The Magic Mirror

Prepared for:

Ms. Larissa Chakarova
Shirley Ryan AbilityLab
Chicago, IL

Date:

March 14, 2020

Submitted by:

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Sponsored by:

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Executive Summary

With the assistance of our client, Ms. Larissa Chakarova of the Shirley Ryan AbilityLab, located in Chicago, Illinois, we have designed a visual deflecting device for patients at Shirley Ryan who have limited head control. Using this device, the user will be able to view a workspace in front of them without moving their head.

To begin the process, we interviewed Ms. Chakarova and visited Shirley Ryan to gather a detailed list of specifications. Using what we learned from the interview, we researched different aspects of the problem, and brainstormed possible solutions. From there, we created three potential mockups, which we then narrowed down to one to use during the initial user testing session at Shirley Ryan. However, there were no users to test on at Shirley Ryan, so we proxy tested on ourselves and our fellow classmates. With the data we collected from the testing session, we were able to refine our design and create our final prototype: the Magic Mirror.

The Magic Mirror utilizes two mirrors to deflect the visual field of the user. The mirrors are placed on two aluminum poles. The mirrors can also be rotated on an angle around the pole due to the use of one-way locking bearings, and the whole system can be adjusted vertically using PVC pipes; the three points of adjustability allow for patients of varying ages and sizes to use the device.

The Magic Mirror fulfills the following major specifications:

- Safety: The sharp edges of the mirrors are covered with a plastic frame. Additionally, all of the edges that are exposed to the user or the client were sanded to reduce the risk of injury.
- Portability: The device weighs less than twenty pounds, so it’s relatively light to carry; however, the use of wheels allows for it to be rolled to any location with ease and negates the need to carry the device.
- Durability: The materials were selected based on their durability. The mirrors are made of acrylic and are framed with ABS plastic. The poles are made of aluminum, and the bearings are made with metal, so the device will be longer-lasting.

Introduction

Patients aged 3-18 of the Shirley Ryan Abilitylab who have limited head control and restricted cervical movement have difficulty seeing what they are doing with their hands while in their laps or at tabletops. The inability for patients at Shirley Ryan to look down is due to the use of a cervical collar, which restricts cervical movement, or a condition they may have. With the interactive nature of therapy sessions at Shirley Ryan, patients who cannot look down to see their workspace, have difficulty doing activities such as playing with toy cars, drawing, or coloring during therapy sessions.

The AbilityLab's current solution is the use of a single tall mirror; not only is this disorientating for the user due to the mirror image produced by a single mirror but also ineffective and tiring for the therapist. Our team, has been working with Ms. Larissa Chakarova of the Shirley Ryan AbilityLab for the last 10 weeks to create a design that expands the users field of view to include their lap and workspace; to meet the users' needs and address the shortcomings of the Lab's current solution, we have created the Magic Mirror.

The Magic Mirror is a freestanding, dual mirror device that redirects the users' vision, allowing them to perform tasks during therapy sessions that they previously had difficulty with. The use of two mirrors offsets the mirror image produced by a single mirror. The three points of adjustability of the design allow for all users to be accommodated, and the streamlined nature of the Magic Magic mirror allows for the device to be used with ease.

The rest of this report details the process of how we created the Magic Mirror and all the considerations and specifications we constructed the Magic Mirror around.

Users and Requirements

Client

Ms. Chakarova, an occupational therapist at Shirley Ryan AbilityLab in Chicago, Illinois, works with patients who have little to no cervical movement and/or lack trunk support for various reasons. Therapy sessions at Shirley Ryan are interactive, which can be difficult for patients who cannot bend down or move their necks. Consequently, Ms. Chakarova would like for us to create a portable device that will redirect the user's field of view and bring their workspace into view when their natural eyesight is fixed at a certain angle.

Main Users

Users of this device are patients at Shirley Ryan AbilityLab, aged 3-18, that have limited mobility of their neck and/or lack truck support due to various reasons such as injury to spinal cord, Muscular Dystrophy, or cervical fracture. As a result of these and similar conditions is the use of a cervical collar which restricts the patient's field of view and makes it difficult for them to take part in activities that require them to use their hands purposefully since they cannot look down. Given the wide variety of users that may use this device, the device must be able to accommodate any patient. Shirley Ryan's current solution is a single stand-up mirror that is unable to accommodate each user and is also disorientating due to the mirror image produced by a single mirror.

