Oregon State University
College of Engineering

School of Mechanical, Industrial, and Manufacturing Engineering

ME611: Modern Product Design

Final Report

The Stand-up Desk

Team 7

Author(s):
Daniel Hulse, Raj Oak, Justin Luc, & Lukman Irshad
Professor: Rob Stone

December 6, 2018

Contents

Abstract

This report documents the design process of a portable standing desk undertaken over a ten-week product design course. The product, a portable standing desk, designed for a market of students and freelance workers, is meant to sit on a pre-existing desk to allow someone to perform work at standing height and then fold into a compact footprint so that it may be carried and compactly stored. Following the design process presented by Otto et al. (2000), customer needs were first identified and a functional model was developed to state the functions to be embodied by the design. Then concepts were generated and screened and a final selection was made. The design was then motivated and informed by a proof-of-concept, alpha prototype, and beta prototype, which helped the designers determine would be most feasible during the design and determine the best ways to make the concept lightweight and easily foldable while remaining strong. The final design, as embodied in the beta prototype, has been demonstrated to fulfill the customer needs of a functional portable standing desk.

1 Introduction

Sitting for long periods of time, regardless of how much physical activity is done, has been reported to have adverse health effects (Evans et al., 2012). Prolonged sitting can adversely affect the health independent of the benefits of physical activity (Van Uffelen et al., 2010). Several studies have demonstrated the association with prolonged sitting and obesity, metabolic syndrome, diabetes, cardiovascular disease risk, and premature death (Van Uffelen et al., 2010; Katzmarzyk et al., 2009; Mummery et al., 2005; Healy et al., 2008). Employees sit around 70% of the time at work (Thorp et al., 2009). In addition they sit for 30 mins of more at stretch around 50% of the time Ryan et al. (2011). One way to keep workers from sitting for long periods of time is to use standing desks. However, since most work spaces have old furniture switching to standing desks is considered a costly option. A solution for this will be a portable standing desk that allows workers to take it around with them so they do not have to rely on companies providing them with standing desks to mitigate the health risks that come with prolonged sitting.

While there are several portable stand up desks in the market, they are expensive hovering around 200 to 300 dollar range. While it may be affordable to a highly paid workers, students and freelance workers may not be able to afford this price. So our team decided to take up this challenge and come up with a portable desk that is portable and at the same affordable. To achieve our goal, first we conducted a ethnographic study to understand the market; interviewed customers to come up with customer needs; used various concept generation methods to come up with concepts; and used concept selection methods to refine our concepts and chose the final concept. One the final concept was chosen, we created proof of concept, alpha prototype, and then a beta prototype, applying the lessons learnt to refine our design as we progressed through each prototype. In this report, we have discussed each of these steps in detail and provided recommendations for the final product.

1.1 Mission Statement

The Mission Statement in Table 1 captures the goals, market, and constraints of the project. The goal of this project is to develop a portable standing desk that will allow people to work while standing at an existing desk. The market of this project is white-collar workers with a focus on students, freelance workers, and other users who spend a long period of time at their desk. The major constraint of this project is the 10-week completion time, as well as our fabrication skills and access to equipment and parts.

Table 1: The Mission Statement

Mission Statement:	**Portable Stand Up Desk Product**
Product Description:	Allow working while standing at workstations
Key Business or Humanitarian Goals:	10 weeks development of beta prototype 30% profit margin Initial 10% market share
Primary Market:	Adults who use a workstation for long periods of time at home or work
Secondary Market:	Students, Freelance Workers, Friends, Family
Assumptions:	Compact and easy set up Easy Storage Long Life (5 - 10 Years)
Stakeholders:	Team 7, User, Offices, Universities, Retailers
Avenues for Creative Design:	Ergonomic Design, Allow for a power supply through various ports (eg. USB, etc.), Portability, Compact Design and Storage, Ease of Use.
Scope Limitations:	Materials: Metal Casting, Plastics Injection Molding, Woodworking Skills: Electronics

1.2 Market Research

This project used ethnographic techniques to understand the customers and environment the product seeks to solve. Using observations, interviews, and visual stories, we were able to characterize the environment, state of mind, and basic needs. Users use their desks following the process shown in the activity diagram in Figure 1. Users arrive at their desk, set their items on it, and work. After they are done working (or if they are taking a break), they pick up their items and leave. Key points are detailed below.

Based on our observations and preliminary interviews with users, we noticed:

- Users are often hunched over and sitting uncomfortably.
- Areas tend to vary significant, but digital devices are commonplace.
- People customize and move things about their work space to feel comfortable to perform multiple tasks at once. For example, a worker might move their laptop to the side to transfer notes from their notebook.

Based on our interviews, we noticed:

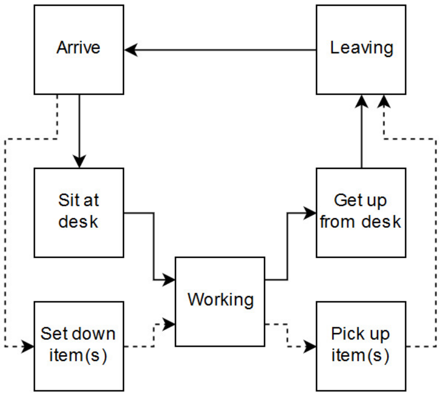


Figure 1: Activity diagram of sitting at a desk

- Users identified a wide number of activities done at the desk. Most often, these activities involved a computer. However, users also would perform a number of activities at the same time (e.g. work with a computer, book, and pieces of paper to perform an assignment)
- Users might work with a desktop built-in to the area, a laptop that they take with them, or both.
- To the extent users had a choice with their working area, they would adjust it to be more comfortable. If users had a choice of workstation, they would find the more comfortable area.
- When prompted about opinions, users preferred having open area on their desk over built-in storage so that they could "sprawl out" their work. They did not like areas that seemed claustrophobic or closed (e.g. if a shelf was overhead). They also preferred smooth surfaces to textured surfaces so that they could write on them.
- Some users who had standing working areas preferred them, while others did not. Most had not used standing desks before. One user would find themselves more likely to walk around when using the standing desk.

Users worked in a variety of different environments. Most users already owned desks or had some sort of work space that they worked at for long periods of time every day (generally 4-6 hours straight, with short breaks breaks), although some worked more intermittently for shorter periods. The work spaces themselves can be broken down by ownership into three main categories: office, home office, and shared environment. In an office, the desk is provided, and may have some existing features (such as a desktop) that the user cannot change by themselves. However, the user has some ability to customize the space and can leave things there if needed.

In a shared space, users must leave the environment as it was when they started working. As such there are limited options for them to customize the area. Finally, in the home office setting, the user may change everything, but may be limited by budget, assembly, and their own space.

Our participants had either relaxed, focused, or stressed states of mind. Often these states were externally-driven (from their work or jobs), but some stress came from the work space. Users expressed dissatisfaction with having cluttered, claustrophobic, or areas where they had to sit in uncomfortable positions. Users were also worried about the health effects of sitting for large periods of time. When asked about cost, users seemed averse to paying too much for a standing desk attachment.

Based on user feedback and an analysis of the situation, a number of basic needs were further identified. Users stated wanting such a device to be portable, sleek, and lightweight. They wanted flat surfaces so that they could write easily. Based on the varying height of users, adjustable height may also be a basic need, to avoid discomfort. Customers also did not want to pay too much for such a device, and were within the range of $20-50$. Functionally, such a device would need to hold at least one laptop, although a larger profile would allow for more flexible work flows (e.g. working with a laptop and external device.) It would also need to interface with a variety of different tables, and would need to provide a sturdy, flat writing surface and would need to prevent tipping. Setting up the device should be simple.

Below is a typical story that would come out of our interviews: Sam is a student. While he uses several different desks throughout the day, that other people bought. As such, he does not find them comfortable, and often finds himself in a poor posture. He will often work in an area like this for long periods of time, only taking short breaks. He has heard standing desks can be more comfortable to work at, but is priced out of buying one new, especially since he does not know if he could stand for long periods of time.

2 Problem Clarification

A background of the problem or system. Describe what lead to this issue if that applies. Your goal should also be clearly specified here.

Table 2: Results of Customer Interviews

Question	**Customer Statement (Summarized)**	**Interpreted Need**
Explain your normal work day?	Works long hours in a single location, with periodic breaks.	Long-term comfort
How do you use your desk? What do you use it for? What sorts of things do you work with on your desk?	Uses desk for a variety of purposes–may at any point in time have single computer or a laptop, a textbook, notes, etc.	Spaciousness–ability to hold multiple items
Is it comfortable? Why? Any pain points?	May get uncomfortable after a while. Tall users noted awkward surface placements.	Comfort Adjustability
How often do you move things on your desk?	Often to not at all	Ease of setup
Did you know sitting for long periods time is not good for your health?	(some did, some did not)	
Have you used a standing desk before? If you could use a standing desk, how do you envision it to be?	Yes, but must be cheap and should be able to use it multiple places and be comfortable, and allow use while sitting	Cost Comfort Portability Adjustability

2.1 Customer Needs

Customer needs were gathered from a variety of sources. First, potential customers were interviewed about their current desk situation what they would like out of a portable standing desk. Second, surveys were sent to a larger set of potential customers to weight the importance of different needs. Third, lead and extraordinary users were considered to gather any additional needs that might motivate design work. Finally, these needs were assessed using the outcome-driven design approach and a needs ontology to determine which needs were strategically most important to consider and which types of needs would be most important to gather.

Table 3: Finalized customer needs from interviews and product survey.

Customer Need	**Importance**
Comfortable	4
Spacious	4
Height Adjustable	4
Easy to Setup/takedown	4
Ability to interface with variety of existing furniture/workspaces (Adaptability).	2
Aesthetically Pleasing	3
Portable	5
Sturdy/Durable	5
Less Costly	4
Having a Cord Organizer	2
Able to hold coffee cups	2

2.1.1 Questionnaires and Interviews

To identify the customer needs the team used two approaches; Interview and Questionnaire. 12 customers were interviewed and based on their response the team derived the customer needs. The interview questions included questions about their current work environment, pain points with their current desk, potential of a stand up desk, and potential features that the user would want in a stand up desk. Then a questionnaire was created and shared amongst potential users. 25 users responded to this questionnaire. The responses from the questionnaire was used to identify the importance of each customer need.

Twelve interviews were conducted using the prompt on Table 2. Shown are “typical” answers as well as interpreted needs. Most of these answers did not vary much, even across those who were outside the primary demographic group we questioned (that were not students).

Based on these interviews, we determined it would be useful to send out a questionnaire which allowed users to rate some of the needs identified on a 1-5 scale, as well as provide some input into the design. The results of this questionnaire, compiled with the qualitative results of the interviews are shown in Table 3.

2.1.2 Considering Lead and Extraordinary Users

In addition to surveys, investigation of needs focused on two sets of users that might be missed in a typical set of customers: lead users and extraordinary users.

Lead users have been stated in previous work as users ahead of the market trend. According to lead user theory, these users have needs which, if identified, will allow the firm to innovate beyond making incremental product improvements (Ross et al., 2018). Such users are often considered to be ahead of market trend, and have a high personal benefit from the expected use of the product

Based on these characteristics, we consider lead users to be freelance workers and students with more than one workspace. Because these users are ultimately responsible for their own workspace (it isn't provided by a company), they are most likely to consider and buy a modular or portable design solution for themselves to interface with existing furniture. For the most part, the customers interviewed in the questionnaires were students, however, so it is difficult to say whether there is an additional segment of that market that would further "lead" the market. These users would value portability and cost much more than other users.

Other users that might act as lead users would be tall people which may be uncomfortable with normal desks. While these users may not be ahead of market trend, they would potentially have a high personal benefit from a product that allows some level of adjustability to their desk space. A few of our users were in this category, and had additional needs around surface height and adjustability, which would need to be emphasized in the design to meet their needs.

Extraordinary users considered in the design process were customers that are not covered by most workplace ergonomics, including customers with painful posture issues, such as scoliosis, and those that are abnormally short or tall. Generally, the main needs of these users are the same as those of lead users: needing a large range of adjustable heights that would allow all users to stand comfortably.

Additionally, some users needed organized workspace. The lack of desk space for most users affects users physical work efficiency as well as mental needs. Some customers interviewed wanted a cleaner work environment, or at the very least, a neat work area to place the myriad of equipment and devices they use. Mentally, a work area that requires constant reshuffling of papers and tools is stress that compounds existing stress from work or school. The need for workspace may not be just the amount of space, but perhaps a need for organization to do work.

Table 4: Scoring of needs from the outcome-driven design method

Desired Outcome	Importance	Satisfaction	Opportunity
Comfort	3.67	3.75	3.96
Work Area Size	3.53	3	4.13
Ergonomic Desk	3.75	3.5	4
Ease of Setup	4.08	3.83	4.33
Portability	4	3.25	4.75
Modular Features (eg: adjustable)	3.92	3.5	4.33
Reduced Cost	4.5	2.5	6.5

2.1.3 Assessment of needs

Needs were then assessed using the Outcome-driven approach of Ulwick (2002) and the ontology-based method of Nix et al. (2017).

