Miracle Manufacturing

Tutorial 13, Group 5

As future members of the engineering profession, we, Miracle Manufacturing, are responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with our names and signatures is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University and the Code of Conduct of the Professional Engineers of Ontario.

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0.0 Summary

As Miracle Manufacturing, we created a device to address our client's need to carry her belongings. As our client, Kim, suffers from multiple sclerosis, she has difficulties transporting cargo on her wheelchair and currently requires the aid of her caretakers and her husband Tim. However, Kim wishes to retain her independence, and so would prefer to be able to handle her own cargo without the assistance of others. Our prototype aims to accomplish this for her. It is easy to take a full range of mobility for granted, but this is an everyday issue for our client. By designing our prototype to be intuitive, unobtrusive, and accessible, we have attempted to create the ideal solution for Kim's needs specifically. Our device is meant to stay out of the user's way as our goal is to improve Kim's quality of life without impeding her in any way. With this philosophy in mind, our device is both lightweight and fully stowable. At any time, the prototype can be disengaged and brought out of her way. It is easy to use, and does not require any fine motor skills to operate. Our device will enable Kim to be more self-reliant. With the use of the prototype, she'll be able to handle her own belongings when she wants to. With this ability comes increased convenience, as well. As this device was designed specifically for Kims wheelchair and with her as the intended user, we believe that it has an advantage over any currently existing alternatives.

1.0 Introduction

1.1 Background Information

In the Engineering 1P03 course at McMaster University, all of the students complete a final design project using the engineering design process they learned throughout the year. The goal of this project is not just to complete an assignment, but it is also meant to help people. This year, students are to choose between two clients, Kim and Tim. Students select a problem that either Kim or Tim is struggling with, and attempt to design a device to address that issue. We chose to help Kim, a person who suffers with multiple sclerosis - a degenerative disease that affects nerve cells and the spinal cord. This has caused Kim to lose strength in her muscles and given her reduced motor control. Kim told students about her struggles going through doors, carrying cargo, and protecting her control pad. For our final assignment, we decided to help Kim carry cargo.

1.2 Refined Problem Statement

Every engineering project consists of an issue or problem that needs solving. To solve the problem properly without missing anything, you have to make sure you have identified the problem properly. To get the most accurate problem statement, we used information Kim told us about her condition and the importance of the problems to her in her everyday life **[7, 8]** . As our group went through the engineering design process we kept on modifying and changing our problem statement until we ended up with our final refined problem statement: To design a cargo holding device for Kim, a person with multiple sclerosis who cannot carry cargo by conventional means. The device should attach to her wheelchair, be unobtrusive, and allow Kim to be more independent of her caretakers. This problem statement is a clear, concise, and covers the full breadth of Kims problem.

1.3 Objectives, Constraints and Metrics

The main objectives for the project design are comfort, ability to carry cargo, and affordability. It is mandatory that the device be removable from the wheelchair. For the device to be comfortable for Kim, it would have to be easily adjustable. This can be achieved by making the device lightweight through the use of low density wood. It would also have to be unobtrusive, and this was done by dimensioning the product so it would never take more than 2 inches of extra room, whether resting or in use.

It is also essential that the device be removable, as the wheelchair is not owned by Kim. This was a constraint in our design. This can be achieved through the use of industrial velcro on the main arm, that allows it to be attached to the side of the chair firmly, while still being removable.

Another constraint was that the device must not require any fine motor skills to operate. As multiple sclerosis is a degenerative disease, Kim’s condition will worsen over time. This means that even is she has the strength required to operate a device now, she may not have that same strength in the near future. This was a constraint that we had to keep in mind over the entire design process.

The device must be able to withstand any weight Kim might reasonably subject it to, and so wood with high tensile strength was used for the product.

Affordability was also a factor, although our priority was to ensure the best possible experience we could for our user so we did not actively hunt cheap prices. Our effective use of campus facilities, however, helped to minimize cost.

We also came up with metrics to test how effective our device is. A diagram of the Metrics and objective tree can be found in Appendix B figure 1, along with a table in Appendix B table 1. The primary objective of our device was to actually carry the cargo; to this end, we created a scoring system for our design. For every five pounds that our device could support, we would award the device one point for the metric, up to a maximum of ten points. We set the maximum at ten points (fifty pounds) because we felt that that was a realistic maximum weight for Kim to be carrying and for us to manufacture for. Our device scored a ten on this metric. We also created a metric for the stowability of the device, or in other words, how quickly the device can be brought from its engaged position to its stowed position. We decided that for this metric, the device's score would start at the maximum 10, and for every three seconds that the device takes to be stowed, one point would be deducted. Our device scored a nine on this metric.

