# *Project Deliverable B: Problem Definition, Concept Development, and Project Plan*

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# 1. Introduction

On January 18th 2023, we had the opportunity to meet with a representative from Bethany Children's Health Center for the first time. She has patients that have motor deficits and need a switch-adapted T-shirt folder. Our group did research and found out that "Motor deficits refer specifically to the effect of damage on motor skills or movement." (*Motor Deficits and Disabilities*). Some examples of motor deficits include paralysis, uncontrolled movements, difficulty carrying or moving objects, and loss of fine motor skills like buttoning a shirt. (*Motor Deficits and Disabilities*). Motor deficits are caused by brain injury, and all brain injuries are considered to be unique depending on the locations of the injury within the brain. The motor deficits could be permanent or temporary because of this. However, in general the human brain is wired so that damage to its left side could cause motor deficits on the right side of the body, and damage to its right side could cause motor deficits on the left side of the body. (*Motor deficits*)

The representative from Bethany Children's Health Center explained that currently only adults utilize the t-shirt folder to fold merchandise for staff members, however now the center wants to get the children involved. When we asked the representative how a child would use the t-shirt folder currently, she said that an adult staff member would have to grab the child's hands and turn the flaps of the folder manually. We have been asked by the representative from Bethany Children's Health Center to design a t-shirt folder, that could automatically fold its flaps with the press of a button. The t-shirt folder should be easy to install, remain stationary when in use, not overly robust and require minimum assistance from the caretakers.

From the client interview, we created a list of statements and observations which described the client's needs. Of all of these statements given to us by the client, the importance of a button being used to activate the folds of the t-shirt folder, the t-shirt folder being stationary, the t-shirt folder not being built with cardboard, and the t-shirt folder being easy to install were highlighted repeatedly. The statements and observations that we recorded from our client, were converted into twelve detailed need statements. These need statements were then organized by their priority, 5 being the most critical need and 1 being the need that is undesirable. The most important need statements were used to create the problem statement. Since we are creating a physical product, there are various different metrics related to it. Once the metrics were identified, benchmarking was done with three different products. The products are an Arduino-powered t-shirt folder, automatic clothes folding machine, and t-shirt folder electric desktop. From the metrics and observations that we made from benchmarking, a set of target specifications have been created. The target specifications outline the marginal and ideal values for each metric. After doing this, we developed final prototypes for three subsystems. The subsystems that we broke our solution system into, are folding actuators, accessibility and control system, and housing and frame. Then we analyzed and evaluated all of the concepts against the target specifications that we defined, using the coarse decision matrix. Then we chose promising solutions that we wish to develop further based on our evaluation. After this, we developed a global design concept, and visually represented it using sketches. Finally, we explained our global concept's

relationship to the target specifications that we created, along with its advantages and disadvantages.

# B.1 Problem Definition

1. List and prioritize client needs/problems and define all relevant known and unknown information.

## Client's Statements and Observations

- User is client's patients, who have motor deficits
- The t-shirt folder is used to fold adult sized t-shirts for staff members
- Currently, the patients do not interact with the switch adapted t-shirt folder, but if they were to interact with it, the staff member will have to hold the patient's hand and arm to fold a t-shirt using the switch adapted t-shirt folder
- When asked about if multiple kids could interact with the switch adapted t-shirt folder, client said it would be possible, but judging by the way it was communicated, it does not seem to be a priority
- Majority of patients are not nonverbal
- They use squeeze switches along with buttons, but client appears to prefer the use of buttons
- In terms of software, they have apple products, but they also have Microsoft Surface Pro tablets
- The client will be personally assembling the switch adapted t-shirt folder
- The client wants us to use straps to hold down the switch adapted t-shirt folder
- The client does not want us to use cardboard in our design
- The durability and strength of the switch adapted t-shirt folder does not seem to be a priority for the client
- Switch adapted t-shirt folder does not have to look visually appealing
- Client wants to use the switch adapted t-shirt folder only for adult sized t-shirts, not for any other articles of clothing
- The client thought it would be nice if the switch adapted folder showed its state to the users, but its not priority