Table 4 shows the results for the outcome-based method derived based on the answers from the customers. Here, the customer need of reduced cost scored the highest opportunity while comfort scored the lowest. This shows that a portable desk with low cost is a highly desirable market need. All other needs scored closed to 4 meaning that they all present an almost equal amount of market opportunity. Based on this assessment, cost and portability were identified as areas of most opportunity for the product.

The ontological approach was used to assess the needs captured by two open-ended questions given in the questionnaire that was used to generate the customer needs list. The questions were:

- “What problems do you have with using your current desk?”, and
- “What additional features do you think that standing desk should have?”

The main results of this assessment were that:

- Our needs were entirely dominated by users in terms of stakeholders. This was because all of the questioned stakeholders that were selected were users of the product, and not manufacturers or purchasers. Unfortunately, that means that our product needs only cover one part of the value chain–the end user. However, for early design this was what we were most interested in.
- While the plurality of needs were focused on specific features the design should have, still other needs were captured around performance, supplementary functionality, and human factors. This questionnaire did not capture aesthetic or

environmental considerations. Further work may develop lines of questioning around these considerations in order to capture any needs the customers have in these categories that were not stated.

- Needs were stated in a variety of ways–the plurality being stated as objectives. This was because of the large numbers of responses asking for “lightweight” or “more space,” which are objectives. Many other needs were stated in several different ways–while some users wanted “more storage” (an objective), others wanted “large drawers” (a solution). Still others thought there was “not enough storage” (a constraint).
- Roughly half of the gathered needs were stated as non-beneficial, reflecting dissatisfaction with current desks. This was because the first prompt was asked “what problems do you have with using your current desk?”, which led users to state their needs as non-beneficial aspects of their current desk. The remaining needs gathered from the next question was relatively evenly split between basic, direct, and exciting needs.
- A slight majority of needs were classified as general as opposed to niche. However, there was some difficulty in this classification because of the way needs were stated. For example, while some customers wanted “better ergonomics” (a general need) others wanted it to “stop making my neck hurt,” which would be considered a niche need since it may only be related to them. In practice, many of the niche needs, while not stated as general needs, could be generalized to most in the population even though the user saw it as an individual need of theirs.

2.1.4 Conclusions

Based on our needs-gathering and assessments, we identified portability, spaciousness, sturdiness, cost, and height adjustability as the most important customer needs to target. However, further needs still needed to be identified about manufacturing and purchasing.

2.2 Constraints

The needs were classified in terms of jobs, outcomes, and constraints, as shown in Table 5.

Customer Need	**Importance**	**Constraint/ Outcome**	**Job**
Comfortable	4	Constraint	Work at the desk
Spacious	4	Constraint	Work at the desk
Height Adjustable	4	Constraint	Work at the desk
Easy to Setup/take-down	4	Outcome	Setup/ Take-down Desk
Ability to interface with variety of existing furniture/workspaces (Adaptability).	2	Outcome	Work at the desk
Aesthetically Pleasing	3	Outcome	Work At the desk
Portable	5	Constraint	Store/Move desk
Sturdy/Durable	5	Constraint	Work at the desk
Less Costly	4	Constraint	Work at the desk
Having a Cord Organizer	2	Outcome	Work at the desk
Able to hold coffee cups	2	Outcome	Work at the desk

Table 5: Customer needs categorized into jobs, outcomes, and constraints

2.3 Product Specification

Functional constraints of the product were specified in a functional model that was performed by decomposing the overall function that the standing desk should fulfill (to support items, as shown in Figure 2) into a number of interacting sub-functions as shown in Figure 3.

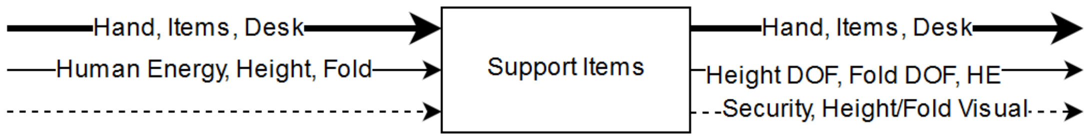


Figure 2: Black Box Model of Stand-Up Desk

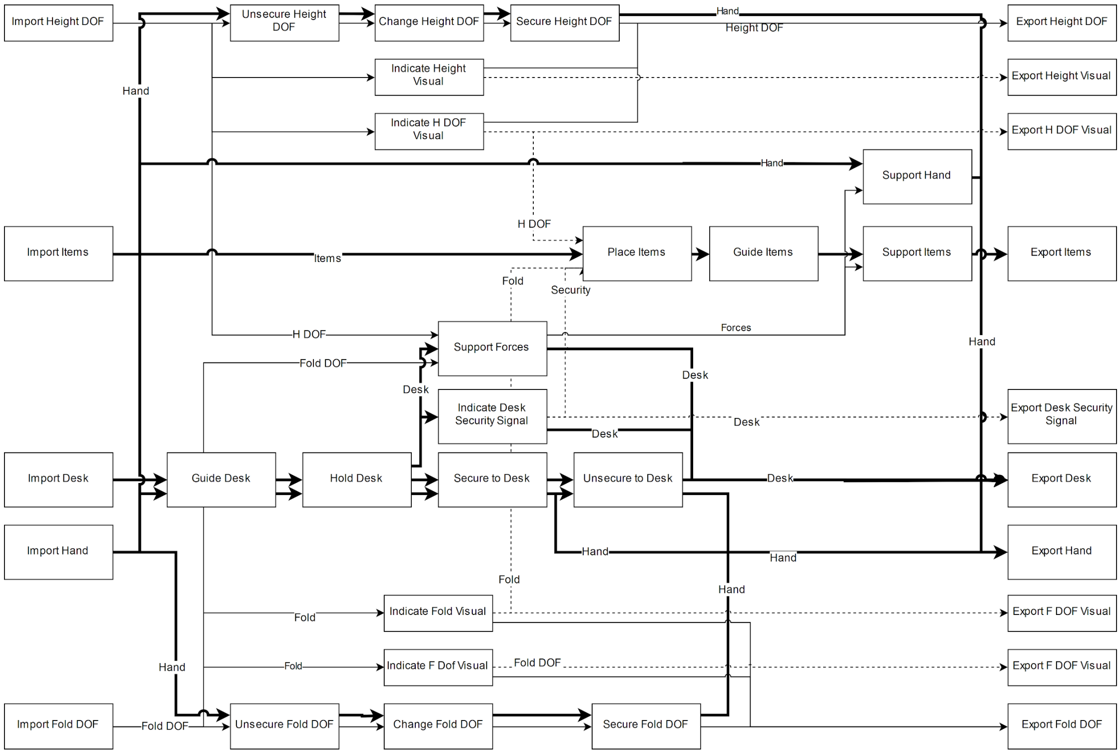


Figure 3: Functional Model of Stand-up Desk

3 Concept Generation and Design

To determine the best concept, twenty design concepts were generated using five different approaches. Then, the Pugh chart was used to screen designs to a list of five, which were then further developed and compared using a utility-based selection approach. The concept chosen through this process is shown in Figure 36

3.1 Concept Generation

Concepts were generated using a variety of techniques, including a morphology approach, a product architecture approach, bio-inspiration, storyboarding, and mind-mapping.

3.1.1 Morphology Approach

Concepts generated by the morphology approach are shown below. In the morphology approach, different solutions for each of the functions are developed , put in a table, and combined to produce the overall concept.

Morphology Concept 1:

Pin-adjustable legs are attached to mounts at the bottom of the desk surface. Folding involves removing the legs, which may be attached via Velcro to the bottom of the desk. Can be seen in Figure 14 in Appendix A.

Morphology Concept 2:

The desk surface is supported by hinged supports with an internal diagonal cut that allows the height of the surface to be raised and lowered. These supports are furthermore attached to the desk via a clamp. To fold, the upper and lower portions are separated and the hinges folded in. A strap or bag would be used to keep pieces together while moving it. Can be seen in Figure 15 in Appendix A.

Morphology Concept 3:

The surface is supported by hinged rectangular legs that collapse within themselves to fold and adjust height. Folding is accomplished by collapsing the legs and folding them in. Further compactness may be provided by providing a hinge on in the center of the writing surface. Can be seen in Figure 16 in Appendix A.

Morphology Concept 4:

The surface is supported by a four-bar linkage with two arms of the same length. An additional bar secures the linkage at a height. These bars would be attached to clamps which hold on to the side of the desk. The surface angle could be adjusted by moving the bars out of parallel with each other. To fold, the linkages would be rotated to be parallel with the writing surface, while the clamps would be detached. Can be seen in Figure 17 in Appendix A.

Morphology Concept 5:

Segmented legs detach from each other to allow for folding and adjusting the height. Dowel pins attached to legs. No specialized clamping/support system would be provided for this design. Legs separate and strapped together or put in a bag when folded. Can be seen in Figure 18 in Appendix A.

3.1.2 Product Architecture Approach

In the product architecture approach, a good product architecture is first conceptualized, which then defines the components.

Architecture Concept 1:

A desk with a diagonal bars that prop the desk up as it is raised, and bending joints that act as supports as the desk is raised. Joints and diagonal bar can not be in line, as they would interfere. Can be seen in Figure 19 in Appendix A.

Architecture Concept 2:

The legs have been rearranged to cross at the middle, and support each other as they support the desk as it is raised. A lot of interference here between each leg. Can be seen in Figure 20 in Appendix A.

Architecture Concept 3:

Taking ideas from 1 and 2, this concept is analogous to a fold-able camping chair or seat. The support struts may not be necessary, as they interfere mostly. Will be hard to adjust joint standing desks, unless it had some stopping mechanism like those push in metal pins. Can be seen in Figure 21 in Appendix A.

Architecture Concept 4:

A standing desk that can fold in, allowing portable use. The desktop is a shelf that can be slid in and out. The desk body and the desktop shelf have Velcro on top that lets them attach to each other. There are interference issues that may or may not be easy to fix, such as the shelf pegs going into the desk body Can be seen in Figure 22 in Appendix A.

Architecture Concept 5:

Same as concept 4, but the middle section is the bottom. This resolves some interference issues found in the previous iteration. Can be seen in 23 in Appendix A.

Architecture Concept 6:

Taking concept 4, the desk has its left and right sections cut in half so that it is two layers rather than three layers. I expect the shelf pegs will probably sink into the center section as a result, but this is easily remedied with a thick enough center section. Can be seen in 24 in Appendix A.

3.1.3 Bio-Inspired Design Approach

Bio-insipired design approaches find inspiration from nature for the solution principles and structure of the design. Concepts generated with this approach are shown below.

Bio-Inspired Concept 1:

Taking inspiration from Cassie, a robot with legs designed by Dr. Jonathan Hurst, the concept is based on on emus which inspired Cassie. The concept is a set of joint legs for the desk that can adjust the height. Can be seen in 25 in Appendix A.

Bio-Inspired Concept 2:

This concept drew inspiration from three separate biological phenomena: hands, wings/appendages, and tree roots. As can be seen, the surface of the desk folds in and out (wings) from a central member for compactness, while the linkage clamp (hands) holds the attachment in place. The table legs (roots), reach far to the left and right for support, provided the members are sized correctly, the resulting design could be compact while providing some protection to moving/sensitive components. The design can be seen in Figure 26 in Appendix A.

Bio-Inspired Concept 3:

Using artifact level analogy, a concept was designed by taking biological words and using a thesaurus for mechanical terms. Cats have supple bodies and can exhibit a large degree of muscle rotation due to the structure of the joint. These joints allow this animal to fold its legs completely beneath its body in a way that they may not be seen by the observer. The joints of the concept could be designed in a way similar to the ball joints found in nature. The joints can be made stiff in order to restrict some degree of freedom yet providing the adaptability. A comparison of catus and the concept can be seen in 27 in Appendix A.

Bio inspired concept 4:

This concept was inspired by the Mimosa (Sensitive Plant) Leaves. The leaves of this plant fold in upon themselves when they are being touched (See Figure 4).

Since the prototype is expected to be portable a similar folding mechanism will be adopted. Overall the desk is expected to fold in and look similar to an umbrella making it easy to transport and store. See 28 in Appendix A.

Figure 4: Mimosa Leaves

3.1.4 Additional Concepts

The following concepts were developed based on a variety of other methods:

Concept 1. Storyboarding Method

Designers always need to design products for somebody else, therefore it is necessary that the designer develops a feeling , insight and knowledge about the desired topic. Storyboarding provides a common language that includes people from different backgrounds to interact on the basis of the design. It consists of telling a story about the product user in the form of pictures. Can be seen in29 in Appendix A.

Concept 2- Story Boarding

The same storyboard resulted in a another concept. This time the table has three modules for the top surface. Each of them collapse on top of the middle one. This resulted from looking at the human carrying a bag to work from the storyboard. The whole concept was developed based on the principle that the person who uses it should be able to easily put it in their backpacks. In addition, all of the other aspects of the storyboard given importance as well. The resulting concept is shown in 30 in Appendix A.

