-table in the “lecture” configuration.
2. Measure starting height of bottom surface of tabletop.
3. Place weights on top of tabletop at location of interest.
4. Measure new height of bottom surface of tabletop and calculate deflection.
5. Measure and mark the middle of each tabletop
6. Repeat the test starting by adding 50 lbs in the middle of the table and stacking on 50 lbs each test up to 200 lbs. Increase maximum weight if interested weight changes or if we want to test to ultimate failure.
7. Repeat these steps for the other tabletop

Data:
See tables on the next page.

Center of Shorter Tabletop		
Load [Lbf]	**Distance from floor [in]**	**Delta from last data point [in]**
0		-
50		
100		
150		
200		

Center of Longer Tabletop		
Load [Lbf]	**Distance from floor [in]**	**Delta from last data point [in]**
0		-
50		
100		
150		
200		

Center of Modesty Panel		
Load [Lbf]	**Distance from floor [in]**	**Delta from last data point [in]**
0		-
50		
100		
150		
200		

Interface between tabletops		
Load [Lbf]	**Distance from floor [in]**	**Delta from last data point [in]**
0		-
50		
100		
150		
200		

Test #3: Force Required to Reconfigure Table

Description of Test:
Determine the overall force required to switch the table configuration from lecture to collaboration, and back from collaboration to lecture. The purpose is to ensure that the user doesn't have to lift and push with a force greater than 20 lbf.

Location: Open classroom

Safety:
- Follow COVID guidelines
- Use caution with heavy weights
- Watch out for pinch points

Required Materials:
- Fully assembled Adapt-Table
- 2 force gauges with the appropriate range (up to 50 lbf approximately)
- Duct tape (used to create mounting points to table)
- Yardstick

Testing Protocol:
1. Start with the table in "lecture" configuration.
2. Create two duct tape loops for force gauge on each corner of the end of the sliding tabletop.
3. Attach force gauges to the loops.
4. Connect the top of the forces to a yardstick with the mounting points spaced 18" apart.
5. Two people pull on the yardstick up and towards the other tabletop at 45, 60, and 90 degrees from vertical.
6. Record max force readings versus from each of the tests.
7. Repeat this test 3 times to ensure repeatability.

Data:

Angle [degrees]	Trial #1 Max Force Reading [lbf]	Trial #2 Max Force Reading [lbf]	Trial #3 Max Force Reading [lbf]
45			
60			
90			

Appendix M: Design Flow Chart

Appendix M contains the design flow chart visually displaying the logic that shall be followed while designing the table. In order from most important to least important design parameter, the parameter will be evaluated if the target is met. If the target is not met, the team must determine whether any prior parameters limit the current parameter. If any previous parameter limits the current parameter, the team must go back and make proper adjustments.

