Final Report: The Step'N Stash

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Executive Summary

Problem

Shirley Ryan Ability Lab is a not-for-profit organization that treats patients with various conditions such as brain or spinal cord injury and guides them through rehabilitation. Physical therapist Lauren Henderson collaborated with the Design Thinking and Communication Program of Northwestern University to commission a product that aids in floor-to-wheelchair and wheelchair-to-floor transfer for her patients.

Research Methodology

The goal of the project was to reduce shoulder strain experienced by users during wheelchair transfers to and from the floor. To do so, we performed secondary research to learn more about wheelchair transfers in general and gain perspective into the day-to-day lives of wheelchair users. We also conducted an observational study of proxy users testing our mockups, shop director consultations, and component testing.

Design

StepNStash is a wooden multi-level step shelf that expands and retracts using drawer slides. The design aims to reduce shoulder strain by dividing the distance into smaller increments from point A to point B, thus dividing the shoulder movement into smaller sections instead of one large shoulder movement. The ability to push in and pull out the step allows the user to save storage horizontal space. Utilizing StepNStash's two back wheels, users can easily transport it within the house without having to exert their arm, leg, and back muscles to carry it. Lastly, because of the wooden material and its similarity to the drawer, the device itself blends easily within the user's home as simply one of the furniture without standing out to be a medical device.

Design Significance

The most significant aspect of the designs is the steps, aiding in reducing shoulder strain during wheelchair-floor transfer. This benefits both the wheelchair-user with Spinal Cord Injury (SCI) and their caregivers, by decreasing the high risk of experiencing fatal falls and body strain for both, as well as the psychosocial effects associated with these challenges for the wheelchair user, such as limited independence, restricted activity, and negative emotions. For the caregivers, their capability, or lack of it, was taken into consideration with the inclusion of a foot opener for the step and two back wheels for easier transport to reduce potential back pain. In addition, the cost is limited to $150 making it an affordable option both for individuals and physical rehabilitation facilities compared to other commercially available aid devices, with similar alternative options being around the price range of 600 dollars and above.

Introduction

The project partner Ms. Lauren Henderson, an Occupational therapist at Shirley Ryan Ability Lab, requested the team to find a solution for individuals with spinal cord injury (SCI) to transfer between their wheelchairs and the floor as this action currently places a significant strain on the individual's shoulders and/or the caregiver assisting. Reasons for transfer include the individuals with SCI playing with their kids and/or pets on the floor and physical therapy. Current solutions include Hoyer lifts, however, they are expensive and large, and thus can’t be transported. After an interview with Ms. Henderson, the team narrowed down the design focus into three categories: decreasing shoulder strain, storage, and homey aesthetic.

With these categories in mind, the team’s solution, the Step’N Stash, aims at decreasing shoulder strain while also being storage-friendly and blend within the user’s home instead of standing out as a medical device. The design is inspired by a drawer mechanism, with individual steps being pulled out when in use. When not in use, the steps are unified into one single rectangular box, thus saving storage space. The Step’N Stash can also be used as a small table in the meantime. And due to it being inspired by a drawer, the device itself can easily blend in as a piece of furniture in the user’s home,

The purpose of this report is to provide comprehensive insights on the development and implementation of the Step’N Stash. In the following sections, the team will delve into the users and requirements, highlighting the specific needs and preferences of individuals with SCI. Additionally, we will explore the limitations of existing solutions, emphasizing the constraints within which Step’N Stash must operate given the available resources. The design concept and rationale section will offer detailed explanations for each design component through written descriptions and visual illustrations. Furthermore, we will explore potential future developments, highlighting considerations that could further enhance the quality and effectiveness of the Step’N Stash.

Users and Requirements

At the start of the course, the team conducted an initial interview with Ms. Lauren Henderson, a physical therapist at the Shirley Ryan Ability Lab, to design a portable device that safely transports wheelchair users with spinal cord injuries to and from the floor with minimal effort. During the in-person interview, we desired to understand the physical therapist's main challenges and limitations/constraints when dealing with patients with spinal cord injuries and performing wheelchair transfers.

Users

Primary Users. This design's primary users are patients who have spinal cord injuries. Typically users range from 30-70 (see and have a caretaker or family member looking after them. Additionally, these patients have difficulty performing daily tasks that require going on the floor on their own such as playing with their kids, cleaning, or doing physical therapy. We haven't worked with any specific spinal cord injury patients from the Shirley Ryan Ability Lab but based on our discussion with Ms. Lauren Henderson, many patients cannot perform this transfer themselves or even with a caretaker at this moment with the tools that they have, and solutions such as Hoyer lifts look out of place in a home and are also very bulky. If users fall onto the floor or get stuck in the middle of their transfer, firefighters would have to be called.