Concept 3- Mind Mapping

Mind mapping was first used by English Scholar Tony Buzan. It is a method of articulating ideas by text and graph. A mind map is created around a keyword and placed in the center to which related ideas, thoughts and words are arranged radially as branches. At the end of each branch higher level of branches can be added. Due to this thinking would be transformed into a visual image. In the given figure the main idea of standing desk is being depicted in the middle of the box. Various branches along with their relationship with respect to particular function are shown. Each branch is further divided into the details of each section. Main branches include control, items, portability, compactness, mechanism. The resulting concept is shown in Figure 31 and Figure 32 in Appendix A.

Concept 4- Mind mapping

This model also consists of the same central idea about standing desk. The key difference in this model is the way in which the branching is carried out. Here, the aspects being considered are the material properties, uses, portability, list of materials. This model provides a constructional basis for designing the product. The model has a pneumatic control mechanism for retracting the legs along with a compressor and regulating valve. The resulting concept is shown in Figure 33 and Figure 34 in Appendix A.

Concept 5 - Mind Mapping

Having the stand up desk in mind, all of the thoughts and objects that followed were drawn out in a tree. For example, after thinking of the stand up desk, adjustable height came into mind. Adjustable height resulted in thoughts about tripods, telescopes and buildings. They are all mapped as a tree. The figure in Table 35 in Appendix A shows the whole mind map .

From the mind map, the features that mostly correlated to the customer needs were selected and put together as a concept. For example, for portability, lightweight and a picnic table folding mechanism was adopted. The resulting concept is in 36 in Appendix A.

3.2 Concept Selection

To select a concept, the twenty designs were first screened through a Pugh chart into a set of five, which were then developed and selected using a utility-based design selection procedure.

3.2.1 Pugh Chart

All of the designs generated in Concept Generation and Design were screened on a variety of criteria using a Pugh Chart as presented in Otto et al. (2000). The considered criteria were:

- Spaciousness: the ability to support a 24" x 11" surface

- Height Adjustability: the ability to adjust to a variety of heights easily and reliably
- Ease of use: ability to set up and take down the table (weight, number of operations, etc)
- Adaptability: ability to interface with a variety of existing furniture and work spaces
- Aesthetics: design's appeal based on design novelty and appearance of quality
- Portability: compactness and weight allows design to be carried easily
- Sturdiness: amount of expected "flex" or "play" in the surface when mounted on a desk
- Cost: expected cost of producing the product
- Ease of prototyping: ability to be made using simple tools and operations
- Safety: likelihood of injuring a person or dropping valuable items

	Concepts																			
Criteria	Datum (M1)	M2	M3	M4	M5	P1	P2	P3	P4	P5	P6	B1	B2	B3	B4	A1	A2	A3	A4	A5
Spaciousness (24" X 11")	0	0	0	-1	0	0	-1	0	0	0	0	0	-1	0	-1	0	0	-1	-1	0
Height Adjustability	0	1	1	1	-1	-1	1	0	1	1	1	1	-1	0	0	-1	0	-1	-1	0
Ease of Use (Setup/takedown)	0	-1	0	-1	1	1	1	0	1	1	1	0	1	0	1	1	-1	1	1	1
Adaptability	0	0	1	0	1	-1	0	0	-1	-1	-1	1	0	-1	0	0	0	1	1	1
Aesthetics	0	1	0	1	0	1	1	0	0	0	0	1	1	0	1	0	1	0	0	0
Portablity	0	-1	1	1	1	-1	-1	-1	0	0	1	-1	1	0	1	0	1	-1	-1	0
Sturdiness	0	1	0	-1	0	0	-1	1	1	1	0	0	-1	-1	-1	0	-1	0	0	-1
Cost	0	0	-1	-1	-1	-1	0	0	-1	-1	0	-1	1	-1	-1	1	0	-1	-1	0
Ease of Prototyping	0	0	0	-1	1	-1	-1	0	1	1	1	-1	0	0	0	1	-1	-1	-1	0
Safety	0	1	0	0	1	0	-1	-1	0	0	0	0	0	0	0	0	0	-1	-1	-1
Positives		4	3	3	5	2	3	1	4	4	4	3	4	0	3	3	2	2	2	2
Negatives		-2	-1	-5	-2	-5	-5	-2	-2	-2	-1	-3	-3	-3	-3	-1	-3	-6	-6	-2
Net		2	2	-2	3	-3	-2	-1	2	2	3	0	1	-3	0	2	-1	-4	-4	0
Duplicate to?	A5									P6						M3				
Infeasible												X	X			X		X	X	

Table 6: Pugh Chart used for early screening

The initial Pugh chart is shown in Table 6, with ratings for each design compared to the Datum design. To aid the ability to show these charts on a single page, each design was given a label corresponding to the method used to generate it and the order listed in Concept Generation. To determine what design each code refers to, refer to the concepts generated in the previous section. M stands for Morphological Approach Concepts, P stands for Product Architecture Concepts, B stands for Bio-Inspired Concepts, A stands for Additional Concepts.

	Concepts								
Criteria	Datum (M1)	M2	M3	M5	P3	P6	B4	A2	A5
Spaciousness (24" X 11")	0	0	0	0	0	0	-1	0	0
Height Adjustability	0	1	1	-1	0	1	0	0	0
Ease of Use (Setup/takedown)	0	-1	0	1	0	1	1	-1	1
Ability to interface with variety of existing furniture/workspaces (Adaptability).	0	0	1	1	0	-1	0	0	1
Aesthetics	0	1	0	0	0	0	1	1	0
Portability	0	-1	1	1	-1	1	1	1	1
Sturdiness	0	1	0	0	1	0	-1	-1	-1
Cost	0	0	-1	-1	0	0	-1	0	0
Ease of Prototyping	0	0	0	1	0	1	0	-1	0
Safety	0	1	0	1	-1	0	0	0	-1
Positives		4	3	5	1	4	3	2	3
Negatives		-2	-1	-2	-2	-1	-3	-3	-2
Net		2	2	3	-1	3	0	-1	1

Table 7: Revised Pugh Chart

In addition to tabulating positives, negatives, and a net ranking for the designs, designs were screened based on their feasibility and whether or not they were overly similar to another design. For designs that were similar, the inferior designs were removed from the list, as was the case with P4 and P5, A1, and M1. Additionally, several designs (B1, B2, A1, A3, and A4) were judged to be unfeasible due to their inability to meet the spaciousness requirement, inability to adjust height, and inability to be made during the course of this project. Additionally, designs that scored poorly (noted in red) were removed from the process.

For the final selection of five designs, the remaining designs were compiled in the Pugh chart in Figure 7. After some discussion of each of the concepts, the top five-scoring designs–M2, M3, M5, P6, and A5–were selected, which all had net positive scores.

3.2.2 Utility-Based Selection

Each of designs selected from the Pugh chart were then investigated quantitatively by determining the dimensions of the design in each configuration, and the resulting properties of each design using the utility-based selection process outlined in Otto et al. (2000). Each design was constructed to have a 18" x 24" surface, and was designed to target a range of adjustment of 5" to 21," although most designs were not able to deliver that range. The criteria were then calculated for each of these designs. The selected attributes were:

- Adjustable range (max height - min height)
- Weight
- Degrees of freedom required to adjust the height up or down
- Volume of the envelope of the folded desk
- Number of pieces to carry around when the desk has been folded
- Number of custom parts that would need to be made
- Aesthetics/subjective appeal

Based on the best and worst attribute of each design, simple linear models for the utility of an attribute value were constructed, as shown in the table in Table 8. The resulting model of utility for each attribute was of the form u(x)=m*x+b, where u is the utility in terms of the attribute value, x is the attribute value, and m and the b are the slope and y-intercepts shown at the right side of Table 8.

Finally, the pseudo-variant approach was used to determine the weights for each attribute. Using this pseudo-variant approach the attributes were rank-ordered in terms of importance. Designs were then developed that had the worst value for every attribute except for a single attribute, which was given the best value. The value for that attribute at which it was indifferent to the next pseudo-variant in the list was determined, as well as the ratio of one utility to the next. These equations relating the proportion of weights given to each design were solved in conjunction

Table 8: Utility model used in the final design selection.

	worst (0 in y)	best (1 in y)	m	b
adjustable range (in)	10	21	0.091	-0.909
weight (lbs)	10.5	4.2	-0.159	1.667
adjust DOF (#)	4	1	-0.333	1.333
folded volume (in^3)	648	216	-0.002	1.500
num. of folded pieces (#)	3	1	-0.500	1.500
num. custom parts (#)	15	4	-0.091	1.364
aesthetics/subj. (1-10)	3	9	0.167	-0.500

with overall relationship determine the value for each weight. This process is shown in Table 9.

Table 9: Utility Matrix 2

Criteria	Pseudo 1	Pseudo 2	Pseudo 3	Pseudo 4	Pseudo 5	Pseudo 6	Pseudo 7
adjustable range (in)	21	10	10	10	10	10	10
weight (lbs)	10.5	10.5	4.2	10.5	10.5	10.5	10.5
adjust DOF (#)	4	4	4	4	4	1	4
folded volume (in^3)	648	216	648	648	648	648	648
num. of folded pieces (#)	3	3	3	1	3	3	3
num. custom parts (#)	15	15	15	15	4	15	15
aesthetics/subj. (1-10)	3	3	3	3	3	3	9
value of indifference	17	300	6	2	6	2	
utility of indifference values	0.636	0.806	0.714	0.500	0.818	0.667	
	a4	a2	a5	a6	a3	a7	
0.339	0.216	0.174	0.124	0.062	0.051	0.034	0.999
= w1	= w4	= w2	= w5	= w6	= w3	= w7	= total

Based on the calculated attribute values, utility transformations, and attribute weights, the utility of each design was calculated, as shown below in Table 10.

3.2.3 Uncertainty Analysis

To perform the uncertainty analysis, the top 4 selection criteria were chosen based on their weight scores calculated using the pseudo variant approach. Then average

Table 10: Utility Matrix 3

	weight	M2		M3		M5		P6		A5	
Criteria:		raw	utility	raw	utility	raw	utility	raw	utility	raw	utility
adjustable range (in)	0.3	10.0	0.0	14.0	0.4	21.0	1.0	21.0	1.0	14.0	0.4
weight (lbs)	0.2	10.5	0.0	4.7	0.9	8.9	0.3	8.4	0.3	4.2	1.0
adjust DOF (#)	0.1	1.0	1.0	2.0	0.7	3.0	0.3	1.0	1.0	4.0	0.0
folded volume (in^3)	0.2	648.0	0.0	432.0	0.5	552.0	0.2	520.5	0.3	216.0	1.0
num. of folded pieces (#)	0.1	3.0	0.0	1.0	1.0	3.0	0.0	2.0	0.5	1.0	1.0
num. custom parts (#)	0.1	5.0	0.9	7.0	0.7	15.0	0.0	4.0	1.0	5.0	0.9
aesthetics/subj. (1-10)	0.0	3.0	0.0	5.0	0.3	3.0	0.0	7.5	0.8	9.0	1.0
	total:		0.11		0.61		0.45		0.66		0.73

weight was calculated using the equation below. Average Weight = Weight of Criterion ÷Sum of the Weights of Tp 4 Criteria. Then the standard deviation was set to 0.0333. Then for the each concept variant the calculated values for each selection criteria was used as the average and the standard deviation was determined by analyzing similar products and by evaluating the potential for changes in the values if some of the initial assumptions was changed. The table below show the values used as inputs for the uncertainty analysis in Table 11.

Table 11: Uncertainty Analysis

Matrix 1			CV1:	M2	CV2:	M3	CV3:	M5	CV4:	P6	CV5	A5
Criteria:	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.
Adjustable Range, in	0.398	0.033	10	2	14	2	21	3	21	3	14	2
Weight, lbs	0.204	0.033	10.5	1	4.7	0.5	8.9	0.6	8.43	0.5	4.2	0.5
Folded Pieces, #												
Folded Volume, in^3												

As seen in the figure below, the uncertainty analysis confirmed the results from the utility theory analysis. The concept A5 had the highest mean utility with the the lowest probability for a utility score of zero and the highest probability for a utility score of 1. Concepts M3 and P6 were the next best performing concepts while concept M2 performed the worst. In addition, the analysis also confirmed that concept A5 will still be the best performing concept even when some uncertainty is introduced to the selection criteria. Based on the results from the utility theory and the uncertainty analysis, the team decided to move forward with concept A5. See Figure 5.