Requirements:

During the client interview and user testing, Ms. Chakarova detailed several specifications for the design

- Adjustability: The design should be able to accommodate patients of various ages and sizes in a few different situations (i.e sitting upright at a table or laying down).
- Safety: The design should maximize safety and minimize the risk of injury for both the user and the occupational therapist.
- Portable and easy to use: The design should be easily portable and easy to use and setup.

- Should be low-tech: The design should not require the use of monitors or an internal signal.

Design Concept and Rationale

Design Overview

We designed a device that will enable the user to see their lapspace despite their limited neck and head control, which limits their vision. The design requires users to look straight ahead at a mirror which will have their workspace projected into it.. The device consists of a dual mirror setup and a base to help the mirrors stand freely, make the device portable, and allow for height adjustability..

We have utilized two mirrors to reflect the true image instead of the mirror image. The design is adjustable to a variety of users from ages 3 to 18, whether they are sitting upright or laying down. The base's height can be adjusted from 2ft to 5ft. The angle of plank between the two mirrors can also be adjusted to fit the user's vision. The angle of the mirrors can be adjusted so that the user can see their workspace through the use of one-way locking bearings which rotate in one direction, allowing for the mirrors to be fixed at an angle since the bearsungs cannot rotate in the opposite direction.

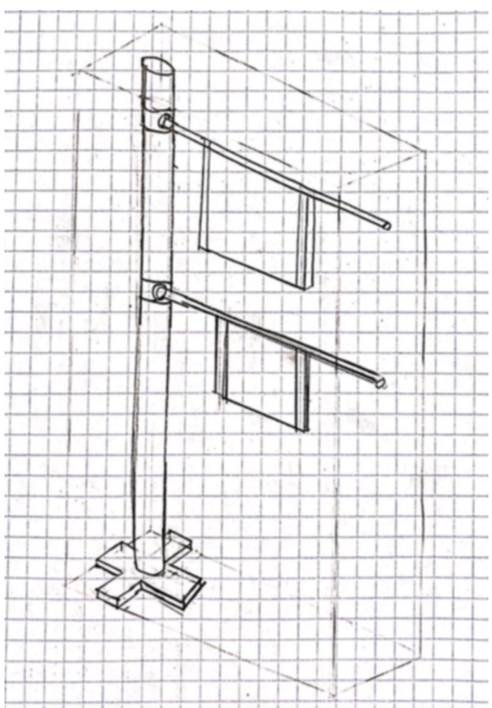

Figure 1: Isometric sketch of the design

Design Components

There are two main components to our design, the base component, and the mirror component.

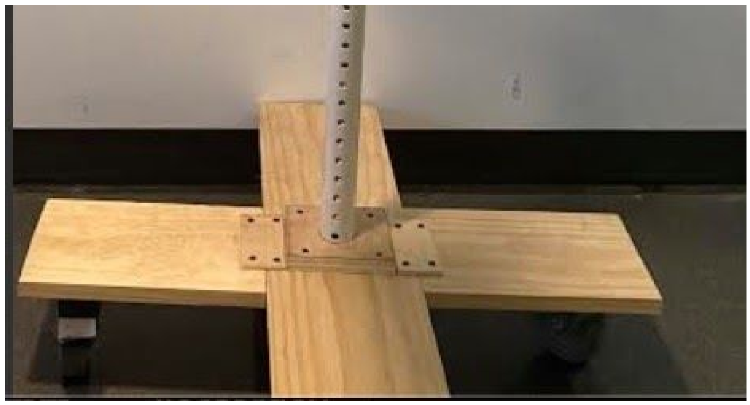

Figure 2: The Base Component

Specifications and Use

The base is composed of 4 locking wheels that can be locked or unlocked easily. Each of these wheels are mounted to a 31” x 7 1/4” x 2” piece of wood and two 11” x 7 ¼ ” x 2” pieces of wood. In the center of the base is a PVC pipe with a 2 inch outer dimension (OD) with 20 holes drilled; there is 1 inch spacing between each hole. Inside the 2 inch OD PVC pipe is a 1 $\frac{1}{4}$ inch OD pipe with 20 holes drilled that are 1 inch apart. A key is inserted into the holes of the two PVC pipes in order to set the base’s height.