# Client Needs

For importance:

5 -The need is critical
4 - The need is highly desirable
3 - The need would be nice but not necessary
2 - The need is not important
1 - The need is undesirable

| # | Need | Importance |
|---|---|---|
| 1 | The switch adapted t-shirt folder is durable and strong. | 3 |
| 2 | The switch adapted t-shirt folder can be used by multiple people at the same time. | 3 |
| 3 | The switch adapted t-shirt folder is easy to install. | 5 |
| 4 | The switch adapted t-shirt folder is not built with cardboard pieces. | 5 |
| 5 | The switch adapted t-shirt folder reduces the movement of hands. | 5 |
| 6 | The switch adapted t-shirt folder can be operated with a mobile app. | 3 |
| 7 | The switch adapted t-shirt folder remains stationary during its use. | 5 |
| 8 | The switch adapted t-shirt folder can be cleaned with a wipe. | 5 |
| 9 | The switch adapted t-shirt folder can be activated through voice. | 1 |
| 10 | The switch adapted t-shirt folder is visually appealing. | 1 |
| 11 | The switch adapted t-shirt folder can be used for other pieces of clothing. | 3 |
| 12 | The switch adapted t-shirt folder communicates its state to the user. | 3 |

## Problem Statement

There is a need for an easy & accessible switch system that would allow patients at the Bethany Children's Health Center, some of whom have motor & speech impediments, to activate an automatic T-shirt folder. The device should not be overly robust, not slide easily while in use, but should be easy to install and need minimum assistance from caretaker staff to use.

## Metrics

| Metric # | Need #s | Metric | Imp | Unit |
|---|---|---|---|---|
| 1 | 1 | Durability | 3 | years of life |
| 2 | 1 | Load Support | 3 | g |
| 3 | 3 | Weight of Product | 5 | kg |
| 4 | 2 | Number of concurrent users | 3 | users |
| 5 | 3 | Installation time | 5 | seconds |
| 6 | 4 | Not built from cardboard pieces | 5 | Binary |
| 7 | 5 | Reduces hand movement | 5 | Binary |
| 8 | 6 | Used with mobile app | 3 | Binary |
| 9 | 7 | Movement during use | 5 | cm |
| 10 | 8 | Cleanable with a wipe | 5 | Binary |
| 11 | 9 | Activated by voice | 1 | Binary |
| 12 | 10 | Visually appealing | 1 | subj |
| 13 | 11 | Possible clothing types | 3 | list |
| 14 | 12 | Communicates its state | 3 | Binary |

## Benchmarking

| Metric # | Need #s | Metric | Imp | Unit | Arduino powered | Automatic Clothes Folding Machine | T-Shirt Folder Electric Desktop |
|---|---|---|---|---|---|---|---|
| 1 | 1 | Durability | 2 | years of life | 5 | 2 | > 1 |
| 2 | 1 | Load Support | 3 | g | >198.5 | >198.5 | >198.5 |
| 3 | 3 | Weight of Product | 5 | kg | 5 | <5 | 200 |
| 4 | 2 | Number of concurrent users | 3 | users | 1 | 1 | 1 |
| 5 | 3 | Installation time | 5 | s | 30 | NA | NA |
| 6 | 4 | Built from cardboard | 5 | Binary | No | Yes | No |
| 7 | 5 | Reduces hand movement | 5 | Binary | Yes | Yes | Yes |
| 8 | 6 | Used with mobile app | 3 | Binary | No | No | No |
| 9 | 7 | Movement during use | 5 | cm | 0 | 0 | 0 |
| 10 | 8 | Cleanable with a wipe | 5 | Binary | Yes | No | Yes |
| 11 | 9 | Activated by voice | 1 | Binary | No | No | No |
| 12 | 10 | Visually appealing | 1 | subj | 1 | 2 | 4 |
| 13 | 11 | Possible clothing types | 3 | list | T-shirt, long sleeve | T-shirt | T-shirt, sportswear,work clothes |
| 14 | 12 | Communicates its state | 3 | Binary | No | No | Yes |