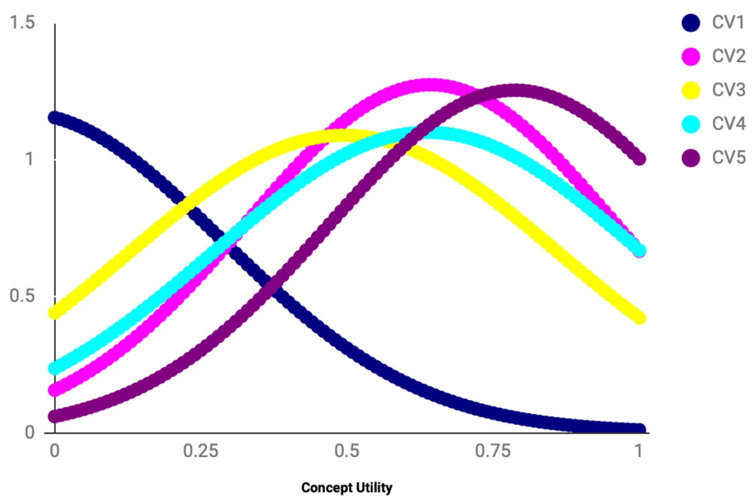


Figure 5: Uncertainty Curves

4 Embodiment Design and Prototyping

After the concept was selected, this concept was investigated by developing a proof-of-concept prototype. Based on what we learned developing this prototype, we chose to go with a different concept. We further refined this concept through CAD models and the alpha and beta prototypes to develop the final design.

4.1 Early Proof of Concept Prototyping

A proof-of-concept prototype was developed to determine the feasibility of triple-collapsible adjusting legs in our chosen design concept. To build this prototype, pieces of stock aluminum were chosen and holes were drilled along the sides. Then chopsticks were improvised to simulate pins which would lock the leg in place.

The goals of this prototype were to investigate:

- Overall feasibility.
- Manufacturing processes (e.g. drilling holes and ability to purchase certain types of materials)
- Potential fit, finish, and sturdiness of the final product
- Any design issues that may uncover themselves in the process of implementation

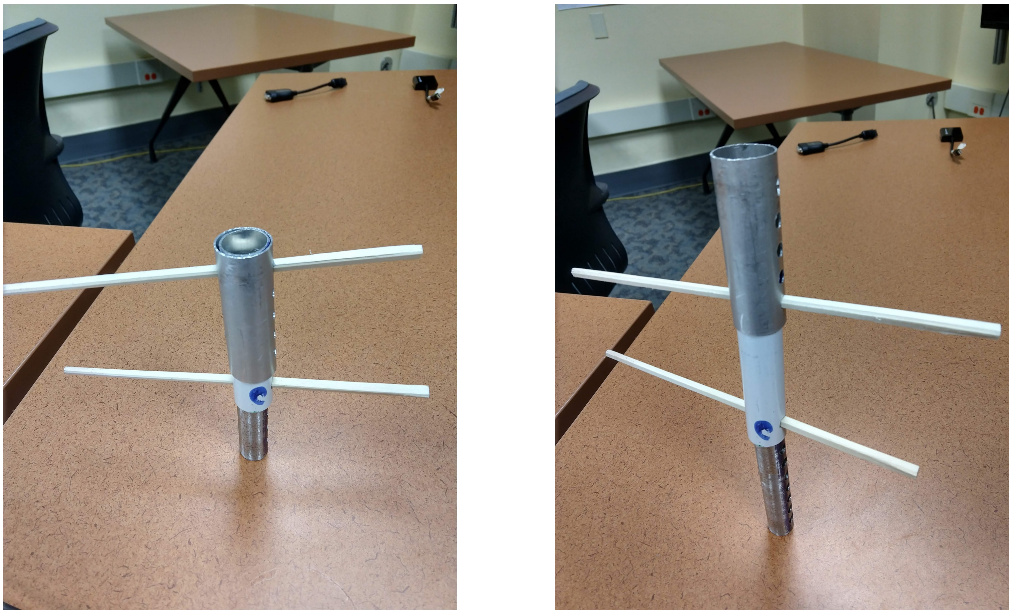


Figure 6: Triple-adjustable leg prototype in collapsed and extended positions.

The functioning prototype is shown in Figure 6. As can be seen, this principle is able to provide a length adjustment as required. In developing the prototype, hole patterns were developed that allow for adjust ability using pins, however, as can be seen, when collapsed there is still some holes left in the prototype to advance further. This is because the pin above is blocking the advancement of the section. The main lesson this provided us is to size each section appropriately so that the holes line up.

Based on this investigation, we discovered some difficulties milling holes in the tube in a straight line. Unfortunately, positioning the tube makes it difficult to drill an exactly straight line of holes as would be needed for a good fit and finish. As a result, we may need to procure tubes with holes in them to develop this.

Overall fit and finish in this prototype was poor, although that would not necessarily reflect on the final prototype, since it will be constructed by properly chosen and dimension ed stock pieces, rather than just what is available in the prototyping lab. Despite this, the leg does appear to be quite sturdy, which gives some confidence in the future design.

However, the most pressing issue with this prototype was the overall difficulty and feasibility of construction. Many parts would be required to be custom-designed or procured (including the legs themselves, pins/frictional adjustment mechanisms, leg hinges, suction cups, the surface folding mechanism, etc) that would slow down

Figure 7: The Alpha Prototype, with laptop and mouse for scale.

prototype development. Given our limited experience with/access to the shop, possible lead times/difficulties with procurement, as well as the impending deadline, this design does not seem to be feasible. Because of this, going forward, we decided to continue the design process with one of our simpler designs that will be easy to fabricate (likely Product Architecture Concept 5 shown in figure 23), since it mostly made out of wood (which will be easy for us to work with) and has few custom mechanisms and parts to design and manufacture.

4.2 Alpha Prototyping

After the alternate concept selection the next phase was the fabrication of the product for the proof of concept. The material that was used was the stock material available–.75 inch medium density fiber (MDF) boards and plywood. The density of the fiber board is quite high up to 720 kg/m3 or 1588 Lb/m3, while the density of the plywood used is around 650 kg/m3 or 1433 Lb/m3, this made the structure non uniform but served the purpose as a working alpha prototype. This prototype weighed about 15 pounds and as a result significant changes were needed to be made in order to make the product uniform and light in weight.

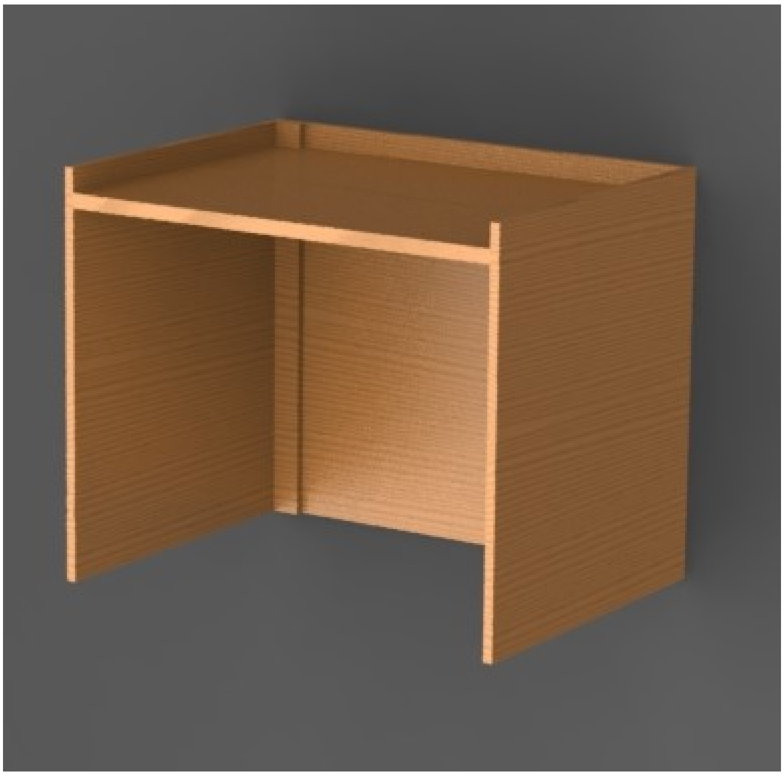


Figure 8: Starting CAD model of product concept.

The side walls of this prototype were embedded with rectangular shelf bracket pegs which stick out from the surface. On the back walls analogous slots were cut in order to accommodate the pegs when the table is folded. This design was quite sturdy except for the possibility of the top shelf falling down due to sliding of the side walls as they are hinged and do not have a mobility constraint, which allows the sides to slide apart, causing the shelf to fall and damaging the components atop.

4.3 Embodiment Design

The embodiment design process was focused on developing the realization that would appeal to the customer while being easy to prototype and manufacture. Embodiment began with the first CAD model shown in Figure 8. This low-fidelity CAD model, without hinges or supports added allowed us to begin to reason about folding/hinge placement and ways of mounting the surface, since that was not yet specified in the design. Some design solutions to these problems were then explored in the Alpha prototype and some CAD modelling.

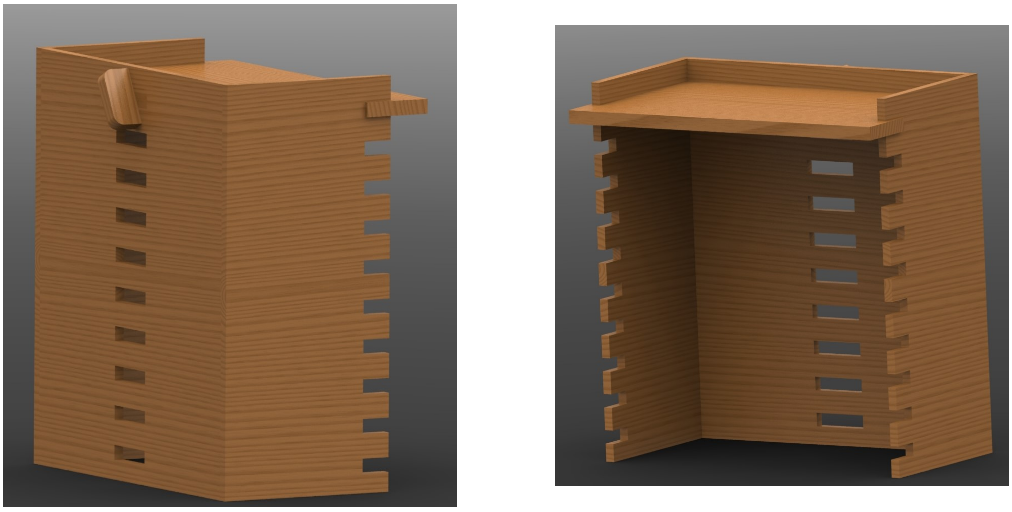


Figure 9: Variant explored in the embodiment design phase.

The Alpha prototype solved the folding issue by mounting the surface on horizontal pegs that fit into vertical slots when folded. It mounted the hinges on the outside of the side and back panel, which unfortunately made it fairly easy to push the sides out, causing the surface to drop. The alpha also divided the center into two panels to allow for a compact storage envelope. Based on these lessons, we decided to go with holding the surface with smaller pins (which would not stick through the wood panel), fold the center, and mount the hinges on the inside with a stopper to block the side panels as they open.

In addition to prototyping, some concepts were explored in CAD to enable easy folding. As shown in Figure 9, this concept ditched the concept of mounting pins in favor of cuts that the surface would fit into. To allow for better folding and lower weight, this concept opted for a smaller size that would allow the side panels to fold into the back panel without interfering with each other. This concept was rejected because in our prototype, the internal cuts in the back would be difficult to make precisely enough to locate the surface. However, the concept of internal hinges first used here was adapted into the final design.

5 Beta Prototype and Final Design

The final design is similar to the earlier prototype with several modifications to improve the aesthetics, functionality, maneuverability and value added modifications. Renders of the final design are shown in Figures 11 and 10 in the folded design.

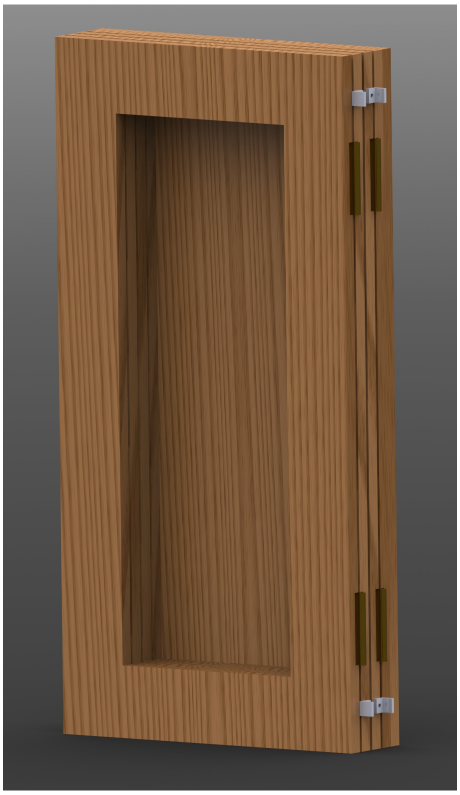


Figure 10: Final design in folded configuration

The beta prototype is shown in Figure 12. A demonstration of product setup and take-down is shown in Appendix B. As can be seen, this design satisfies the customer needs of being portable, allowing for a wide range of heights, being generally sturdy, and having enough space to work with a laptop and a few items.