1.4 Prior Art

1.4.1 Existing Products

Right now, there are already existing commercial products that provide solutions to Kim's problems, although these solutions aren't specifically tailored for her. As stated earlier, we chose to help Kim carry cargo. Addressing the problem at hand, A company called Advantage Bag company has created a product that acts as a storage device for wheelchairs (Figure 1 Appendix D). This device is attached under the wheel chair seat, connecting from one side of the wheelchair frame to the other. It is attached using velcro loops that go around the frame. The method of attachment on this product is good because it is a non-permanent solution, and if Kim wants to return the wheelchair she will be able to. This device does solve Kim's problem, but it does not meet some of the constraints specified. First of all, because of Kim's low upper body strength and weak motor control, it would be very hard for her to reach down and store cargo under her chair. Most of the times she would need to ask her caretakers or Tim to help her with it, and this does not help with that fact that Kim is trying to be more independent. [3]. Furthermore, there is another commercial product that provides a solution to one of Kim's problems. This product is a backpack for electric wheelchairs (Figure 2 Appendix D). It is mounted on the back of the electric wheelchair and provides a lot more cargo space than the initial factory design offers. The only drawback for this solution is the positioning. Because of her damaged nerves from Multiple Sclerosis, she would have difficulties twisting to get it from behind her. In addition, there is another product that provides Kim with a cargo carrying solution. It is a storage pouch with a built-in cup holder (Figure 3 Appendix D). This pouch is mounted onto her arm rest, using strong elastic polyester straps. The only issue with this product is that it would be difficult for Kim to install and remove the pouch, but as this is a low-profile storage device she may not have the need to do so. Because of the location, this device lets Kim put cargo in the holder and remove it easily, and makes her every day life more efficient. [4]

1.4.2 Patents

The problem we chose to solve is helping Kim to carry and hold things in her wheelchair. However there are already numerous pieces of technology that have already been designed to tackle similar problems to ours. Therefore, we had to be aware of these pieces of technology to make sure that we not only avoid patent infringement but also open ourselves to different possibilities. This could help give an idea of what can be improved on existing designs to match Kims needs. The following are some of the pieces of technology we need to keep in mind.

Firstly, there is the “Tray supporting device for a wheelchair”, invented by Simon Suh in 2001. This device has an attachment on the back of the wheelchair. The attachment connects to an arm that elongates to the front of the user, where the holding tray is attached, as seen in Figure 4 of Appendix D. This device was designed to hold food and drink items on the tray but it can be used to hold other items as well [1].

Then there is the “Receptacle attachment for wheelchair arm”, invented by L. Bennet in 1971. This device has an attachment to the wheelchair arm, which mounts a case onto the wheelchair. When the cover of the case is opened, two compartments are revealed, as seen in Figure 5 of Appendix D. This device was designed to receive and contain sundry articles in its compartments [2].

Finally there is the “Holder apparatus attachable on a wheelchair for holding a catheter bag and the like”, invented by Lynn V. Shirk in 1988. This device is a holder apparatus that attaches to the back of the wheelchair frame. The apparatus includes a rectangular shaped compartment that is closed on the bottom and open at the top. Attached to the compartment is a pivot rod that allows the device to be tilted away from the wheelchair, as seen in Figure 6 of

Appendix D. This device was designed to hold catheter bags but also can be used to hold other items [6].

Being aware of these pieces of technology, we made sure to be original with our design and not produce an exact copy of any of these designs.

2.0 Conceptual Design

2.1 Brainstorming

As a team, we went through a comprehensive brainstorming process before arriving at our final design. We started by choosing which issue to tackle. Kim needed help leaving and entering the house, protecting her control panel and carrying cargo. We felt that, relative to the challenge of carrying cargo everywhere she goes, the door and control panel challenges were less ubiquitous issues in her day to day life, and so decided on helping her with the cargo problem. We felt that a device addressing this problem would be the most often utilised by her and offer her the most independence. We discussed the objectives and constraints of our design, and by using the 6-3-5 method, generated several potential designs. To start off the design process we made a morph chart that consisted of many functions and means of solving the problem at hand (Appendix B Table 2). Using the morph chart, and the constraints set we determined the most feasible designs. Once these designs were made they were then assessed using metrics (Appendix B Figure 1 & Table 1) we created that best measured how well the objectives were being met. For one of our designs, we had a tray that attached to an arm, and utilised a double hinge mechanism that allowed it to be moved from it's vertical resting position on the side of the wheelchair to its useable horizontal position resting on the armrests (Appendix B Figure 2). This initial design did meet our objective of carrying cargo. Because of the double hinge design, it would be more difficult for Kim to actually use the device because of her Multiple Sclerosis, this would cause it to do very poor in terms of our other metric, removability. To fix this design flaw, one of team members suggested replacing one of the hinges with a pivot for more easier, fluid overall movement. Another design alternative suggested was a tarp that could be used as a makeshift tray and that was attached to PVC tubing, and able to be stored on the side of the wheelchair when not in use (Appendix B Figure 3). This design is very easy to stow away and can score high based off of our metrics. The loose material of the tarp will cause it to be unstable and it will do a poor job of carrying cargo. A teammate suggested the tubing mechanism be attached to the wheelchair by magnets to allow for easy attachment and removal. All of the suggested designs meet the constraints provided, such as it being a non permanent solution, does not requires fine motor skills and low cost.