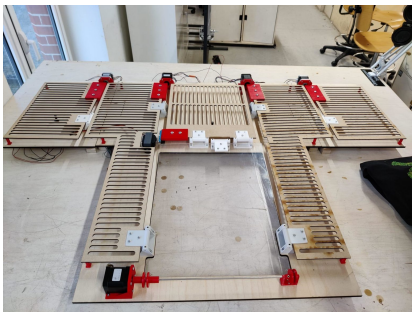


*Fig 1: Arduino powered (left), Automatic Clothes Folding Machine (middle), T-shirt Folder Electric Desktop (right)*

## Target Specifications

| Metric | Unit | Ideal Value | Marginal Value | Reasoning |
|---|---|---|---|---|
| Durability | Years of life | > 4 | > 2 | We want this product to last a long period of time, however its robustness and durability is not that big of a priority for our client. |
| Shock Resistance | Joules | 50 | 30 | The device should be able to withstand an accidental bump or fall from a average table |
| Load Support | g | >198.5 | >85 | We found out that the average weight of shirts are between 85 g and 198.5 g. So ideally we want our solution to support more than the maximum of the average weight of shirts, but it is acceptable if it's able to support at least above the minimum of the average weight of shirts. |
| Weight of Product | kg | <3 | <5 | We want our product to be easily installed which means that it has to be easily portable from one location to another. This is not possible if the product is heavy. This is why we want our product to be below 5 kg, and we ideally want it to be lower than 3 kg to beat our Automatic Clothes Folding Machine competitor. |

| | | | | |
|---|---|---|---|---|
| Number of concurrent users | users | >1 | >0 | We want this product to work for at least one person, as the client indicated to us that this feature appears to be “nice to have” and not necessary. So if it's possible, we could make it usable by more than one person, but it definitely at least has to be used by one person. |
| Installation time | Seconds | <30 | <60 | The device should not take a very long to set up because we want it to be convenient |
| Movement during use | cm | 0 | <2 | The device should stay in place when it is being used by the user. |
| Cleanable with a wipe | Binary | Yes | Yes | The device should stay in place |
| Activated by voice | Binary | Yes | Yes | The device should be activated by voice because some users do not have the capability to activate it in other ways. |
| Visually appealing | Subj | 5 | 3 | The device should be visually appealing to look upon. |
| Possible clothing types | list | Adult T-shirt | T-shirt | The device should fold an adult sized T-shirt. |
| Communicates its state | Binary | Yes | Yes | The device should communicate its current state. |
| Software compatibility | - | 2 | Apple iOS & Microsoft | The client uses both Apple and Microsoft products and the t-shirt folder should be compatible with both, however, the most important is Apple. |

# B.2 Concept Development

There is a need for an easy & accessible switch system that would allow patients at the Bethany Children's Health Center, some of whom have motor & speech impediments, to activate an automatic T-shirt folder. The device should not be overly robust, not slide easily while in use, but should be easy to install and need minimum assistance from caretaker staff to use.

1. Based on your problem statement, develop final prototype concepts for each subsystem, as well as the entire assembled system required to solve the problem.

Based on the requirements outlined by the client and further problem refinement into a problem statement, the solution system can be broken down into 3 subsystems.

## Folding actuators

The core of the problem revolves around the need to autonomously operate the t-shirt folder. This includes the 3 separate movements, alongside resetting the device after each step. All sensors, motors and physical mechanisms involved in maneuvering the t-shirt folder fall into this subsystem.

Mechanism concepts:

- Sliding slot drive - Motor below the folder, connected using a single bar to a slot that runs the length of the folder.
- Sliding surface/string drive - Motor below the folder, single bar lays freely along a flat surface that runs the length of the folder. There is a string attached to the folder for retracting.
- 2 bar linkage - Motor below the folder, connected to a fixed pivot on the folding platform using 1 linkage made up of 2 bars and a joint.
- Inline drive - Motor inline with the folder hinge, connected with a set of braces.