Rationale

The wheels allow for portability, and the base allows for stability. The two PVC pipes allow for height adjustability, which will let the design be suitable for a variety of users

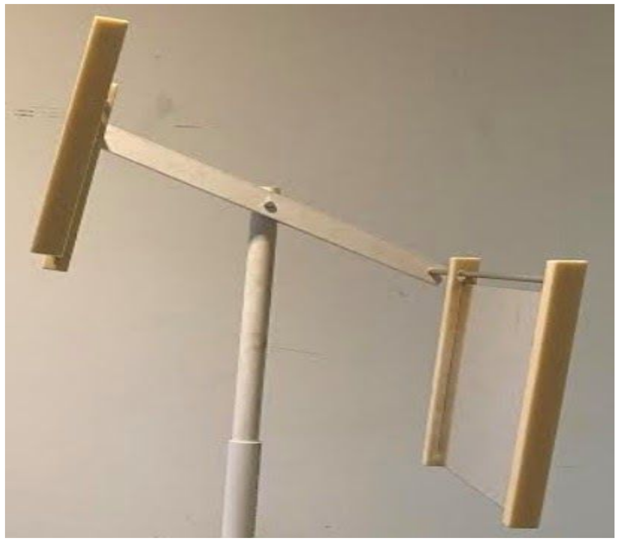

Figure 3: The Mirror Component

Specifications and Use

The mirror component is composed of a plank that connects the mirror component to the base, aluminum poles, and the mirrors themselves. The aluminum poles hold the frames of the mirror upright; the frames are made from ABS plastic. Inside the frames are a 12’’ by 12’’ mirror and a 9’’ by 9’’ mirror. For each pair of frames, there is a one-way locking bearing pressed into one of the frames and a through hole through the other. The aluminum poles are passed through the through holes and inserted into the bears. The mirrors rotate around the aluminum poles.

Rationale

The solid aluminium poles support the weight of the mirrors and the frames. The frames maximize safety by eliminating the sharp edges of the mirrors and are able to hold the bearings. The bearings allow for the therapist to easily adjust the angle of the mirrors by only allowing them to rotate in one direction

Overall Safety Considerations

Currently the design is safe; however, over time different parts of the design may wear down. It is not recommended to place the mirrors directly over the head of the user in case the frames get loose. Other than this there are no safety concerns that should arise from use and time.

Conclusion

The Magic Mirror allows a user with limited neck mobility to view a workspace not in their field of view by looking into a mirror that reflects their field of view through a second mirror that is capturing their intended field of view This design meets the requirements outlined by our partner, Miss Chakarova (Appendix F).

The advantages of that Magic Mirror are the well-designed features with special attention to safety and adjustability. All of the edges have been filled so there are no sharp edges for a child or an occupational therapist to cut themselves on. Each mirror is framed with an ABS plastic bar that also reduces sharp edges. Additionally, the smaller mirror is the one situated closer to the user's head, so that if it were to be a break, it would cause less harm than a larger mirror. In this way, the device is very safe to use in a facility with children.

The device is also adjustable to many different users. The drilled holes in the PVC pipe allow for the device to be adjusted vertically to accommodate users with different heights. The use of one-way locking bearings allow for the mirrors to be adjusted at an angle. Finally, the poles rotate about the PVC pipe, which allows for further adjustability and doubles as a compact storing mechanism.

These features allow the device to be safely and easily used by an occupational therapist.

Future Development

Designs can always be improved upon, and the Magic Mirror is not an exception, if we had more time to work on this design and a higher budget, the following would be our next steps:

- Make the Magic Mirror lighter and more portable
  - Our target weight for the prototype was under 20 lbs; we were unable to reach this goal in the 10 weeks we had to work on our design. The area of improvement is the base. We were unable to find any suitable material to make the base of our design out of besides wood, which increased the weight of the prototype significantly. Additionally, the wheels we are currently using are large and bulky; a change we would make is to reduce the size of the wheels, thus further reducing the overall weight of the design.
- Allowing for various distancing between the stand and the mirrors
  - Our original plan was to allow for the mirrors to be adjustable along the aluminum bar supporting them. Unfortunately, the use of one-way locking bearings prevented the poles from going completely through a frame on each mirror, which prevented the mirrors from being adjusted along the x-axis
- Extend the situations the Magic Mirror can be used in
  - With more time and a larger budget, it would be possible to create a product that can be used in a greater variety of situations, making the product more popular and more likely to fit the specific needs of the users.