2.2 Process

Our preliminary design alternative was a tray connected to an adjustable arm attached to the side of the chair using industrial Velcro. Both the arm and the tray have a soft cushioning. There is a hook that stabilizes the arm with the armrest on the wheelchair. There is also support under the tray which attaches to the other arm. The tray has a tactile surface, and elevated rims to keep cargo from falling off the tray. We didn't end up using this design fully due to the fact that during brainstorming we saw that the double hinge system of connection would be harder for Kim to operate (Figure 2 Appendix B)

Our secondary design alternative was a piece of cloth/tarp supported with a collapsible frame tubing. It attaches to the wheelchair with Velcro. It acts as a makeshift bag when collapsed and can be flipped to the side using a hinge. (Appendix B Figure 3)

To generate these designs, we consulted our morph chart (Appendix B Table 2). We felt that both of these designs addressed Kim's issue more specifically than the existing commercial products. Furthermore, we analyzed those same existing products with the objectives, metrics and constraints that we had already agreed upon. We found that the biggest constraint violation in both the Advantage Bag and the storage pouch designs were their inaccessibility due to Kim's condition. The backpack was unfortunately placed such that Kim would not be able to reach it, and the storage pouch wouldn't be feasible to Kim to install or remove. However, when choosing a design alternative for ourselves between the two that we came up with, we had to consider the same constraints and objectives.

2.3 Outcomes

We evaluated the 2 final design alternatives by using the Priority Checkmark Method (Appendix B Table 3), and the team decided to move ahead with our "arm-tray" design. We decided that adjustability was our most important objective, followed by stability and finally the amount of weight the design would support. We came to these conclusions while reviewing the design ourselves, along with going over the tutorial 7 feedback (Appendix C, Tutorial 7 Design Review Feedback). While both designs were equal in regards to comfort and weight, it was clear the arm tray design would offer more stability. There was still a problem with the arm tray design: initially we had the tray between the main arm and the wheelchair, but after reviewing the design, it was found that due to the length of the tray, it would collide with the supporting arm when in the stowed position. To solve this, we moved the tray to the outside, putting the main arm between the tray and wheelchair. This cost us a bit more space, but the design was still more favorable than the others due to its strength in other areas. Our first prototype can be seen in Appendix B, Figure 5, and our second in Appendix B, Figure 6.

3.0 Final Design

3.1 Description

The device is a cargo-holding wheelchair attachment for our client, Kim. The device is an easy-to-interact with object that allows Kim to carry a substantial amount of weight on her persons without external aid. The device is lightweight and very manageable for people with multiple sclerosis, who have deteriorating grip strength and fine-motor skills. The materials used to build the device were chosen specifically for its light-weight and durable properties, as well as cost-efficiency. The arm attached to the chair, as well as the jointed arm and tray, is made of hardboard, and are linked together with a metal hinge and a half-threaded bolt. The tray is layered with rubber shelf-liner for a tactile and comfortable surface, as shown in Figure 4 Appendix B.

3.2 User (Interaction and Use)

The device needs to be attached to the wheelchair initially, which requires outside help. After it is attached, Kim can bring up the tray whenever she desires by simply pulling on the lever to raise the tray, and allowing gravity to do the rest of the work by setting the tray on to the arm wrests. She can put whatever she wants on it without having to worry about it falling as the tray has a high grip surface. Whenever she wants to put it back in resting position, she can use the back of her hand and push from under the tray which brings it to the side-raised position. At this point, a nudge to the lever should allow the tray to fall back in to place at the side of the chair. Please refer to Figure 1, Appendix A for a diagrammatic user's guide.