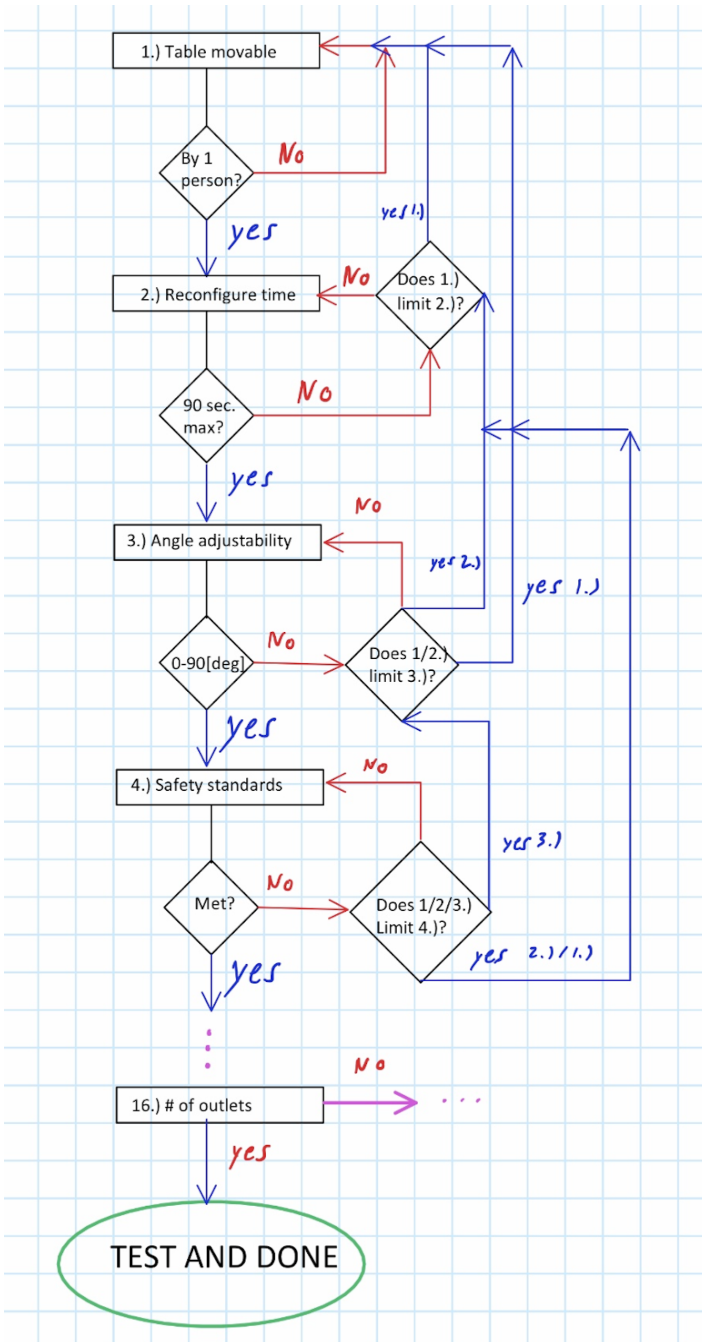


Figure M-1. Design Flow Chart

Appendix N: Gantt Charts

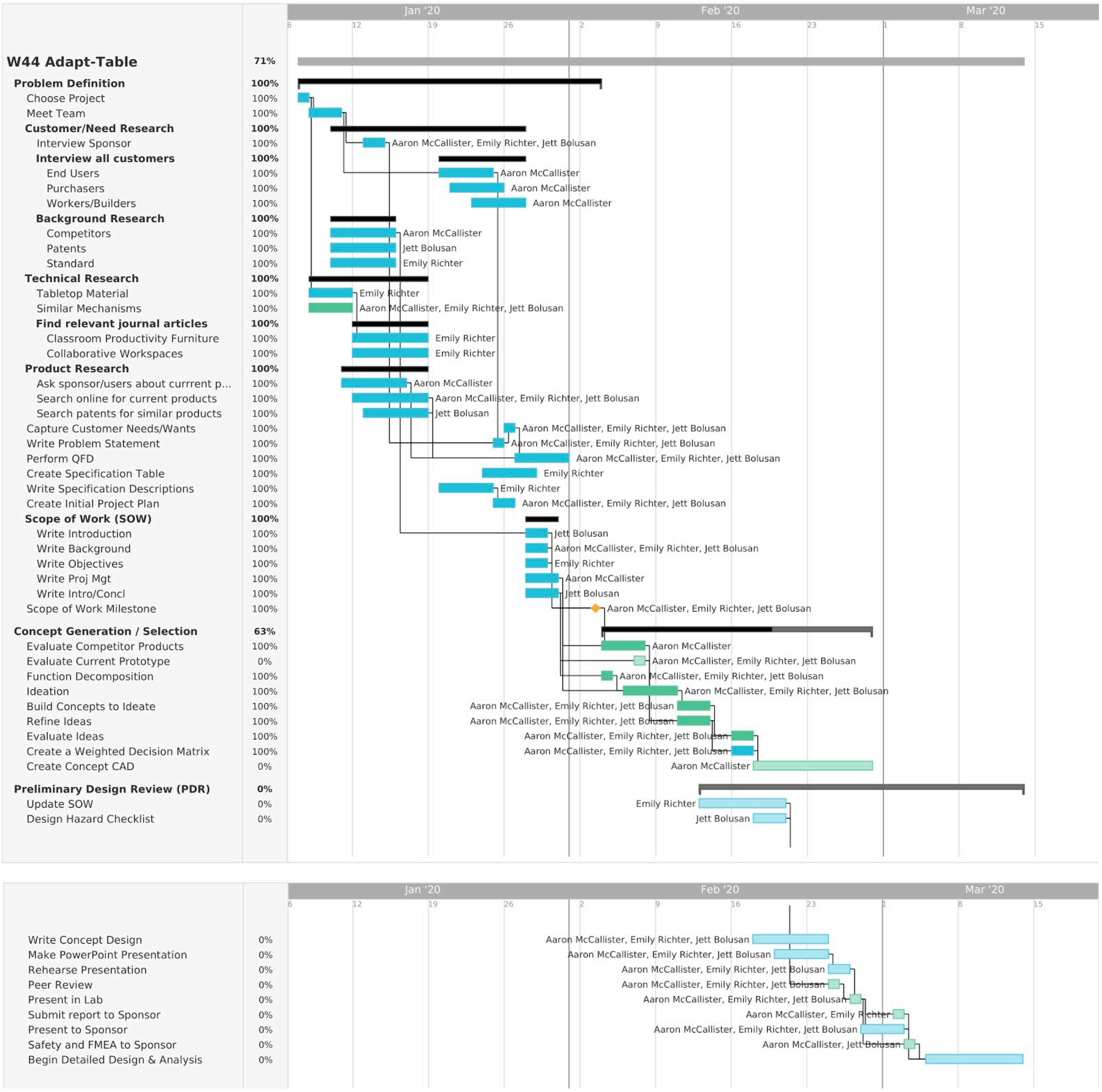


Figure N-1. Gantt Chart for Winter Quarter