Motor drives:

- Stepper motor
- DC motor with limit switches
- Servo

## Accessibility and control system

In order to control the folding actuators, power the device and collect inputs, there must be a control system that connects and communicates with all components. An important notice in the design of this project is the need for accessibility. The design must be compatible with the center's pre-existing accommodative switches or be operated with another accessible system.

Accessibility concepts:

- 3.5mm Audio jack adaptation - The client explained that the center has access to a number of accessible buttons that connect using a 3.5mm audio jack
- Touchscreen
- Mobile device connection

Outside of the accessibility concepts, the majority of the electrical hardware including power management, microcontroller, and indicators is fairly constant. The specifics would be adapted as the main concepts are developed.

## Housing and frame

By design, the t-shirt folder requires a level surface to rest on that will act as a support while the folder is in use. Further, the housing should provide an area to contain all electronics as well as make the solution ergonomic and safe to use.

General Concepts:

- Contained box - A large box frame below the folder, matching its outline.
- Stilt supports - A set of extended legs that raise the folder higher off the ground.
- Disconnected control box - No changes to the original shirt folder, only a separate box for controls/electronics.

2. Analyze and evaluate all concepts against the target specifications you defined. Use simple calculations and/or simulations to make decisions. Justify the process and methods used for analysis and evaluation.

In order to evaluate the quality of each concept, a coarse decision matrix will be created for each group of selection criteria. We believe that a coarse decision matrix is a right choice because it provides a platform to bring up the right comparisons, without requiring a depth of assumptions or more abstract judgments. Similarly, we have decided to not sum the weights. Instead, in the succeeding points, the coarse weights will be used as context in decision-making.

## Folding actuator

| Selection Criteria: Mechanism | Sliding slot drive | Sliding surface/ string drive | 2 Bar linkage | Inline drive |
|---|---|---|---|---|
| Chance of failure/jam | - | + | 0 | 0 |
| Price | 0 | + | - | 0 |
| Range of motion | - | 0 | + | 0 |
| Space required | 0 | + | - | + |
| Long-term reliability | - | - | + | 0 |
| Overall complexity (parts, design time, cost) | + | 0 | - | + |

| Selection Criteria: Motor | Stepper motor | DC w/ limit switch | Servo |
|---|---|---|---|
| Reliability | 0 | - | + |
| Price | - | 0 | + |
| Torque | 0 | + | - |
| Space required | 0 | - | + |
| Speed | 0 | + | - |

## Accessibility and control system

| Selection Criteria: Accessibility | 3.5mm Audio jack adaptation | Touchscreen | Mobile device connection |
|---|---|---|---|
| Price | + | - | - |
| Ease of use (for kids) | + | - | 0 |
| Availability | + | 0 | + |
| Reliability | + | 0 | - |

## Housing and frame

| Selection Criteria: Frames | Contained box | Stilt supports | Disconnected control box |
|---|---|---|---|
| Stability | + | 0 | - |
| Ease of assembly | 0 | + | + |
| Ergonomics | + | - | + |
| Safety | + | - | 0 |
| Space given for mechanics | 0 | + | - |