3.3 Construction

The materials for the device we constructed can all be found in Home Depot and Dollarama. We utilized a 25 by 25 inch piece of hardboard with a .25 inch thickness for the construction of the majority of the device. First, the tray was cut out from the hardboard using the Laser Cutter found in Thode Makerspace. After the tray was fashioned from the hardboard, the connecting joint-piece was created, as well as the main attaching arm. The lip of the tray was also cut out from the hardboard using the Laser Cutter. Once the necessary parts were cut out from the hardboard, we proceeded to the assemble the device. First, the hinge was attached to the joint-piece using screws and a hand drill. The hinge connected to the center of the right handle of the tray. This was done to make the excess wood past the hinge on the handle act as a stopper for the rotation of the tray about the hinge. The hinge and screws were purchased from Dollarama. The next step was to drill a 1 cm hole in the center of the joint-piece. Once drilled, the 2.5cm long half-threaded bolt, with a 1 cm diameter, was placed in the hole. The non-threaded part rests against the wood and allows smooth rotation about the bolt and allows the tray to be easily engaged and disengaged. The half-threaded bolt, as well as the hardboard, was purchased at Home Depot. The next step was to drill a 1 cm hole into the attaching arm. The half-threaded bolt was the screwed onto the arm as well, attaching the arm and joint-piece together. Once the arm was attached to the joint piece, a protruding piece of wood was connected to the bottom of the arm in order to attach the device to the wheelchair without interference from the wheelchair. A 10cm x 5cm x 5cm block of scrap wood from Thode Makerspace was used, and was attached with wood glue. The block was clamped using a plastic clamp for 25 minutes to allow the glue to dry properly. Industrial-strength Velcro was then attached to the wooden block using the adhesive already on the Velcro. Once the main parts were completed, the finer details of the device could be worked on. The lip of the tray was glued onto the tray using wood glue and was clamped on with plastic clamps for 25 minutes. Once the lip was solidly in place, the shelf liner meshing was attached to the tray. The shelf liner was attached using a hot glue gun. Once dried, the lever was attached to the joint-piece of the device. The lever is a 25 cm x 5 cm x 2.5 cm piece of scrap wood taken from Thode Makerspace. Finally, the lever was attached with wood glue to the bottom right corner of the joint-piece, angled at 45 degrees below the horizontal. When dried, the lever was then layered with shelf liner and attached using hot glue.

The construction of the device required a drill, laser cutter, saw, screwdriver, file, hot glue gun, and wood glue. The saw was used to cut the excess of any screws protruding out of the other side when screwed in. The file was used to smoothen the cut screws. Constructing this device would be impossible without passing the Laser Cutter Safety Test on Avenue to Learn, and without the necessary skills needed to operate a drill and glue gun. The construction approximately took 3 hour total to complete, and the cost of the materials was 14 dollars total. The final prototype can be viewed in Appendix B, Figure 7.

3.4 Safety

Safety was the top priority when designing this device. The most important objective of this device is to allow Kim to safely and comfortably carry cargo on her persons. For a person with multiple-sclerosis, this device must be very lightweight and comfortable to adjust and utilize. This is why the durable and lightweight hardboard was chosen for the primary material to construct the device out of. The shelf liner also adds to the safety of the device. The lever layered with the plush shelf liner is much more comfortable than a bare wooden lever, and the shelf liner adds a great amount of friction to the device without being uncomfortable. The lever is placed on Kim's right-hand side of her wheelchair due to her right arm being stronger than her left arm. The lever itself was designed to be used without any need of fine-motor skills or gripping. With the flat, back of Kim's hand, the entire device can be utilized to its maximum potential. Because picking a dropped object off the ground is nearly impossible for Kim, we designed an attached lip to the tray in order to exponentially reduce the risk of dropping items. The tray is also lined with the comfortable and textured shelf liner. This adds friction to the tray in order to add more stability to object resting on the tray, and reduce sliding. With these designed safety precautions, this device is very safe to use, and has a very low potential to cause any future problems for Kim.

3.5 Final Design Decision Explanation

When deciding on our final design, we first re-consulted our priority check-mark design matrix (Table 3 Appendix B). We decided that our objective priorities had not changed, and set out to refine our design. Next, we went through all of the feedback that we received in our design reviews (Appendix C). We did our best to address each piece of feedback when creating our final design. Our device must prioritize adjustability, to the end of making our design as accessible as possible. It must also minimize horizontal space when in its stowed position, so as not to get in the way of the wheelchair's regular motion. To this end, we implemented a lever (as recommended in our design reviews) to make it easier for Kim to lift. We also intended on changing the side of the arm upon which the tray would stow, but late discovered that our design was not feasible as the tray was too long. This was a minor sacrifice in horizontal space for a functional prototype. We decided on our final design because we felt that it best addressed our objectives, as well as meeting all of our constraints.