5.1 Improvements in the Final Design

Various changes were made to the design during the design process leading up to the beta prototype to increase the value of the final product. Major portions of the walls are removed without compromising the strength of the design, which makes it light in weight (6-7 lbs) and easy to carry around. All the walls are made of Birch ply wood, Birch being an excellent material offers rich patterning and high strength-to-ratio. All the wooden structure is double coated with a combination stain and polyester coating to give it an excellent look and provide protection from water spills and moisture. The rectangular shelf pegs are replaced by sleek flat top round micro pegs that look much more aesthetically pleasing and subtle. All the

Figure 11: Final design rendering as viewed from front and back.

metal mountings are made of brass which gives a royal look on high quality polished surface. The long rectangular slots on the back walls are completely eliminated by just making holes wide enough to accommodate the mini pegs on the side walls.

The functionality has been greatly enhanced by adding locks, a Velcro strap, and a central gap in the wooden panels. Locks are provided near the hinges which restrict the backward movement of the side walls thus reducing the risk of top shelf falling and thus protecting the valuable placed atop the shelf. A travel band (Black colored band) is attached to the working shelf which can be fastened across the side walls as shown in the figure above. The band equipped with a handle can be wrapped around all the components when folded which facilitates ease of mobility. The vacant space in the middle of the back walls are well suited to pass the heavy cable web on the other side of the device and assist in chord management.

The longitudinal slots along the back walls are eliminated to reduce machining time and improve the rigidity to the entire structure. They have been replaced by holes which can be machined in much lesser time and do not compromise strength or aesthetics, since they do not need to pass all the way though the back panel.

All the rectangular sections of the table are made symmetrical to reduce the complexity and for ease of manufacturing. This operation can be easily carried out on a table saw by a semi skilled technician. Other types of machines that can be used are circular saw or a reciprocating saw. Along with this, pre-cut sections can be ordered or outsourced directly to reduce the machining time.

Figure 12: Beta Prototype, with laptop and mouse for scale.

5.2 Manufacturing and Assembly

The general manufacturing and assembly sequence is shown below for a manual fabrication and assembly process. This process may change given the use of automated and more specialized/advanced manufacturing techniques. The final drawings, BOM, and materials list are shown in Appendix C.

1. Cut plywood into 24x12" sections.
2. Measure and place all hole locations.
3. Cut central gaps into plywood.
4. Drill all holes to required diameters, lengths, and widths.
5. Chisel locations for hinges.
6. Sand plywood panels.
7. Apply coats of varnish and allow time to dry.
8. Place and glue mounts in holes.
9. Staple velcro strap to surface panel.

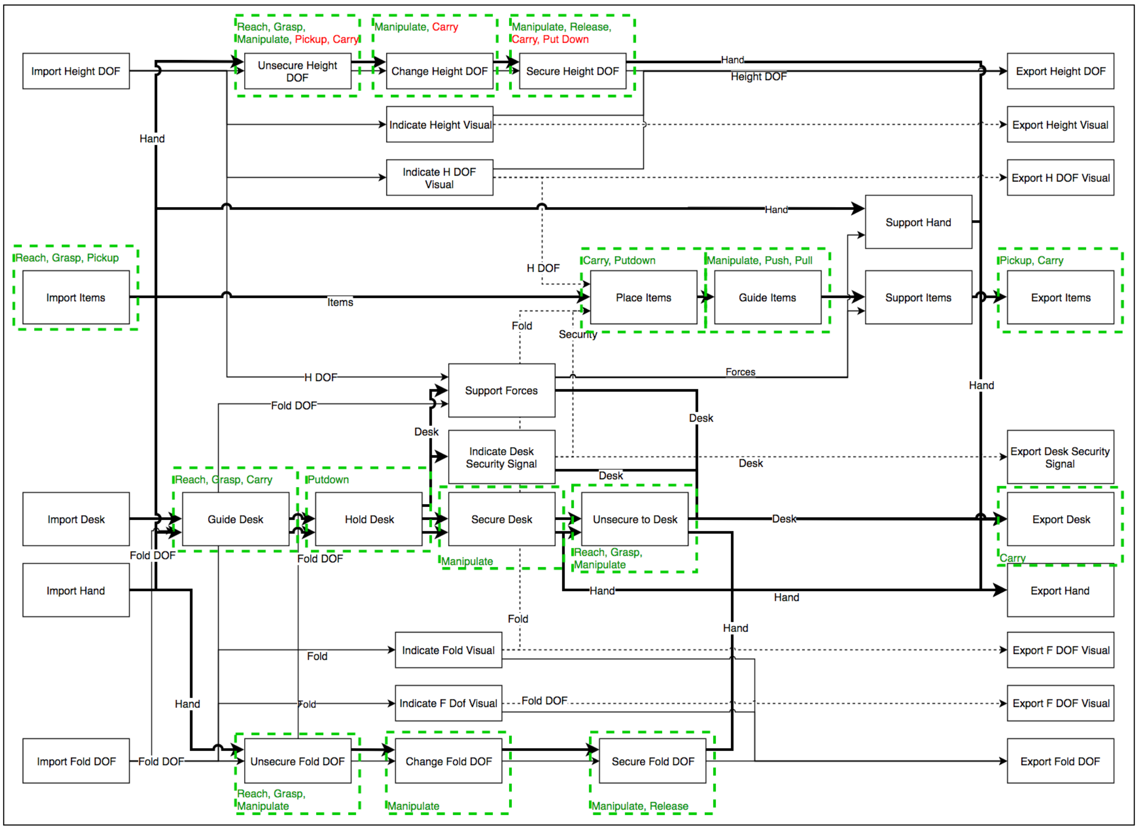


Figure 13: Action Function Diagram of the Stand-Up Desk

10. Assemble panels with hinges.
11. Screw stoppers to back panels.

More instruction about manufacturing and assembly is given in the BOM and drawings in Appendix C.

6 FHEDM Post-Conceptual Design Analysis

To gather data about the FHEDM method of Zurita et al. (2018), a post-design application of the method was performed to see if the FHEDM process performed at the beginning of the design process was predictive of human errors that would occur in the final product. To summarize, the functional model did not require any modifications since the overall functionality of the desk and how they will be achieved. However some user interactions had to be modified in order to fully reflect the user product interactions after the concept was developed. The newly added user interactions are indicated in "red" text in fig. 13. The user interactions for the functions related to adjusting the height of the desk were modified because the mechanism to change the height of the desk was different that what was originally planned. Originally, the height adjustment mechanism was imagined to be achieved by having adjustable legs. However, in the final design this was achieved by moving the table top. Hence, the actions, picking up, carrying, and putting down had to be added to the functions related to unsecuring height degree of freedom, changing height, and securing height degree of freedom. The added user interaction changed the overall composition of the function-human error matrix.

Table 12 shows the function-human error matrix that resulted from the FHEDM analysis. The cells that are bordered with "red" dotted lines indicated the entries that have changed with the post conceptual analysis. The cells highlighted in "blue indicate entries that have a score greater than one. The changes were seen in the functions relating to changing the height of the desk. This is expected because the user interactions relating to these functions had changed. As far as errors that score greater than one, they were related to reach, grasp, manipulation, engaging/disengaging objects, and applying force. The same set of errors scored greater the one during the original analysis and some adjustments were made to mitigate these errors. For example, to mitigate errors to reach, grasp, and manipulate the design was adapted to have large reach surfaces with good grip. Since the mitigating actions were already considered in the for those errors, the new design does not require any additional modifications.

Table 12: FHEDM Function Human Error Matrix

	Generic Error: Fail to														
Function	Reach Specific Target	Reach Small Object	Grasp target Object	Re-grasp Object	Manipulate	Engage Object	Disengage Object	Release	Pick up	Transfer Object to Exact Location	Move Grasped Object	Transfer Object Correctly	Fail to Position Object	Apply Force	Apply Pressure
Unsecure Height DOF	3	3	3	3	2	2	2	0	1	1	1	0	0	0	0
Change Height DOF	1	1	1	1	2	1	1	0	0	1	1	0	0	0	0
Secure Height DOF	1	1	1	1	2	1	1	2	0	1	1	1	1	0	0
Import Items	2	2	2	2	0	1	1	0	1	0	0	0	0	0	0
Place Items	1	1	1	1	1	0	0	1	0	1	1	1	1	0	0
Guide Items	0	0	0	0	1	1	1	0	0	0	0	0	0	2	2
Export Items	2	2	2	2	1	0	0	0	1	1	1	0	0	0	0
Guide Desk	2	2	2	2	1	1	1	0	0	1	1	0	0	0	0
Hold Desk	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0
Secure Desk	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
Unsecure Desk	1	1	1	1	1	2	2	0	0	0	0	0	0	0	0
Export Desk	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0
Unsecure Fold DOF	1	1	1	1	1	2	2	0	0	0	0	0	0	0	0
Change Fold DOF	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
Secure Fold DOF	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0

However, some ergonomic vulnerabilities that could affect user safety were found during the embodiment and prototyping process. Several sharp edges, pointy corners, and potential pinch points were identified in the prototype. These were vulnerabilities that were only recognized during or after prototyping. If such vulnerabilities were known early in design, we could have come up with designs that safer. While FHEDM does not help with identifying such ergonomic vulnerabilities, tools like Digital Human Modeling allow designers understand such risks. As future work, we would like to run a Digital Human Modeling Analysis to identify any unforeseen ergonomic vulnerabilities and mitigate them.

7 Conclusion

In this report, we have gone through the details of the design process of a Stand Up table. The report started with identifying the problem and performing market research. Then, potential customers were identified and customer needs were gathered using customer needs gathering techniques such as customer interviews, ontological method, and outcome driven method. Next, potential concepts were generated using morphology approach, product architecture approach, bio inspired design, story boarding method, and mind mapping. A Pugh chart was then used to select the top 5 concepts generated. Utility based selection and uncertainty analysis was used to select the final concept. Once the final design was chosen, a proof of concept was developed. Using the lessons learned from the proof of concept an alpha prototype was then created. Then, the design was further refined and a beta prototype was created. The design gives recommendations for the final design are also provided. The manufacturing method is then described in detail. Finally, an FHEDM analysis is performed to the final design to understand human product interactions and identify potential human errors.

7.1 Project Insights

Based on our experience with this project, the design space for this product is fairly large, and several concepts appeared throughout the concept generation and embodiment design processes that would be fruitful to explore further. However, we were not able to pursue them because of the time constraint for the whole project. This 10 week constraint, in addition to narrowing the design space we were able to explore, kept us from embodying the best-scoring concept from our selection process. Once the proof of concept was done, we realized that we will not be able to manufacture the concept that came out of the concept selection process on time. So, we had to change course and chose an alternative concept that can be manufactured within the time frame even though we knew that there were better designs available. However, once that roadblock was cleared we were able to make the best out of the chosen concept making satisfy all of our customer needs. The various stages of prototyping helped immensely to test the product in person and to tailor the design to fit the customer needs while being cheap and manufacturable.

Apart from the issue mentioned above the overall experience was enlightening. We were able to get a deep a sense of the product development process while not just learning the theories but also by applying them. In addition, we were able to learn soft skills surrounding working as team. Furthermore, the FHEDM process helped us understand the user-product interactions and potential for human error very early in design allowing us to have the capabilities and limitation of the users in mind through the design process. The prototyping of the product helped understand the importance of having manufacturability in mind while coming up with concepts. These are lessons we as a team will carry forward during our future design endeavors.

References

Evans, R. E., H. O. Fawole, S. A. Sheriff, P. M. Dall, P. M. Grant, and C. G. Ryan (2012). Point-of-choice prompts to reduce sitting time at work: a randomized trial. *American journal of preventive medicine 43*(3), 293–297.

Healy, G. N., K. Wijndaele, D. W. Dunstan, J. E. Shaw, J. Salmon, P. Z. Zimmet, and N. Owen (2008). Objectively measured sedentary time, physical activity, and metabolic risk: the australian diabetes, obesity and lifestyle study (ausdiab). *Diabetes care 31*(2), 369–371.

Katzmarzyk, P. T., T. S. Church, C. L. Craig, and C. Bouchard (2009). Sitting time and mortality from all causes, cardiovascular disease, and cancer. *Medicine & Science in Sports & Exercise 41*(5), 998–1005.

Mummery, W. K., G. M. Schofield, R. Steele, E. G. Eakin, and W. J. Brown (2005). Occupational sitting time and overweight and obesity in australian workers. *American journal of preventive medicine 29*(2), 91–97.

Nix, A., M. Lemke, R. Stone, and R. Arlitt (2017). The creation of an ontology to examine customer needs. In *ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, pp. V007T06A043–V007T06A043. American Society of Mechanical Engineers.

Otto, K. N. et al. (2000). *Product design: techniques in reverse engineering and new product development*. Pearson.

Ross, R., K. Rouen, and J. Austin-Breneman (2018). Extending lead user theory to participatory co-design: A case study in a base of the pyramid context. In *ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, pp. V007T06A028–V007T06A028. American Society of Mechanical Engineers.

Ryan, C. G., P. M. Dall, M. H. Granat, and P. M. Grant (2011). Sitting patterns at work: objective measurement of adherence to current recommendations. *Ergonomics 54*(6), 531–538.

Thorp, A., D. Dunstan, B. Clark, P. Gardiner, G. Healy, T. Keegel, and E. Winkler (2009). Stand up australia: sedentary behaviour in workers. *Docklands, Victoria, Australia: Medibank Private Limited*.