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Appendices

Appendix A: Background Research

We directed background research after receiving the written project description from our partner, Ms. Chakarova, who works in the Shirley Ryan AbilityLab in Chicago, IL. The project was to design a visual deflecting device that would allow a child with limited head movement to see a workspace out of their visual field. The background research allowed us to be more prepared for the client interview.

Shirley Ryan AbilityLab:

Our partner is Larissa Chakarova from Shirley Ryan AbilityLab. The Shirley Ryan AbilityLab is a rehabilitation center in Chicago, Illinois. The lab describes itself as a translation research hospital where clinicians, scientists, innovators, and technologists are working together 24/7 to come up with new ideas and approaches that will improve patient outcomes and also apply their research in real-time. Covering 1.2 million square feet and operating for more than 60 years (1953), Shirley Ryan is the first and only translational research hospital in the world and the largest rehabilitation hospital in the US. The Lab has been the number 1 rehabilitation hospital in the US for the last 29 years (1991).

The Lab is made up of 5 Innovation Centers that focus on a specific area of biomedical science (Brain, Spinal Cord, (Nerve, Muscle & Bone), Pediatric, and Cancer), and 5 Ability Labs that focus on generating specific functional outcomes (Arms & Hands Lab, Legs & Walking Lab, Strength & Endurance Lan, Think & Speak Lab, and the Pediatric Lab). The five labs allow for active research and analysis and patient care. Another component of Shirley Ryan is the “wet” lab; the "wet" lab is a lab that allows scientists and researchers to study diseases, conditions, and injuries that can only be studied at the cellular level.

Conditions that decrease head movement:

One possible condition that the user might have is Whiplash. This can occur in a person of all ages, including children. Whiplash is the overarching term that describes any injury caused by rapid head movement in any direction, which causes strain in the tendons and ligaments in the neck, thus damaging those tendons and ligaments. The injury is most commonly seen after an automobile collision. Frequently, Whiplash results in lack of head movement, headaches, and neck movements, and typically disappear within a few months. While someone affected from Whiplash does not usually wear a cervical collar, maintaining good posture is crucial to a fast recovery process.

Another condition that our user might face is Torticollis, which most frequently presents itself in children. It can be caused by crowding in a mother's womb, or by an automobile accident. Within the term of Torticollis, there are three distinct types. The first is acquired, which happens when the neck of the child tightens to one side, so the child is reluctant to move their head due to extreme pain. The second type of Torticollis is congenital, where the neck tightens because scar tissue forms in the neck muscles or there are congenital defects in the spine. The final type of Torticollis is traumatic, where damage occurs due to an injury. In some cases of Torticollis, the child may also have difficulty hearing.

The final condition that our user might be affected with is Meningitis. It presents itself in both a viral and bacterial manner. Meningitis requires immediate hospitalization or the patient is at risk for serious brain and nerve damage. Fever, headache, and a stiff neck are the fastest symptoms to appear with seizures and coma typically onsetting later. However, Meningitis is very rare; there are only 2,600 cases of Bacterial Meningitis per year, so it is relatively unlikely that our user is affected with Meningitis.

Current Solutions

There are few current solutions on the market now. Shirley Ryan AbilityLab uses a single floor-length mirror. While it does reflect the workspace, it creates a mirror image that can be disorienting for the user. In addition, it cannot be adjusted to the height of many users, nor can it be adjusted for users laying down. The single mirror only provides very little for the user because the user cannot read or write with it.

Appendix B: Client Interview Summary

Date: Monday January 13, 2020

Time: 6:30 - 7:30

Location: Ford G 205

Team members in attendance: Catherine Updegraff, Kelvin Lao, Bre Williams

Client / Design Problem Overview

- Larissa Chakarova
- Occupational Therapist
- Shirley Ryan AbilityLab

Our client, Larissa Chakarova, an occupational therapist at Shirley Ryan Ability Lab, works with children who have little to no cervical movement and users who need trunk support. Shirley Ryan makes therapy sessions interactive, which can be difficult for patients who cannot bend down or move their necks. Consequently, Ms. Chakarova would like our DTC section to create a portable device that will redirect the user's field of view and bring their workspace into view when their natural eyesight is fixed at a certain angle.