3.6 Discussion of Feedback from Design Reviews

We received a variety of feedback from the two Design Review sessions. Some of the feedback was helpful so we chose to implement it in our design but some just did not benefit our design so we chose to omit it. Although we wanted to use plexiglass in our final prototype, we were unable to get enough plexiglass from Thode Makerspace to use for our prototype so we used wood as an alternative lightweight material. Another piece of feedback we incorporated into our design was adding a lever on the edge of the tray's arm so that it would enable Kim to lift the tray with minimal force. We made sure our tray was thin, compact, and easy to fold away so that it would not disrupt the movement of the wheels or take up too much horizontal space when stowed away. Although our device did take up space on Kim's armrests, we made sure the amount of space it took up was minimal and we wrapped that part of our device with shelf liner as a form of cushioning, so it is still comfortable for her to rest her arms on. We decided not to replace our tray with a bag and not to add a bag for protecting her joystick controller, as both these ideas did not fall within the objectives of our design. Additionally, we did not replace our hinge with a ball joint as a ball joint does not add any benefits to our design that we need that a hinge does not already provide us with. Finally, we did not make our tray slidable as this idea would overcomplicate our otherwise simple design and would also require fine motor skills to operate, which Kim does not possess.

4.0 Conclusions

We made the choice to address Kim's issue of carrying cargo. We felt that this was the most important of all of the challenges to tackle, because such a solution would help to grant her the independence that she expressed a desire for. By progressing through the entire design process, we learned a great deal about engineering design. We learned to prioritize, set realistic goals, and meet important deadlines with tangible deliverables. Most of all, we found purpose in our work as engineers by attempting to help a local client to improve their daily lives. We felt that our final device was functional, but could be improved upon in a final product; we could seek out our original material selection of plexiglass, or make additional iterations upon our design with the feedback we received at our final presentation. Furthermore, we could refine the aesthetic of the design to be more in line with commercial products already available, and re-evaluating our safety measures to ensure that they are to the requisite standard. More metrics with which to judge our prototype, as well as more rigorous testing with the existing metrics, would help us ensure that the device is up to our standards. Nonetheless, we are proud to have designed a product specifically with our client's needs in mind, and to have delivered a functional final prototype.

5.0 References

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Appendix A - Device User Guide

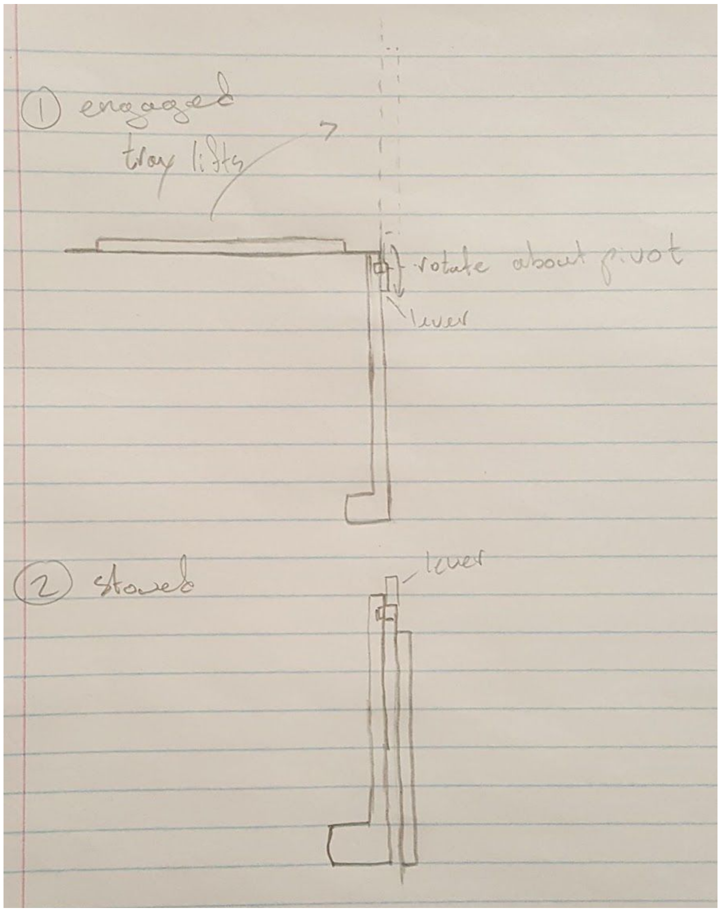

Figure 1: User guide for stowing and lifting device

Appendix B - Tutorial Workbook Information

Initial Problem Statement

Design a cargo holder that Kim can use in her wheelchair.

Figure 1: Objective Tree and Metrics

Table 1: Objective Tree and Metrics

Objective:	**Carrying weight**
Metric:	**1 point for every 5 lbs it can hold, up to a maximum of 10 points**
Objective:	**Stowability**
Metric:	**Starts with 10 points, -1 point for every 3 seconds it takes to set the device into resting position.**

Redefined Problem Statement

Design a cargo holding device for Kim, a person with multiple sclerosis who cannot carry cargo by conventional means. The device should attach to her wheelchair, be unobtrusive, and allow Kim to be more independent of her caretakers.