3. Choose one or a few promising solutions you wish to develop further based on your Evaluation.

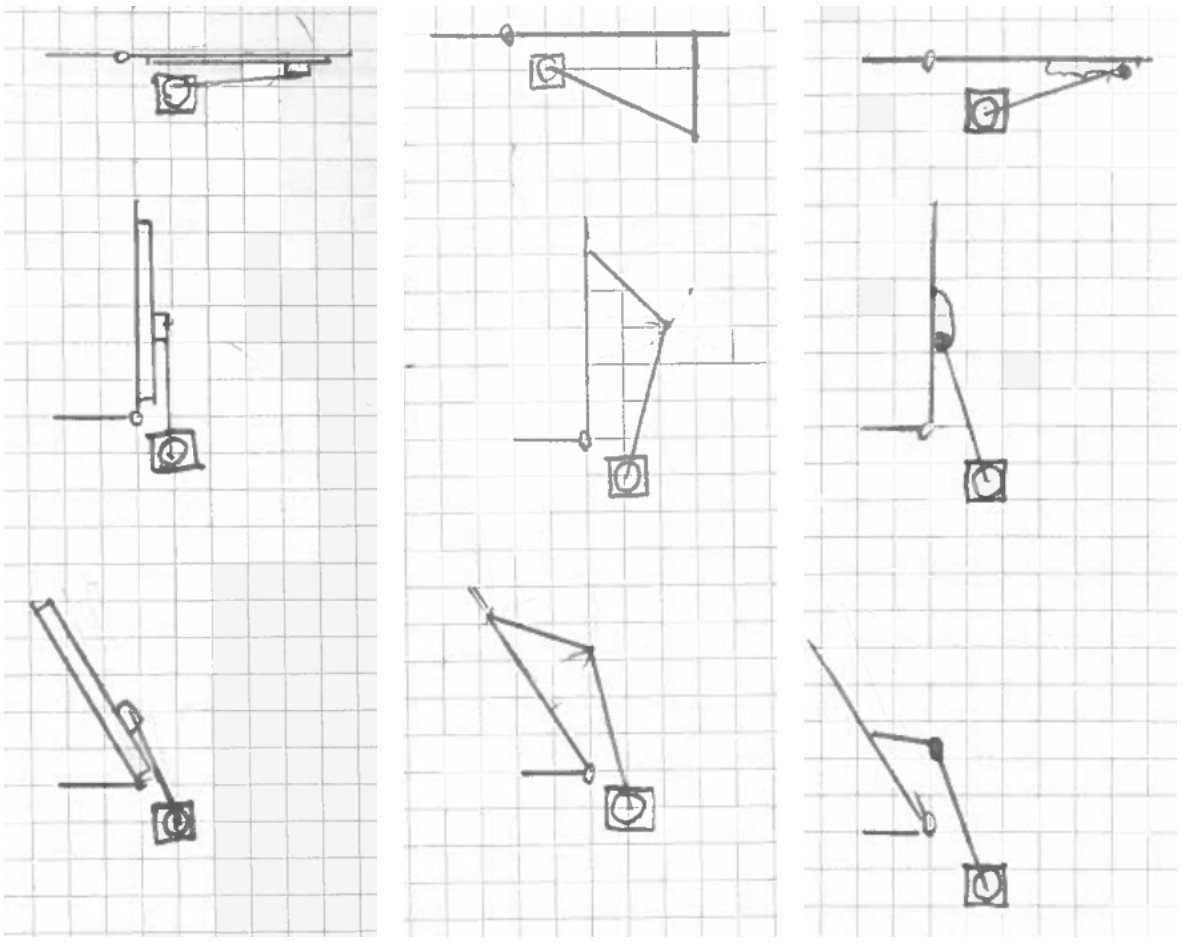
## Folding actuators

Mechanism:

Because of the stiffness and geometry of the t-shirt folder the inline motors are not compatible as a solution. Each of the 3 remaining concepts each has its own corresponding application, benefits and drawbacks. Basic sketches of each have been made to better understand how each mechanism integrates with the design, and how they might perform.

At rest Vertical fold Finished fold

Fig 2. The 3 phases of motion using the t-folder



Sliding slot drive | 2-Bar linkage | Sliding surface/string drive

Fig 3. From top to bottom the 3 phases of motion for each mechanism.
Motor is represented by a circle inlaid into a square.