Users

- Patients (children aged 3-18 years)
- Patients have limited mobility of their neck and trunk
    - Due to therapy equipment (such as a neck brace) or a paralyzing disability
    - This limited mobility limits the patient's range of view
- Patients must be able to have their vision deflected to their laps and/or workspace
- Patients must not be able to accidentally knock into or destabilize the product
- Patients must not have their personal space invaded by the product

- No goggles, glasses, or close screens
- Therapists who are working with patients
- Therapists must be able to easily adjust and move the product
    - This is so the product can be used on a large range of people
- Therapists must be able to easily move and store the product

Product

- The product will be used in an environment that houses a wide array of individuals
- Must be adjustable in height to accommodate different users
- Product will deflect vision towards the user's lap/working space
    - Preferably with no magnification or any disorienting features
- Product should not be made with potentially dangerous materials
    - Glass, sharp edges, unstable design, etc.
- Product must be portable and easy to operate

Figure 4: Example position of the user on the grey beds. The table spans approximately 30 inches by 1 foot. The thickness of the bed is 4 inches, and can be raised off the ground between 2 and 4 feet.

Figure 5: Examples of position of the user. No specific measurements were given. Rather, this is a guideline of how the user might be positioned while using the product.

Table 1: Client Preferences*

Attributes	**Goals**
Weight	Sturdy enough to not fall or rock when bumped into
Standing profile-width	Adjustable. Shortest height adjustment should accommodate a 3-year-old. Tallest height adjustment should accommodate an 18-year-old
**Client did not provide specific dimensions for the product. Only these guidelines.*	

Conclusions and Next Steps

Conclusion:

- The ideal product would be adjustable to accommodate a wide variety of users
- The ideal product would be adjusted and handled by a therapist, not by the patient
- The ideal product would minimize disorientation and maximize safety

Next Steps

- Record and analyze research from the user observation session
- Research ways of deflecting light
    - Mirrors, prisms, existing products
        - Telescopes, special goggles, etc.
- Research specific dimensions for the product
- Brainstorm designs for the product’s first iteration

Appendix C: User Observation Summary

Date: January 15, 2020

Time 5:00-6:00 pm CDT

Location: Shirley Ryan Abilitylab

Team members in attendance: Ellie McGhee

Other key attendees: Members from other groups

Objective: The purpose of this observation session is to qualitatively evaluate how the product will be used and where it will be used. Also, this should clarify any lingering questions about the age of the user, condition of the user, and where the user will be positioned.

Observation conditions

The observation was conducted in the evening, while no children were using the facilities. It was quiet, well-lit with normal "room" temperature. The space was clean, with little to no clutter, or evidence of visible dirt. The environment was very bright and openly spaced, with little privacy in the main room. Privacy is only afforded in the sound-proof rooms and testing rooms. The color scheme on the walls was bright, adding to the cheerful atmosphere. There was no user meeting, but the partners had high energy and were enthusiastic about the product and the children in Shirley Ryan.

Session overview

There was no user meeting, so the partner acted as the child might act using the product. This was performed in a variety of locations with a variety of tables and positions to help demonstrate where the bed should be.

Information gathered

Users can be in multiple positions: lying down on a bed, sitting down on a bed, or sitting at a table. When laying down or sitting on a bed, users will have a small lap table. The lab table can be seen in figure 1.

Figure 6: Example of a user lying down on a bed with a lab table

Figure 7: Example of a table the user would use

Conclusions: The product must be adaptable to a variety of ages 3-18 with patients having different conditions. In addition, it must be portable and utilizable in several locations at Shirley Ryan.

Appendix D: Mockup Plans

Objective: The objective of this mock up is make it possible for someone whose eyesight is fixed at a certain angle use their hands purposefully.

This mockup only used one mirror, so the major problem we were testing is how disorientating a single mirror would be. Some activities were easy to do (e.g., playing with legos and toy trucks, finding certain beads to make a bracelet, and playing with a water sensory toy), whereas others were more difficult (drawing). Although we did not have a mirror to use with our product, Ms. Chakarova, let us borrow a 10” x 14” mirror. This sized mirror showed a large portion of the workspace- enough to bring the task into view. We were able to see our hands and workspace while in the positions the user would be situated in. he mockup is not free-standing, but it is height adjustable, and the angle of the mirror can also be adjusted. Ms. Chakarova mentioned the idea of the mirror being able to slide along what it's attached to.