Ulwick, A. W. (2002). Turn customer input into innovation. *Harvard business review 80*(1), 91–7.

Van Uffelen, J. G., J. Wong, J. Y. Chau, H. P. van der Ploeg, I. Riphagen, N. D. Gilson, N. W. Burton, G. N. Healy, A. A. Thorp, B. K. Clark, et al. (2010). Occupational sitting and health risks: a systematic review. *American journal of preventive medicine 39*(4), 379–388.

Zurita, N. F. S., R. B. Stone, O. Demirel, and I. Y. Tumer (2018). The function-human error design method (fhedm). In *ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, pp. V007T06A058–V007T06A058. American Society of Mechanical Engineers.

A Concepts Generated

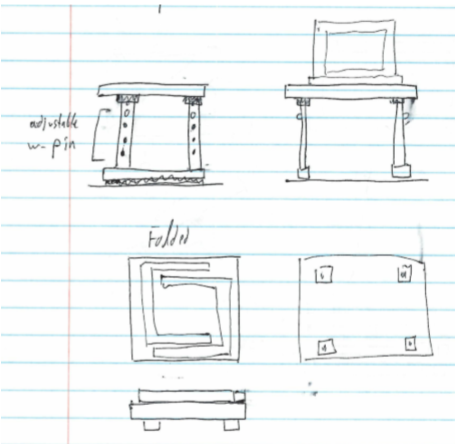


Figure 14: Morphology Concept 1

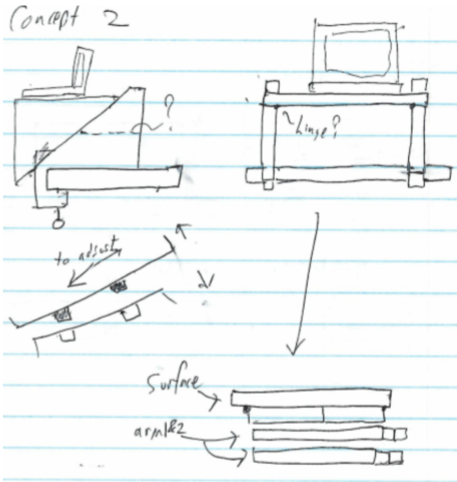


Figure 15: Morphology Concept 2

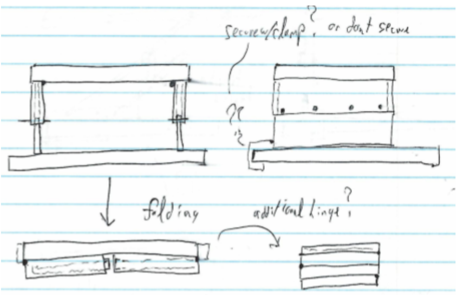


Figure 16: Morphology Concept 3

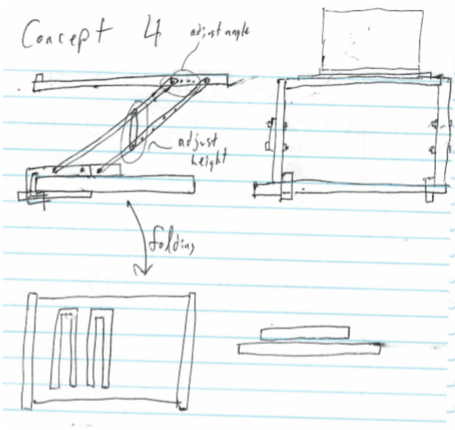


Figure 17: Morphology Concept 4

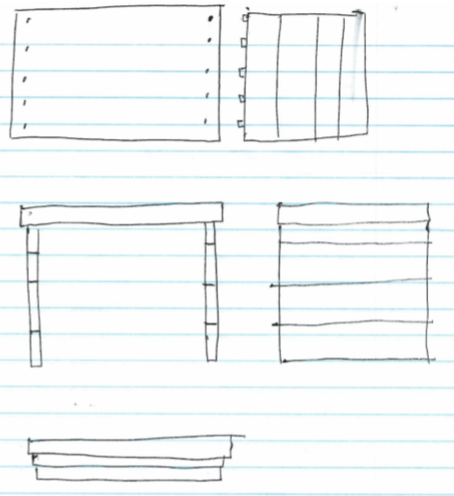


Figure 18: Morphology Concept 5

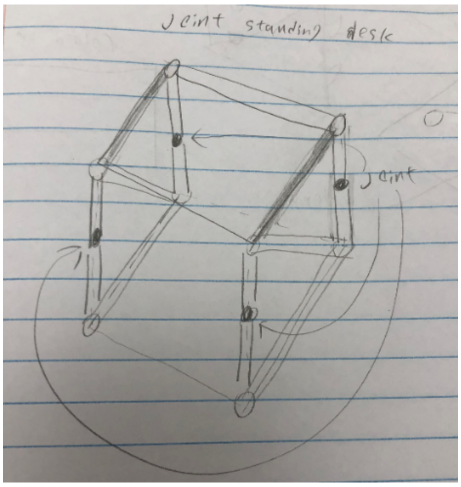


Figure 19: Product Architecture 1

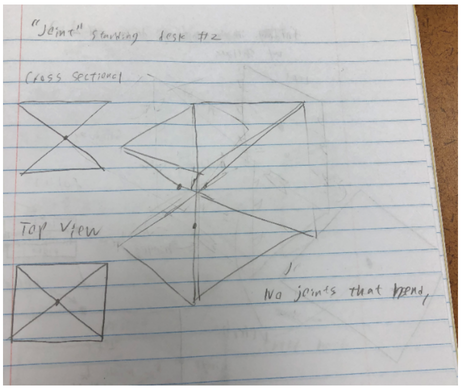


Figure 20: Product Architecture 2

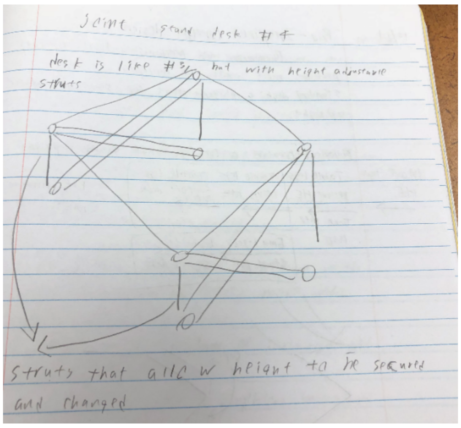


Figure 21: Product Architecture 3

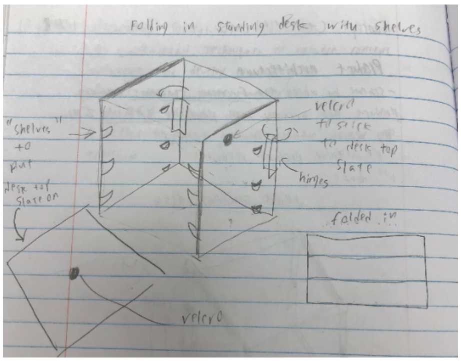


Figure 22: Product Architecture 4

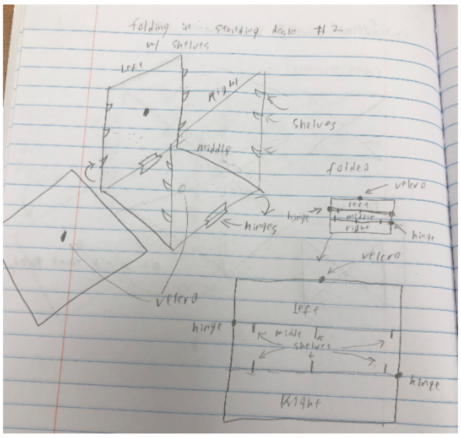