Table 2: Morph Chart

Functions	**Means**					
Carry cargo	Tray	Bag	Basket	Hammock/ cloth	Cup	
Be attachable	Latch	Hook	Clamp/vise	Velcro	Tape	Magnets
Stability	Support struts	Suspension /cords	Tape	Magnets	Beam/pilla r	Velcro
Adjustable position	Shifts along rails	Multiple joints on arms	Suspension	Hinge	Collapsible /telescopin g arm	Hook

Protects cargo	Lid	Net	Umbrella	Bag/cover	Tactile/non-slip surface (good grip)	Elevated edges
Comfort	Cushioned	Soft Material	Smooth texture	Tactile/non-slip surface		

Design Alternatives, Prototypes, and Final Design

Figure 2: Preliminary Alternative

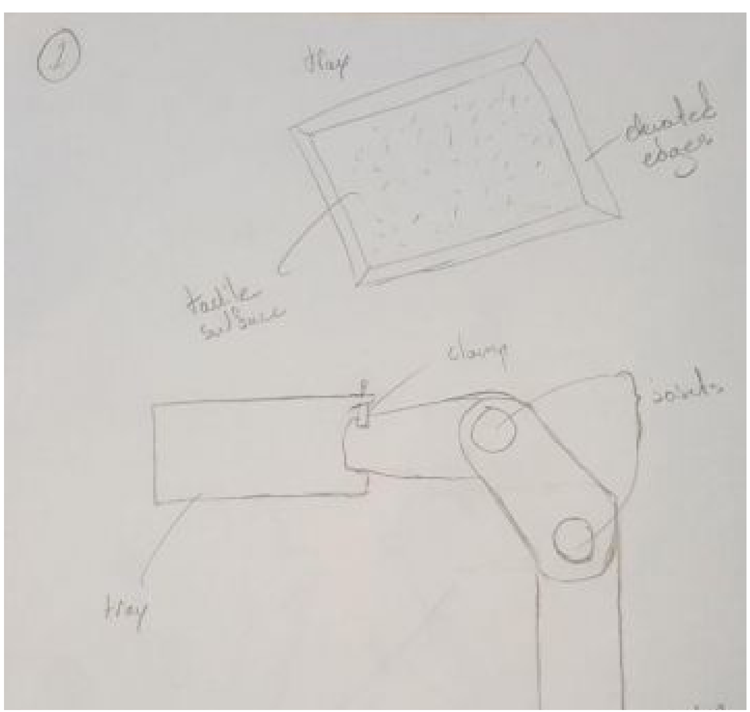

Figure 3: Secondary Alternative

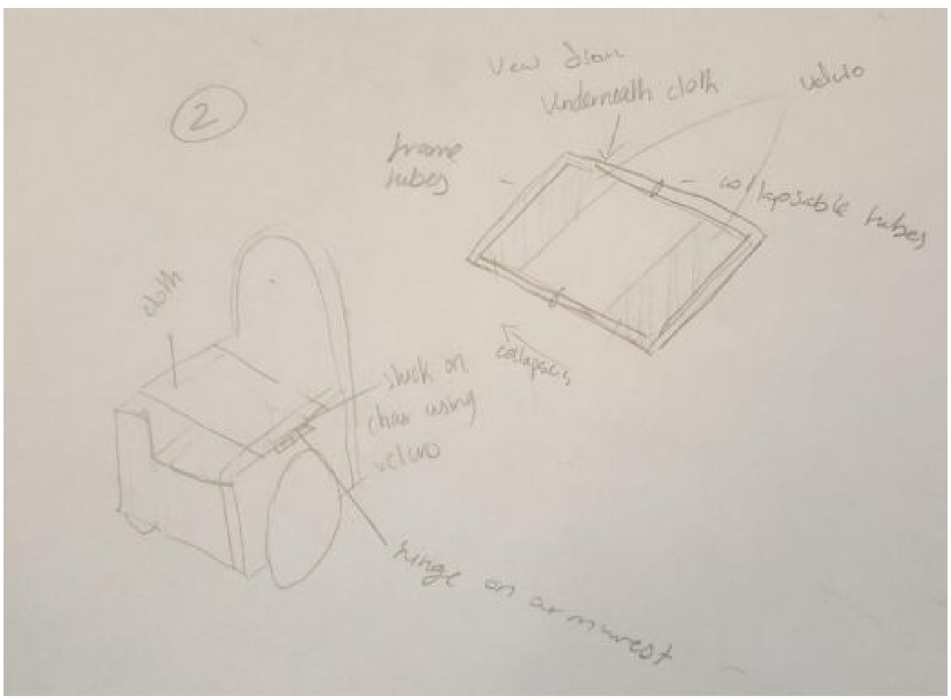

Table 3: Decision Matrix and Evaluation

Design Constraints(C) and Objectives(O)	**Priority (✓)**	**Design 1(Arm-Tray)**	**Design 2 (Bag)**
C: Doesn't require fine motor skills			
C: Costs less than			