Motor:

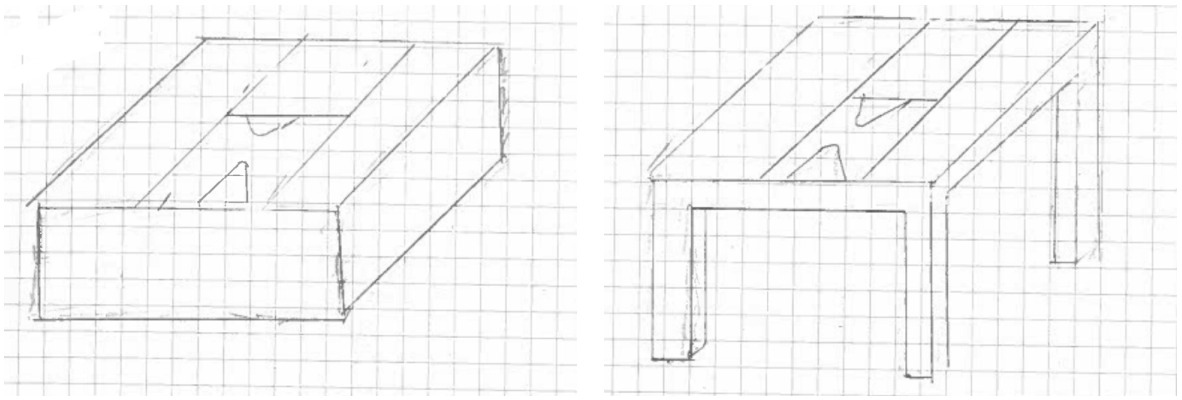
Using a dc motor with limit switches would allow for more complex mechanisms because of the higher torque, and perhaps cheaper design. However, this is outweighed by the complexity, cost and space requirement of the additional limit switches. A failure of the limit switches could make the device dangerous, and as such unsuited for our application. Outside of more research, no more development on the choice of motor can be made.

## Accessibility and control system

Based on the much-increased price, and our understanding of the client's requirements, using a touchscreen for user interaction seems unrealistic. Again, outside of more research, no more development on the choice of accessibility system can be made.

## Housing and frame

Out of all the concepts for mechanical linkages all of them require some form of space below the t-shirt folder. This means that having an external control box with no supports below the folder is not possible. Sketches have been made for the remaining 2 concepts to better visualize how they might impact the other subsystems.



Contained Box Stilt Supports

Fig 4. Sketches of the 2 support concepts

4. Develop a global design concept which is either an integration or modification of the promising concepts chosen in the previous step, or a brand-new concept created from these ideas. Justify your approach.

## Folding actuators

There are 3 separate folding operations that must be made: left sleeve, right sleeve, and the flip. The left and right sleeve folds are prone to crumpling, If the actuator does not make the full 180-degree rotation of the folder, there is a chance the t-shirt might fold improperly. Having a full range of motion to execute the fold is important to prevent this from occurring. The 2 folds also physically move the most fabric and plastic on the folder, this means that continuous force is needed through the fold.

The 2-bar linkage fills all of these requirements, depending on the positioning of the motor and lengths of linkages used it is able to rotate through the full 180 degrees. The other two concepts: sliding slot and sliding surface respectively lack the ability to rotate fully, and apply continuous force during the fold. As such, we will use the 2-bar linkage for the left and right folds.

It would be the most simple to apply the same method of folding to all 3 operations. The last fold, the “flip” is much simpler: a single fold to turn over the folded halves of the shirt onto itself. The two-bar linkage is suitable for this application, except for issues concerning the shape of the t-shirt folder. There is a supporting piece of plastic below the folding plate, this would make it impossible to operate the 2-bar linkage without significantly altering the t-shirt folder. Because of this, one of the two alternate concepts had to be chosen.

Out of the 2, our design concept will use the sliding surface/string drive. The drive has the ability to operate with almost no clearance underneath the folding plate. It also has the advantage of being more mechanically simple compared to the 2-bar linkage. It should be noted that the drive cannot provide full force throughout the fold. However, this is much less of an issue with the final flip, as the shirt’s own weight is enough to complete the fold. Because of this, our design concept will use a single sliding surface drive for the flip operation.