Figure 23: Product Architecture 5

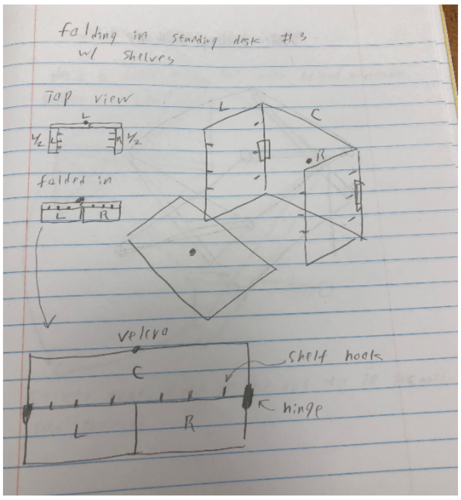


Figure 24: Product Architecture 6

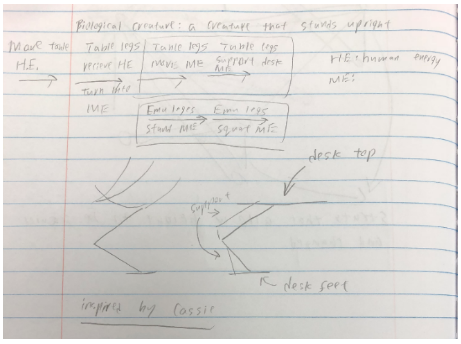


Figure 25: Bio-Inspired Concept 1

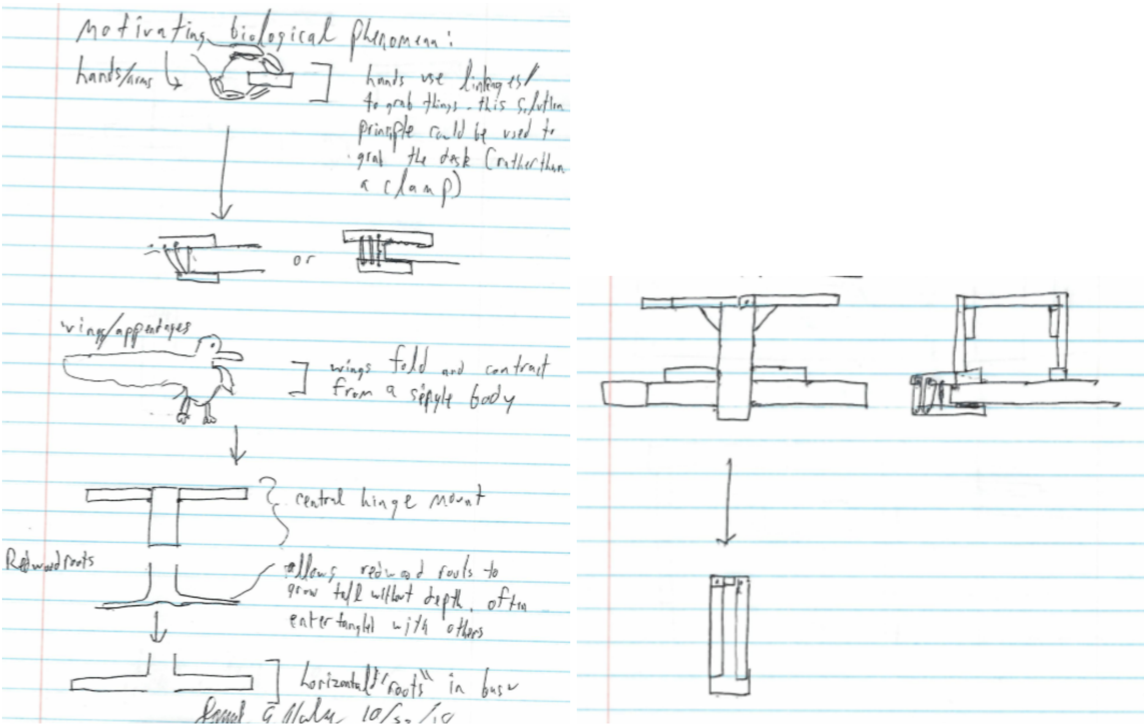


Figure 26: Bio-Inspired Concept 2

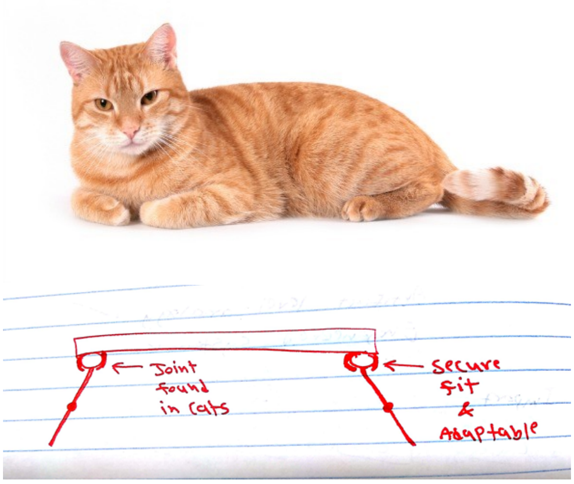


Figure 27: Bio-Inspired Concept 3

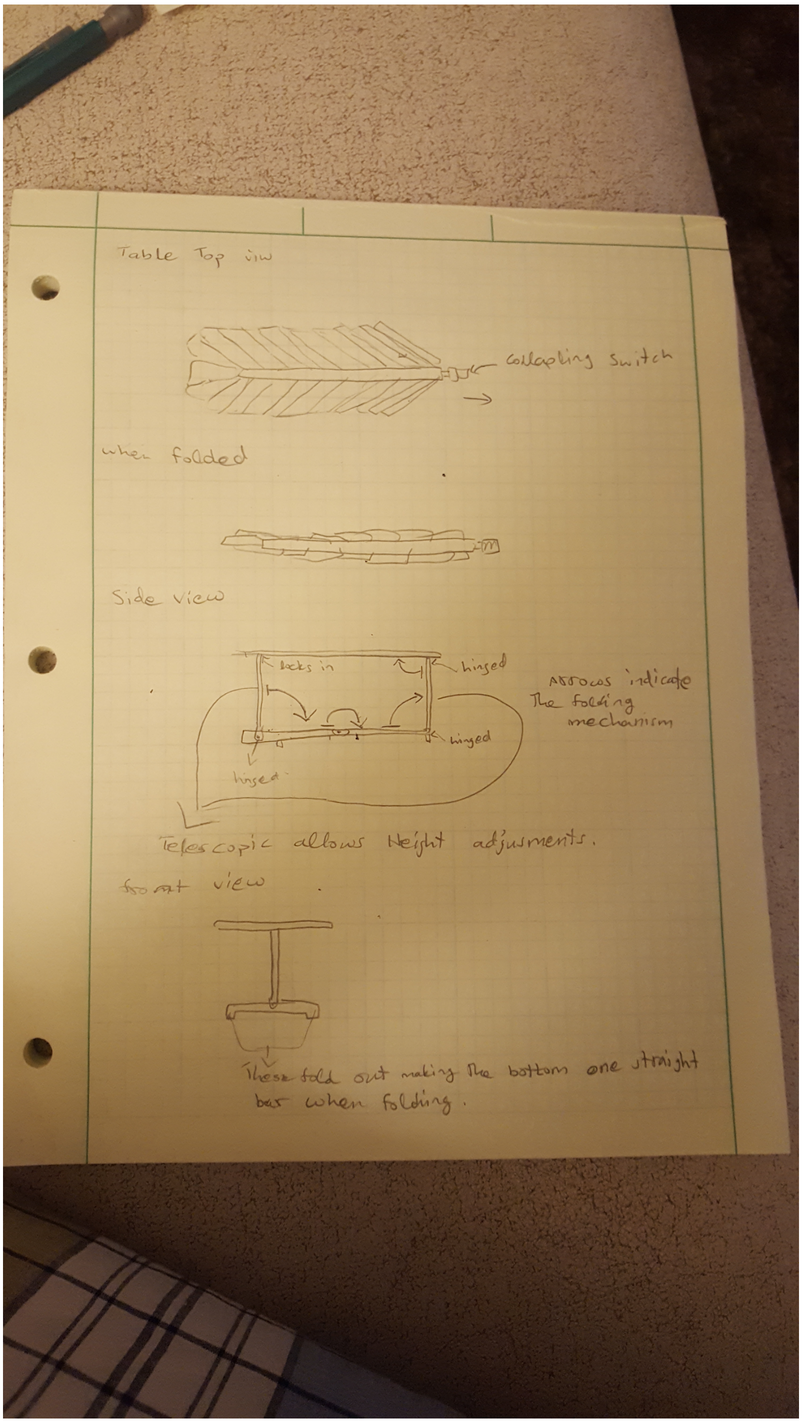


Figure 28: Bio-Inspired Concept 4

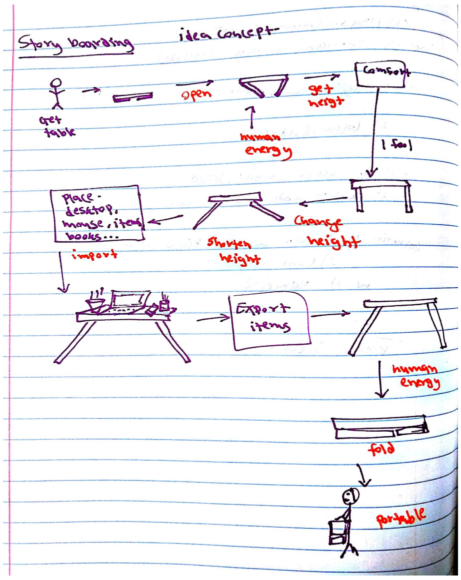


Figure 29: Story Telling Concept 1

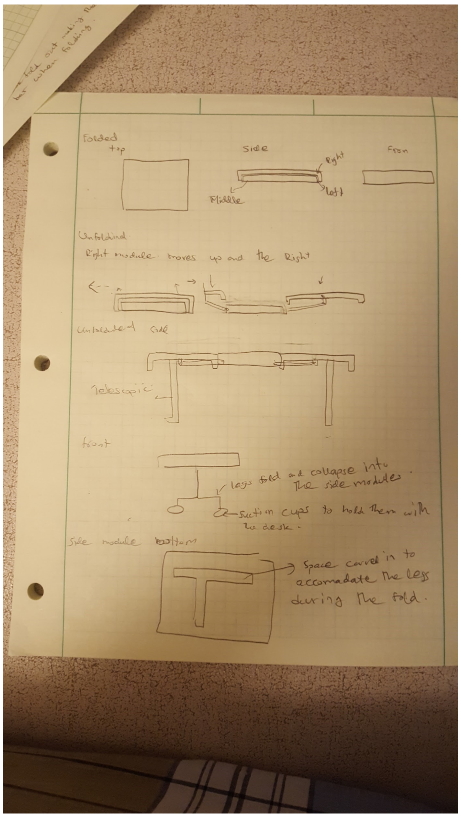


Figure 30: Story Telling Concept 2

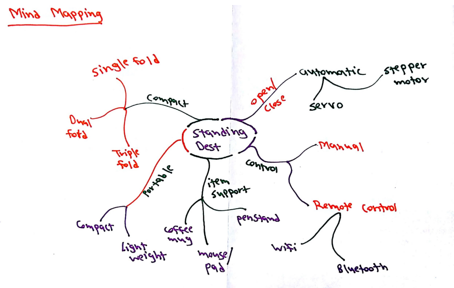


Figure 31: Story Telling Concept 3

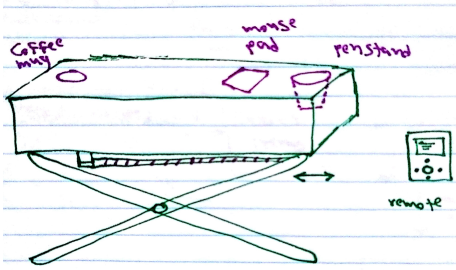


Figure 32: Story Telling Concept 1

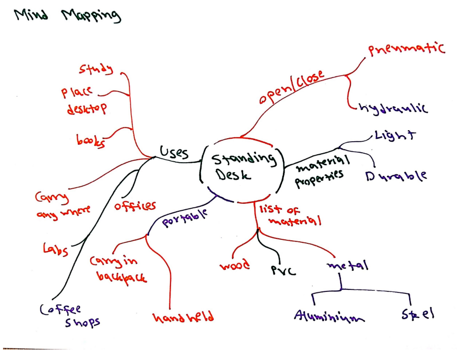


Figure 33: Story Telling Concept 2

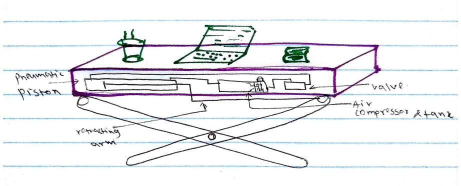


Figure 34: Story Telling Concept 2

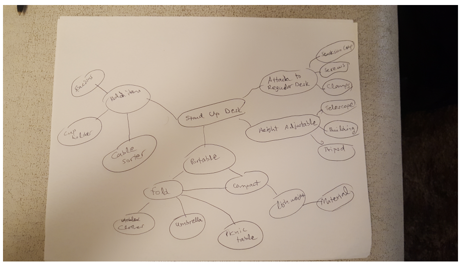


Figure 35: Story Telling Concept 3

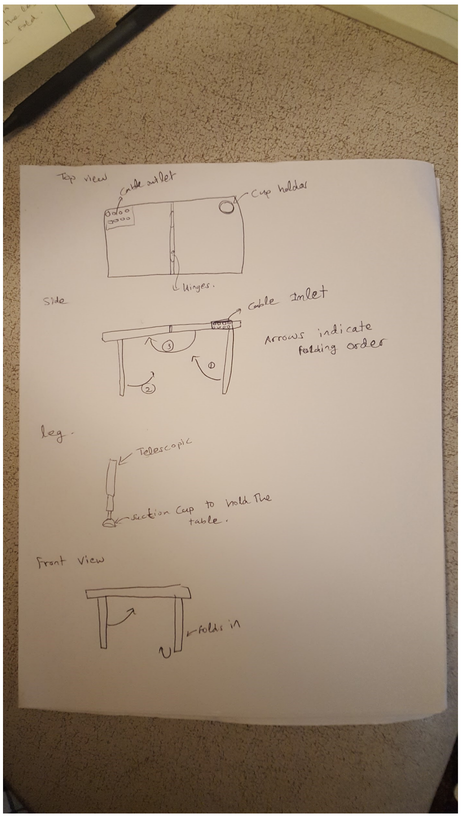


Figure 36: Story Telling Concept 3

B Beta Prototype Images/Demonstration

Figure 37: Folding the desk.

Figure 38: Folding and securing the desk in a compact configuration.

Figure 39: Carrying the desk and size comparison of Alpha and Beta prototypes.

C Final Drawings

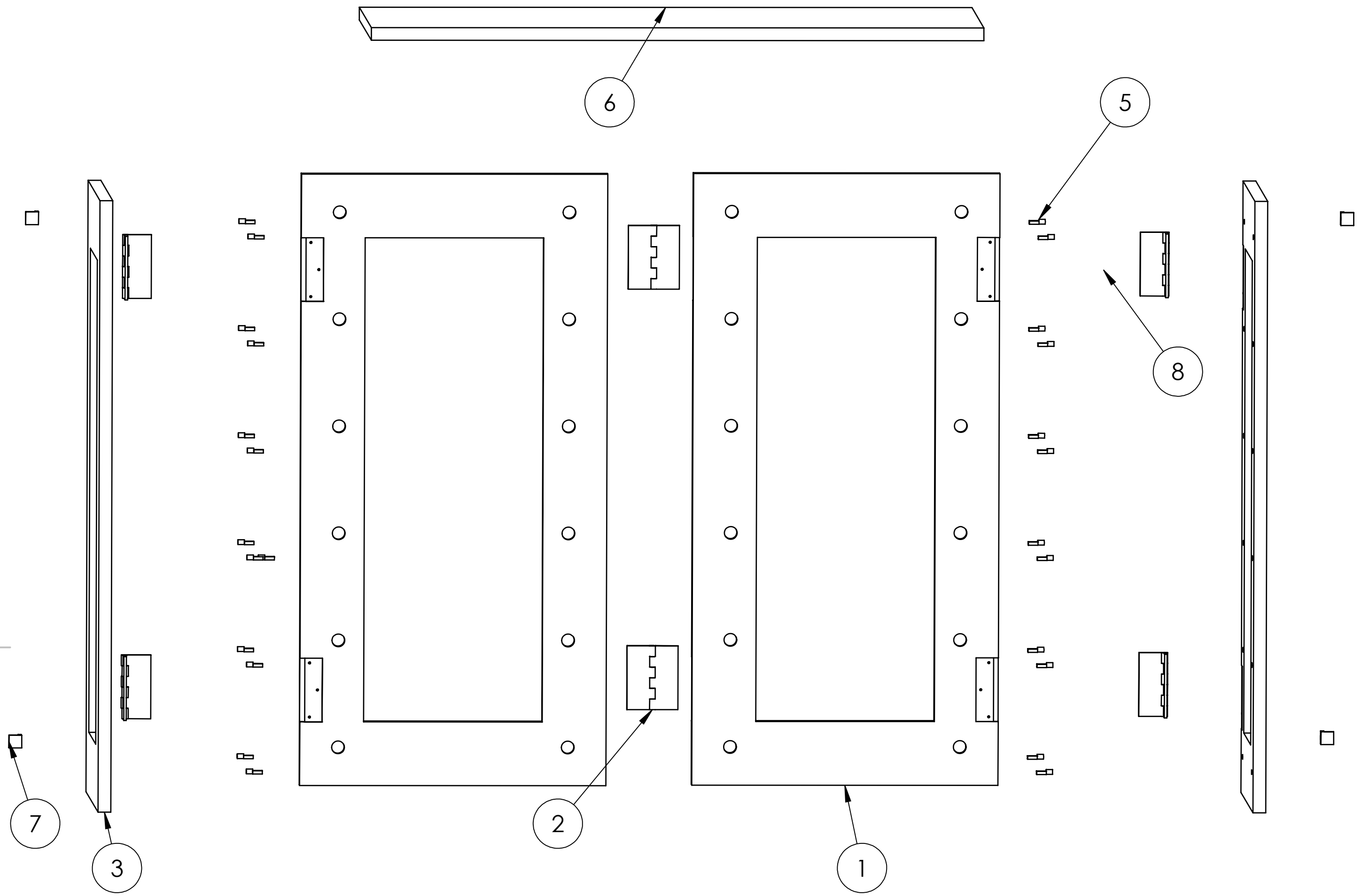
C.1 Assembly Drawing (Page 48)