$100 to build			
C: Removable			
O: Carries a substantial amount of weight	✓	1x✓ ✓	1x✓ ✓
O: Easily adjustable	✓✓✓	1x✓✓✓ ✓✓✓	1x✓✓✓ ✓✓✓
O: Stable	✓✓	1x✓✓ ✓✓	0x✓✓ ..
TOTAL		6✓	4✓

By using the Priority Check-mark Method, our team decided to move ahead with our "arm-tray" design. We decided that adjustability was our most important objective, as our design must be as accessible as possible to accommodate Kim's condition. We felt that both of our designs met this objective, as they can both be manipulated into various positions. Our second priority was stability, to ensure that our final device is capable of carrying the cargo safely. We felt that our arm design was significantly stronger in this regard, and that it was a weak aspect of the bag design. Finally, our lowest priority objective was the amount of weight that could be carried, as we'd rather be able to safely carry less cargo than to carry more cargo with less stability & adjustability. We felt that both the armtray and the bag designs met this objective.

Figure 4: Final Design Alternative

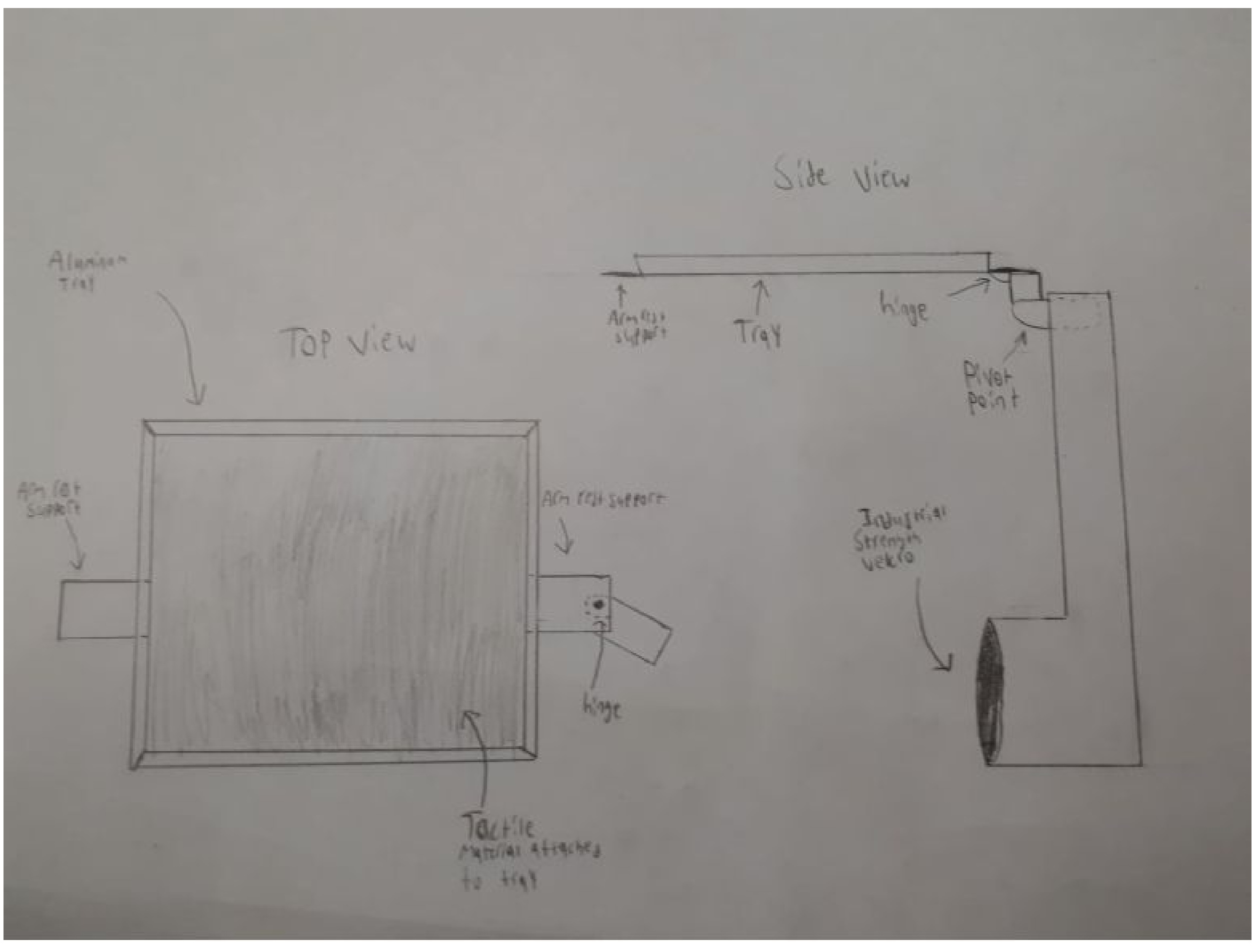

Figure 5: The First Prototype

Figure 6: The Second Prototype

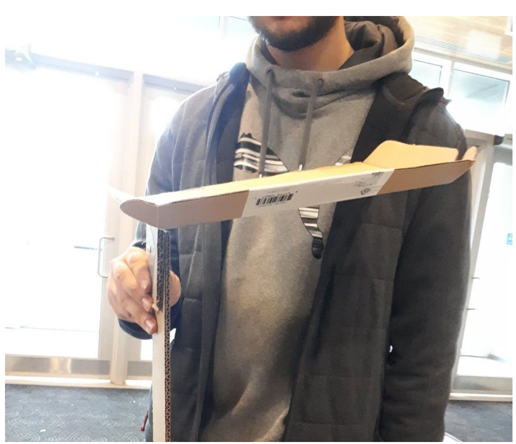

Figure 7: The Final Product

Appendix C - Design Review Feedbacks

Tutorial 7 Design Review Feedback

Science Review Feedback:

- Clear bag for protective joystick controller so she can see through bag and use joystick.