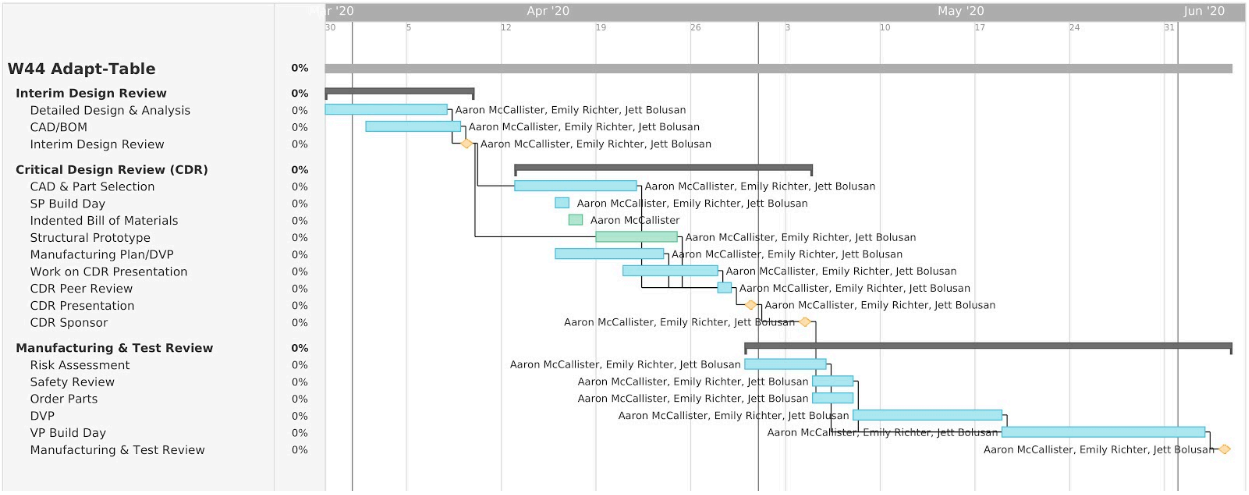


Figure N-2. Gantt Chart for Spring Quarter

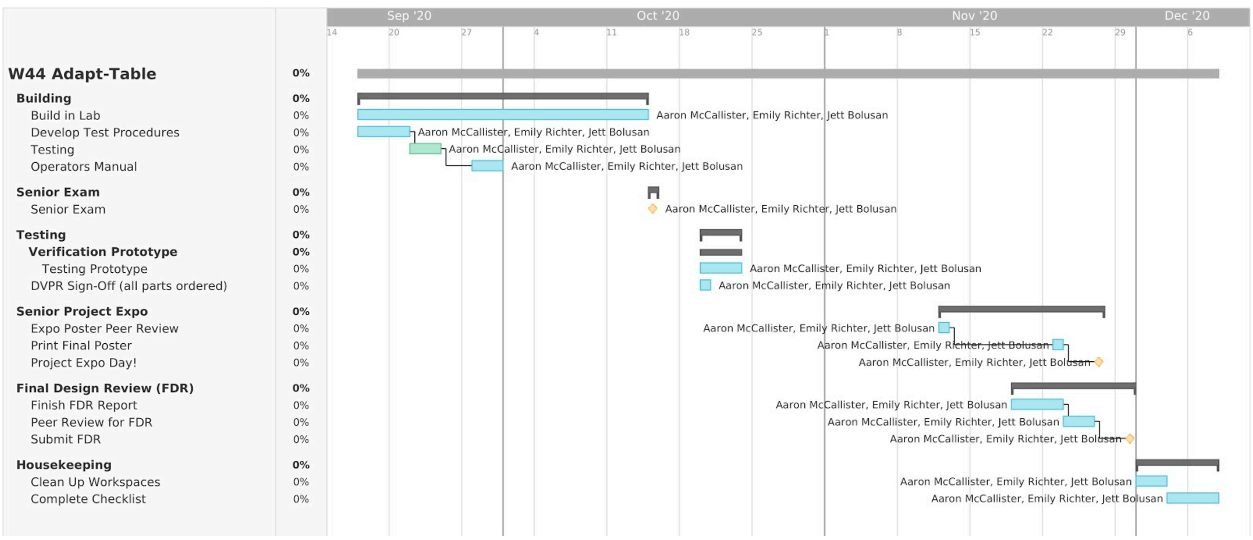


Figure N-3. Gantt Chart for Fall Quarter