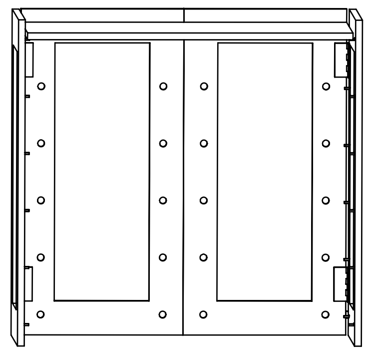
C.2 Back Panel Drawing (Page 49)

C.3 Side Panel Drawing (Page 50)

C.4 Bill of Materials (Page 51)

C.5 Raw Materials List (Page 52)





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Back	see: back-panel drawing	2
2	hinge	Hinge, non-mortise 1 4/5 in x 2.5 in.	6
3	Side	see: side-panel drawing	2
4	N/A	N/A	
5	mount	Shelf Pin, 5mm, Brass	25
6	surface	12x24x1/2" Birch Plywood, stain/poly finish	1
7	stopper	20 lb. 1/4 in. Nickel-Plated Shelf Support Pegs	4
8	screw	Wood Screws, Brass, #6, .5" length	34
9	velcro strap	Velcro strap with handle, 2in x 6 ft	
10			

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:
Varathane Stain and Polyurethane, Antique Walnut, Satin

DEBURR AND BREAK SHARP EDGES
SAND AND APPLY PUTTY WHERE REQ'D

DO NOT SCALE DRAWING

REVISION 1

	NAME	SIGNATURE	DATE
DRAWN	DANIEL HULSE		12/3/18
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:
Standing Desk Assembly

MATERIAL:

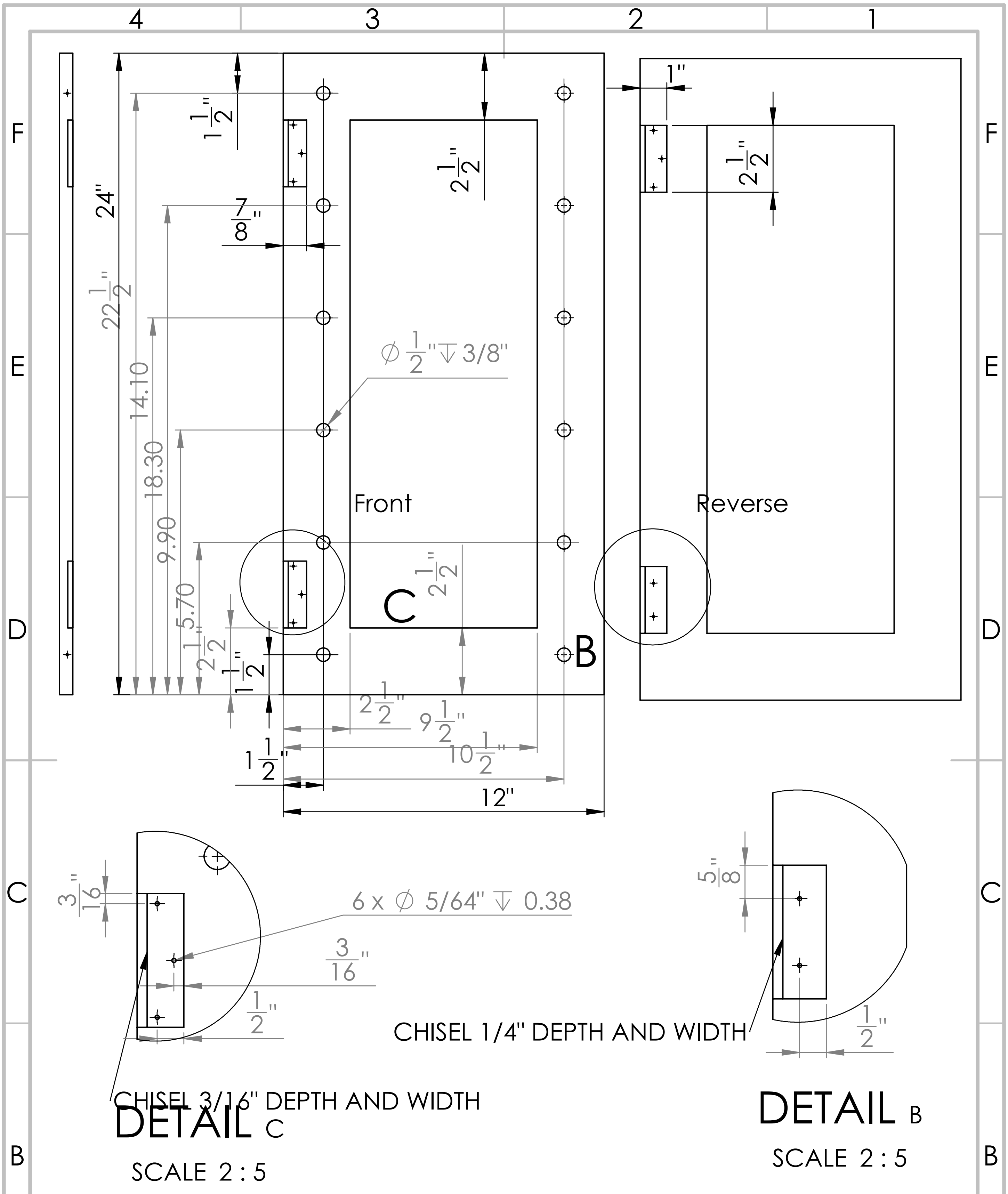
DWG NO.
desk

A3

WEIGHT: 7 lbs

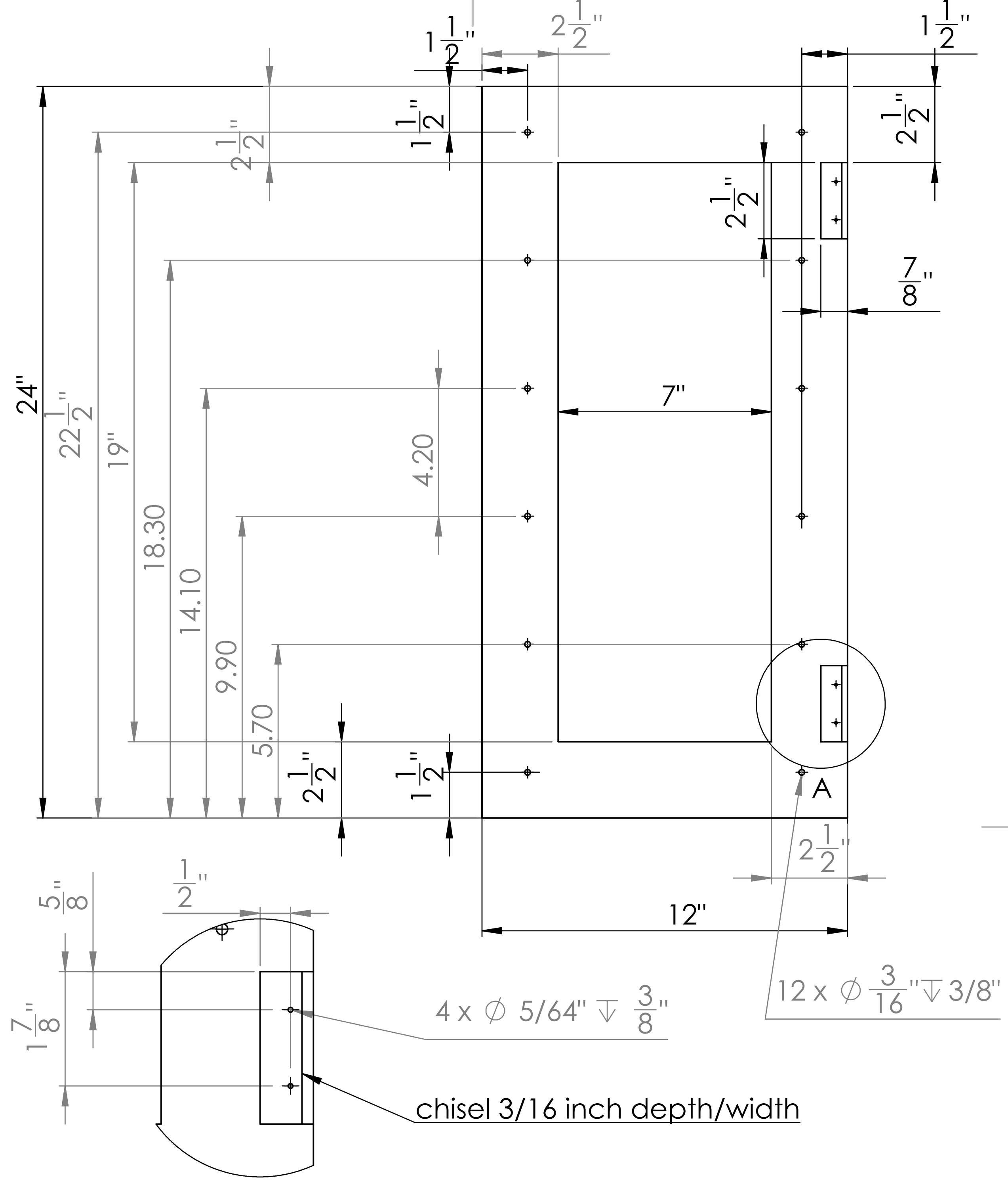
SCALE:1:20

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: Varnish withVarathane Stain and Polyurethane, Antique Walnut, Satin	DEBURR AND BREAK SHARP EDGES SAND AS REQ'ED	DO NOT SCALE DRAWING	REVISION 1

	NAME	SIGNATURE	DATE			TITLE: Back Panel
DRAWN	Daniel Hulse		12/3			
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:1/2" Birch Plywood		DWG NO. back-panel — A4
				WEIGHT: 1.5 lbs		SCALE:1:10 — SHEET 1 OF 1



DETAIL A
SCALE 2 : 5

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH: Varnish with Varathane Stain and Polyurethane, Antique Walnut, Satin	DEBURR AND BREAK SHARP EDGES SAND AS REQ'D	DO NOT SCALE DRAWING — REVISION 1

	NAME	SIGNATURE	DATE
DRAWN	Daniel Hulse		12/3
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Side Panel

MATERIAL: 1/2 inch Birch Plywood

DWG NO. side-panel

A4

WEIGHT: 1.5 lbs

SCALE:1:10

SHEET 1 OF 1

BOM	
Product:	Standing Desk
Author:	Daniel Hulse
Rev:	1
Date:	12/03/18

#	Description	Qty	Function	Mfg/Assm Plan	MFG Time, hrs	Dimensions/Characteristics	RM#
1	Back	2	stabilize size supports	cut profile, bore holes, drill holes for screws, chisel hinge inserts, varnish	4	½ x 12 x 24 birch	6,1
2	hinge	6	allow folding of dof	Screw to back and side panels as per screw locations	N/A	1 4/5 in x 2.5 in non-mortise	5
3	side	2	hold and stabilize surface	cut profile, drill holes for screws, chisel hinge inserts, varnish	4	½ x 12 x 24 birch	6,1
4	N/A						
5	mount	25	hold surface and allow for height adjustment	Apply contact cement and press into holes in side panels	N/A	5mm brass	7
6	surface	1	hold items	Cut dimensions, varnish	0.25	½ x 12 x 24 birch	6,1
7	stopper	4	constrain dof of hinges below 90 degrees for safety	Screw to back panel	N/A	Nickel-plated, ~1/2 inch	8, 2
8	screw	34	connect hinges, stopper, side, back panels	N/A	N/A	wood screws, brass, #6, .5" length	4
9	velcro strap	1	lock dof, carry desk	Staple to surface	N/A	2in x 6fth	3

Raw Materials List	
Product:	Standing Desk
Author:	Daniel Hulse
Rev:	1
Date:	12/03/18

#	**UPC/SKU**	**Description**	**Source**	**Qty**	**Cost, $**
1	020066427689	Varathane Stain and Polyurethane, Antique Walnut, Satin	Home Depot	1 Qt.	13.28
2	070798001053	Weldwood Contact Cement	Home Depot	3 Oz.	5.98
3	075967904821	Velcro strap with handle, 2in x 6 ft	Home Depot	1	8.47
4	887480020625	Wood Screws, Brass, #6, .5” length	Home Depot	100	6.68
5	030699150885	Hinge, non-mortise 1 4/5 in x 2.5 in.	Home Depot	2	2.27
6	090489314057	1/2” Birch Plywood	Home Depot	2x4 ft	21.47
7	887480024142	Shelf Pin, 5mm, Brass	Home Depot	48	6.86
8	331325	20 lb. 1/4 in. Nickel-Plated Shelf Support Pegs	Home Depot	8	1.86