- Foldable tray so that it is compact but can be opened up.

- Make sure device doesn’t limit her armrest space.
- Make sure device doesn’t disrupt movement of wheels.
- Use lightweight material because her arm strength will continue to degenerate.

Peer Review Feedback:

- Possibly replace the tray with a bag.
- Material shouldn’t be too heavy that it is difficult for her to operate, but also not too light that it is fragile.
- Could add a bag to protect her joystick controller from rain (solving two problems with one device).

Tutorial 9 Design Review Feedback

Science Review Feedback:

- Consider the ease of stowing tray away.
- Make sure tray isn’t too thick to not take up too much horizontal space when stowed away.
- Ball joint instead of hinge.

Peer Review Feedback:

- Use clear plexiglass from Thode Makerspace.
- Add lever that is easy for Kim to maneuver.
- Avoid interfering with armrest space.
- Make tray slidable.

Appendix D - Extra Content

Commercial Products

Figure 1: Under chair storage device [3]

Figure 2: Wheelchair backpack storage device [4]

Figure 3: Wheelchair cargo/cup holder [5]

Patents

Figure 4: Tray supporting device for a wheelchair [1]

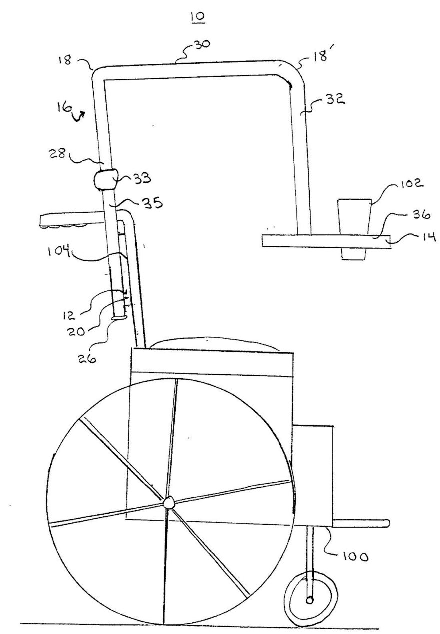

Figure 5: Receptacle attachment for wheelchair arm [2]

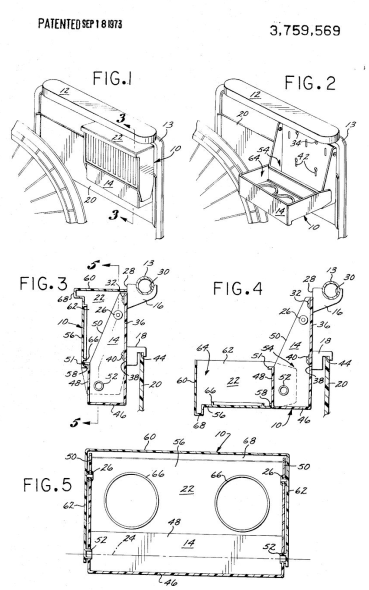

Figure 6: Holder apparatus attachable on a wheelchair for holding a catheter bag and the like [6]