On top of the mechanism, we will be using servo motors in our design concept. According to our estimates, average hobby-grade plastic servos provide enough torque to operate the drives. While stepper motors can provide more torque and accuracy, they are significantly more expensive, and require many more supporting electronic parts. On top of this, stepper motors may become unreliable if a t-shirt would get jammed, the motors would lose steps causing the device to move unpredictably. Servo motors keep internal position tracking and would simply stall if a t-shirt got jammed.

## Accessibility and control system

Accessibility for the center is one of the most important factors of the control subsystem. Both the button and mobile device control have their own benefits and drawbacks, however, they are not mutually exclusive. Providing an excess of options will help make our device as accessible as possible. Based on rough budget and requirement estimations it seems reasonable to include both in our design. Below is a high-level summary of the control system.

- Powered via 5v USB power bank
- Programming and control done on a arduino
- LCD for status.
- EEPROM for storing total number of cycles.
- 3.5 mm audio jack for connecting accessible buttons.
- Bluetooth module for mobile device connection.

Prototypes will be built on breadboards, which are suitable for the final design. However, transferring the design to a milled or custom-ordered PCB would increase reliability and longevity of the design. Adapting the design to a PCB is highly dependent on the amount of free budget and time remaining. We will re-evaluate this as the design process continues.

## Housing and frame

Of the requirements for the device housing, there is a divide between providing room for the mechanisms to operate and creating a design that is stable and safe. We have chosen to use the 2-bar linkage in our design, which is one of the most space-intensive mechanisms. With a requirement for excess space, this makes using the stilt design attractive, since it provides an excess of space for mechanisms to move. This design brings issues of safety, stability and accessibility. The stilts will leave moving parts exposed, creating a potential safety hazard. The stilts also might raise the folder to the point that it may be hard to reach for the kids in the center. Our global design will use the contained box concept, adapted to provide enough room for the 2-bar linkages. The contained box isolates components, provides a stable footing and lowers the folder making it easier to use.