Mockup

This mockup is made of duct tape, two square metal pipes with holes in it, a PVC pipe, and foam core. We used duct tape to mount a 9” x 9” foam core square onto the PVC pipe, which was then attached to the metal pipe with duct tape. To allow for the mirror to be placed at different angles, we used duct tape to fix the mirror at different angles; the piece of tape tapped to the PVC pipe was moved to change the angle of the mirror. The holes in the metal pipe allow for the design to be height adjustable

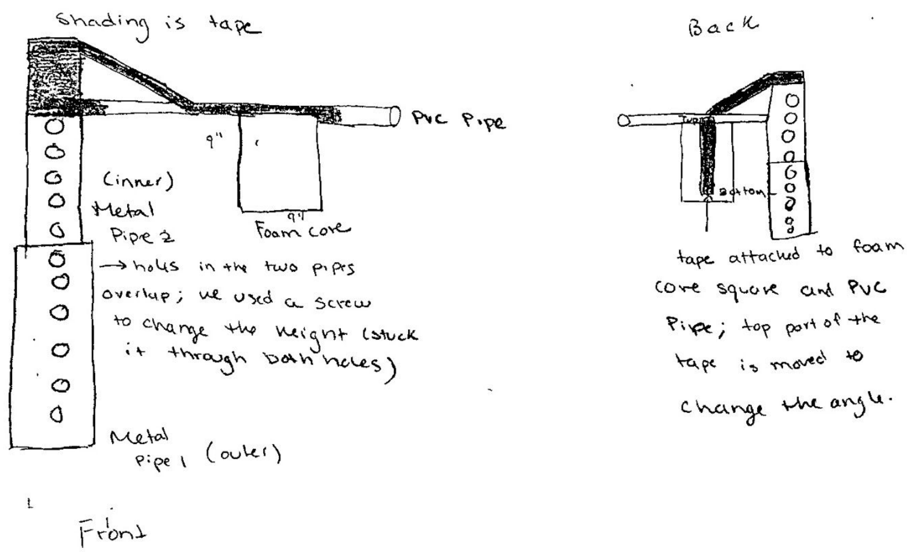

Figure 8: PVC pipe is connected to the inner square metal pipe with duct tape. Attached to the PVC pipe is a 9” by 9” foam core square to imitate a mirror. The smaller (inner) metal pipe is placed inside of the wider (outer) metal pipe, and a screw is used to change the height of the inner pipe. Along the backside of the foam core square is a piece of tape connected to the PVC pip to adjust the angle of the square; the piece of tape attached to the PVC pipe is what moves to change the angle.

Questions

- How difficult will it be to perform a task while looking at a flipped image?
  - Will one mirror be too disorentating?
- What is a good size for the mirror?
- How easily can the design be adjusted?

Appendix E : User Testing Report

Date: February 5, 2020

Time 5-6:15

Location: Shirley Ryan Abilitylab

Team members in attendance: Ellie McGhee, Kelvin Lao, Bre Williams

Other key attendees: Members from other groups, Ms. Chakarova

Objective

The purpose of this session was to test our single mirror prototype; we were testing the difficulty of completing a task while looking at a reverse image. Additionally, since our groups had dual mirror setups, this was a great opportunity to contrast the single mirror set up with a dual mirror setup. We also used this session as an opportunity to gain feedback from Ms. Chakarova.

Testing conditions

A user was not present for this session, so we tested the prototypes on ourselves. We were put in the two positions the user would most likely be in: sitting upright at a table and positioned at an angle while on a bed. We performed activities the user would. Since we were isolated from other patients, workers, and parents, there were no obvious environmental factors that could potentially affect the user if the user was present during the session.

Testing session overview

As previously mentioned, a user was not present for this session, so we tested the prototypes on ourselves. We were put in the two positions the user would most likely be in: sitting upright at a table and positioned at an angle while on a bed. We performed activities the user would, such as drawing, stringing beads, playing with a toy car, and playing with a water sensory toy. Each group was able to test at least one of their mockups. Since our mirrors did not arrive in time for the testing session, Ms. Chakarova, kindly lent us a 10” x 14” mirror to test with our prototype. To adjust the mirror, we used verbal communication with Ms. Chakarova to imitate the therapist-patient interaction that would occur when adjusting the design. Designs using single mirrors, dual mirrors, cameras, and iPads/iPhones were tested.


Figures 9 & 10: Example position of a user laying down and the mechanism provided for comfortably positioning the user.

Figure 11: The table the user would sit at while in an upright position.

Figure 12: Water sensory toy the user may play with.

Analysis and Implications for the Design

Based on our observations collected during the session, we have decided that a dual mirror setup is best because it offsets the reverse image created by a signal mirror. Additionally, since adjustability is a necessary component of the design, we have decided to make our design height adjustable between 2’ and 5’: 2’ for the lowest possible height of the table and 5’ for a ballpark maximum height. The 10” x 14” mirror brought a large portion of the workspace into view, so we will also be using a mirror of similar dimensions. We learned from another group's prototype that a large and small mirror combination may work well, so we will be using a smaller sized mirror as our second mirror. Since the tabletop is 3’ x 3’, our goal is to have our dual mirror setup bring a 3’ x 3’ workspace into view. Ms. Chakarova liked our stand, so we plan on keeping the overall design of our stand but with some adjustments.

Appendix F: Design Review Summary

Design Review Summary:

Date: 2/20/20

Time: 1:00 - 1:30

Team Members in Attendance: Kelvin Lao, Ellie McGhee, Catherine Updegraff, Bre Williams

The following table details the feedback received during the design review.

Table 2: Design Review Summary

Design Attribute	**Positive Feedback**	**Negative Feedback**	**Suggestions and Additional Comments**
4 - legged base	Heavy - puts center of mass back closer to the y-axis	Heavy without a mechanism for easier portability	Use wheels to increase portability
Wooden Rod	Cheap material, easy to find	Is too weak to hold up mirrors, could bend too much	Use a different material that has a stronger tensile point
Stand (not including base)	Wood, strong, sturdy	Can’t be easily adjusted	Use a mechanism similar to crutches to increase adjustability or use a tripod

Mirror adjustability (horizontally)	Flexible for many different users	They move independently; might be harder for the occupational therapist to set up the mirror easily	1) Have one mirror that “locks” in a certain position 2) Have both mirrors move as one unit
Use of the 1-way locking bearing to adjust the angle of the mirror	They allow the mirrors to be strongly locked at a certain height	To set it “back”, the bearing has to rotate all of the way around the rod	Use a different type of bearing or a flange plate mount
Top mirror location	Allows user to gain a bigger view of the workspace	Could protrude into the user’s sense of space, and give them a feeling of claustrophobia	Keep the top mirror in front of the user; be cognisant of that during user testing

Follow-up:

Given the feedback that were provided to us, Team 3 will perform the following steps:

- Meet with a shop specialist about the use of a flange plate rather than a bearing
- Reframe the mirrors with plastic
- Add bearings to the design
- Pay critical attention to set up time/ease of set up during the next round of user testing

Appendix G: Problem Definition

Project Name: Visual Deflector Watching Hands Play

Client: Larissa Chakarova, Shirley Ryan Abilitylab

Team Members: Ellie McGhee, Catherine Updegraff, Kelvin Lao, Bre Williams

Date: February 25, 2020

Mission Statement:

- Design a portable design that will bring the user's workspace into view when their eyesight is fixed at a certain angle.

Project Deliverables:

- Final prototype
- Final report
- Final poster

Constraints:

- $100 budget
- 10 weeks to build product
- The design solution cannot touch the user
- Deliverables must be completed by March 14, 2020

Users and Stakeholders

- Patients at Shirley Ryan AbilityLab who cannot see their lap or workspace due to limited cervical movement or limited head movement
- Larissa Chakarova: as an occupational therapists, Ms. Chakarova will utilize this device during therapy session

User Profile:

- Users of this product are patients at Shirley Ryan AbilityLab aged 3-18. Patients that will use this product have limited mobility of their neck and/or lack truck support. Patients with these conditions have trouble taking part in activities that require the use of their hands. Larissa Chakarova of Shirley Ryan wants us to design a device that will allow patients to redirect their vision to their lap or workspace.

User Scenario:

- The patient sits down on a seat and has a lap table. They try to look down to see what they are doing in their hands but their vision doesn't go that far. They are wearing a cervical collar so they can't bend their neck down. They wish they were able to see what they were doing with their hands and be able to engage with other patients.