5. Visually represent (sketch, diagram, CAD model, etc.) your global concept.

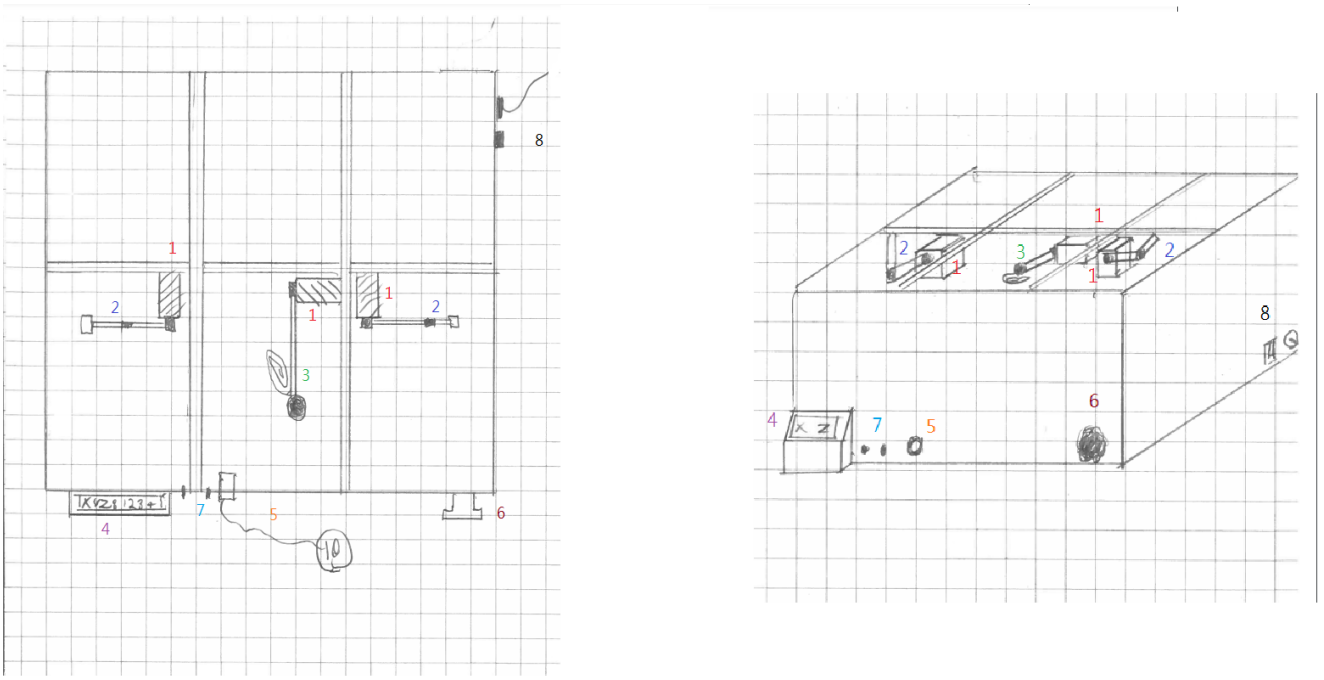



Fig 5. (Left) Top view of design concept. (Right) Overview of design concept.
The images have been annotated with component numbers, indexed in the table below.

| Component Number | Description |
|---|---|
| 1 | Servo |
| 2 | 2-Bar linkage |
| 3 | Sliding surface drive and attached string |
| 4 | LCD display |
| 5 | 3.5mm Audio jack for accessibility button attachment |
| 6 | Emergency stop |
| 7 | Control/setting buttons |
| 8 | Power switch and USB power port |

6. Provide a few lines explaining your concept's relationship to the target specifications, as well as its benefits and drawbacks.

Currently, our concept is related to the target specifications in a variety of ways, firstly by the material it will be made of. We are thinking of using MDF or balsa for the prototype. By using these materials our group will be able to gauge how durable the device would be. In addition to this we will be able to get a rough idea of the device's weight. A drawback to potentially using balsa would be that it's quite light and if we decided to change material later the motors may not be strong enough because they were intended to lift balsa. Secondly, our concept should have a good setup time because it will be just a matter of connecting the input, whether that's a tablet or button. As resistance to movement goes it will not be difficult to secure our concept to a table with straps. A drawback to using straps though would be that it would increase the setup time of the device.

# Closing remarks:

# Reflection

This client meeting provided our team with a better view of the problem that we are trying to solve. We learned that people with motor deficits face countless challenges when it comes to doing simple everyday tasks like folding t-shirts. After hearing from the representative from Bethany Children's Health Center, our team realized that our solution is truly important because it helps these children be able to complete a task that they otherwise would need a lot of assistance from adult caretakers to complete. Also our solution will help increase the efficiency of the t-shirts being sold to staff members.

There is still some information that remains unknown. For the next client meeting, we are hoping to talk to one of the children directly to get a better understanding of the problem from his/her point of view. We also want to make sure that the button is comfortable for the children to use, which means we need to know exactly what material the button's exterior should be made from. We also need to know the dimensions of the table the client uses, so that we can find out the dimensions that our final product needs to be.

# Conclusion

To conclude, the information that we collected from the first client meeting has allowed us to empathize with our client's needs. We got more information about the constraints of our final solution, like not using cardboard, for example. We also were able to determine the team's focus in this deliverable by coming up with a great problem statement from the need statements, along with metrics, benchmarking and target specifications. We were also able to develop final prototype concepts for each subsystem of our solution, and selected solutions that we want to develop further in the future. We also came up with a global design concept which is represented with a CAD model, and described its relationship to the target specifications. The next steps for Deliverable C is to provide a detailed design and bill of materials for our switch adapted t-shirt folder.

# References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2. *Motor deficits*. Matrix Neurological. (n.d.). Retrieved January 26, 2023, from https://www.matrixneurological.org/information/deficits-of-acquired-brain-injury/physical/motor-deficits/