Requirements:

- Safe: The product must be safe enough to not break when touched or cause injury to the user or therapist
- The product should work when placed various distances from the user
- Adjustability: accommodate users of different sizes and ages and with different conditions
    - Be able to be positioned at different angles and heights
- Product cannot touch user

Specifications (Target):

- Minimize safety risks
- Be easily stored in a room next to the lab
- Adjustable within 2.5 and 5 feet in height
- Stronger reinforcements
- Bring a 3' x 3' workspace into
- Mirrors are adjustable on the line parallel to the plane of the floor (i.e. able to move left and right) within 2 feet centered around the user
- Use two mirrors to offset mirrored image
- Free standing structure
- Portable: weighs less than 20 lbs and easy to move

Appendix H: Instructions For Use

- Set the design in front of the user; make sure that the smaller top mirror is above the workspace.
- Locate the locking mechanism on the wheels and press down on it to lock the wheels into place.
- Remove the pin from the stand to adjust the height of the mirrors and the stand.
- Raise or lower the stand until the larger, bottom mirror is aligned with your eye.
- Place the pin through the holes once satisfied with the height of the stand.
- Angle the top mirror so that it captures the workspace and reflects in the direction of the bottom mirror; the mirror rotates towards you
- Adjust the bottom mirror until you are able to see the top mirror through it; the mirror rotates towards you

Appendix I: Instructions For Construction

1. The Base
    a. Obtain a 31” x 7 1/4” x 2” piece of wood and two 11” x 7 ¼ ” x 2” pieces of wood
    b. Assemble the pieces of wood in a T shape, with the 31” piece of wood in the center vertically and the two 11” pieces of wood placed next to the 31” piece horizontally
    c. Nail the pieces of wood together

2. The Stand
    a. Obtain a 30 inch of 1.75” diameter and a 40 ¼ inch of 1 1/16 diameter PVC pipes
    b. Choose one end and drill 20 holes with a diameter of 3.9” make each hole 1 inch apart; do this with both PVC pipes.
    c. Obtain a 4.5” x 5 “ x 0.75” wood, and cut a circle into the middle with a diameter 1.75”
    d. Glue the 2 pieces of wood together with wood glue and let it dry
    e. Put super glue around the hole
    f. Place the larger PVC pipe, holes side down, into the hole and let it dry
    g. Nail the PVC pipe and the wood onto the larger T shaped stand.

3. The Frame
    a. Obtain a 6 foot long piece of ABS plastic
    b. Cut the plastic into two 14” pieces and two 11” pieces
    c. Using a Lathe and Mill
        i. Using one of the 14” pieces of plastic and one of the 11” pieces of plastic

        1. Edge find the edges of the plastic
        2. After finding the edges, obtain an ⅜ end mill and press a 1.1 mm hole about 1 inch from the end of the plastic
            a. Place a bearing in each hole
    ii. Switch out the ⅜ endmill for a 3/32 end mill
        1. Drill a 12.25" x ⅛" x 0.2" deep slit into the 14 inch pieces
        2. Drill a 10.25" x ⅛" x 0.2" deep slit into the 9 inch pieces
d. Place the 14" plastic frames around the 12" mirror and the 11" plastic frames around the 9" mirror

4. Obtain two 13 inch aluminum pipes of ⅜" diameter
5. Obtain a 22" x 1.5" x 1.5" piece of wood and drill a hole of ⅜ diameter at both end of the piece of wood; drill the holes about 0.5" from the end
6. Line the holes with super glue and place the aluminum poles into the holes
7. Drill a hole of ¼" about 1" from the top of the 40 ¼" PVC pipe
8. Dill a hole of ¼" in the middle of the wooden piece
9. Using a 2" nail of the same diameter, place the nail through the ¼" holes in the PVC pipe and the wood. Secure the hole with a nut.
10. Place the mirror and the frames onto the aluminum pole; make sure the ends of the pole lock into the bearings.
11. Place the PVC of smaller diameter into the larger PVC pipe; use a pin to adjust the height of the PVC pipes. Place the pins through the holes in each pipe to adjust the height.

Appendix J: Bill of Materials

Bill of Materials

Table 3: Bill of Materials

Item	Description	Qty	Source	Part #	Unit Cost	Total Cost
⅜ inch one way bearing stainless steel	Locking needle roller bearing, 301 stainless steel, ⅜” shaft diameter	2	McMaster Carr	2489K29	22.93	45.86
Aluminum Rod	High-Strength 7075 Aluminum Rod, ⅜” diameter, 3 feet long	1	McMaster-Carr	90465K72	12.66	12.66
Acrylic Mirror	Plastic, damage-resistant mirrors	2	McMaster-Carr	8344T51	15.28	30.56
ABS plastic	Plastic, 6 ft	6	McMaster-Carr	8702K82	3.19	19.14
PVC Pipe	Standard-Wall Unthreaded Rigid PVC Piper for Water, 1 Pipe Size, 5 Feet Long	1	McMaster-Carr	48925K93	5.28	5.28