Secondary Users. The secondary user in this illustrative scenario is Ms. Lauren Henderson, a physical therapist at the Shirley Ryan Ability Lab. She has been working with multiple patients with spinal cord injuries. During her sessions, she has interacted with several users who utilize small, homemade platforms like pads or tables to aid floor-to-wheelchair transfers. She has been eager to create a device that allows her patients to perform these transfers consistently and initially envisioned a solution involving steps that nest inside each other like Russian dolls for storage. These could be extended to create a 10-inch gap between each step, enabling users to gradually prop themselves onto their wheelchairs. Though this succeeds in assisting users during the transfer and relieving shoulder strain, it is still very time-consuming, hard to transport out of storage, and requires a long set-up time.

Design Requirements

Based on the initial interview with the Shirley Ryan Ability Lab with Ms. Lauren Henderson as well as our mockup testing, we elicited the following requirements for primary users:

1. Safety: The device should show no signs of degradation after users readily put all their weight onto the device repeatedly.
2. Increased independence: The user should be able to perform repeated transfers with the help of a caretaker whenever needed.

3. Minimal Size: It should take up as little space as possible within the house.
4. Aesthetic: The design should fit in with home decor and not look out of place or like a medical device.
5. Durability: The design needs to be long-lasting and be able to work for a long time without significant deterioration in quality.
6. Portability: The device should be able to be transported around the house easily by the caretaker, and when necessary, taken out of the house into a car.

Design Concept and Rationale

Overview

The Step’N Stash (Figure 1) is a flight of four stairs that pull out in a way similar to how drawers do, except that in the case of our product, each subsequent step pulls out further than the last. The idea behind our product is to reduce the amount of space that normal stairs take up by having the product collapse into itself, as well as keeping the product aesthetically pleasing by making it out of wood to give it a homey look.

Our product utilizes wheels in the back of the design that only contact the ground when the product is tilted at an angle, similar to the way two-wheeled suitcases need to be tilted to be effectively maneuvered. To help with the transportation of our product by these wheels, the back surface has a hole cut out in it for users to pull out with their feet.

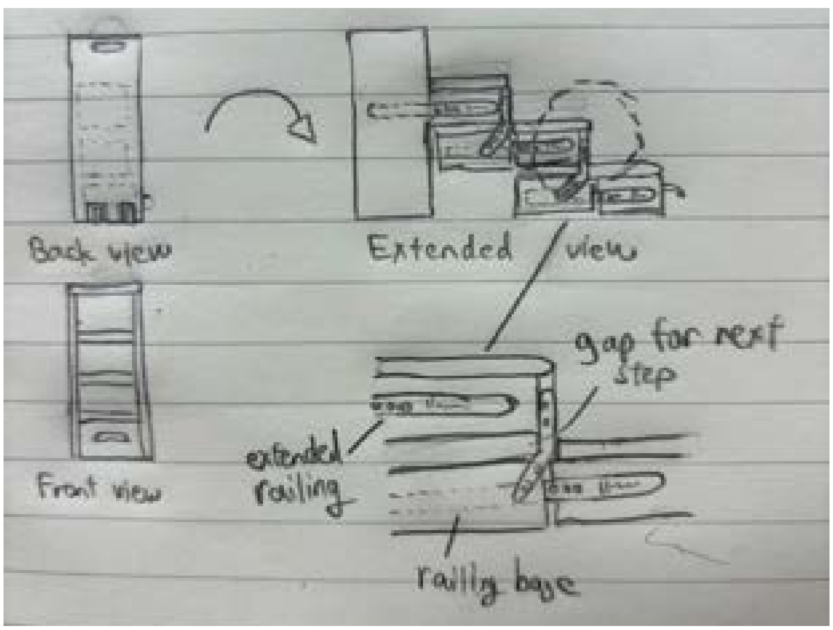

Figure 1: Engineering Drawing of the Step’N Stash

Our product is made up of mainly two components: The bottom three steps, which we’ll refer to simply as the steps, and the top “step”, which is also the housing that encloses the bottom three steps. The following sections will describe these two components, the steps, and the housing, more in-depth, and the rationale behind them.

Steps

Each step consists of two sheets of wood, one that is 18 x 10 in. and another that is 18 x 3.3 in, which are fastened together at a 90-degree angle to create steps that are 4 in. in height, 10 in. in-depth, and 18 in. in width (Figure 2).

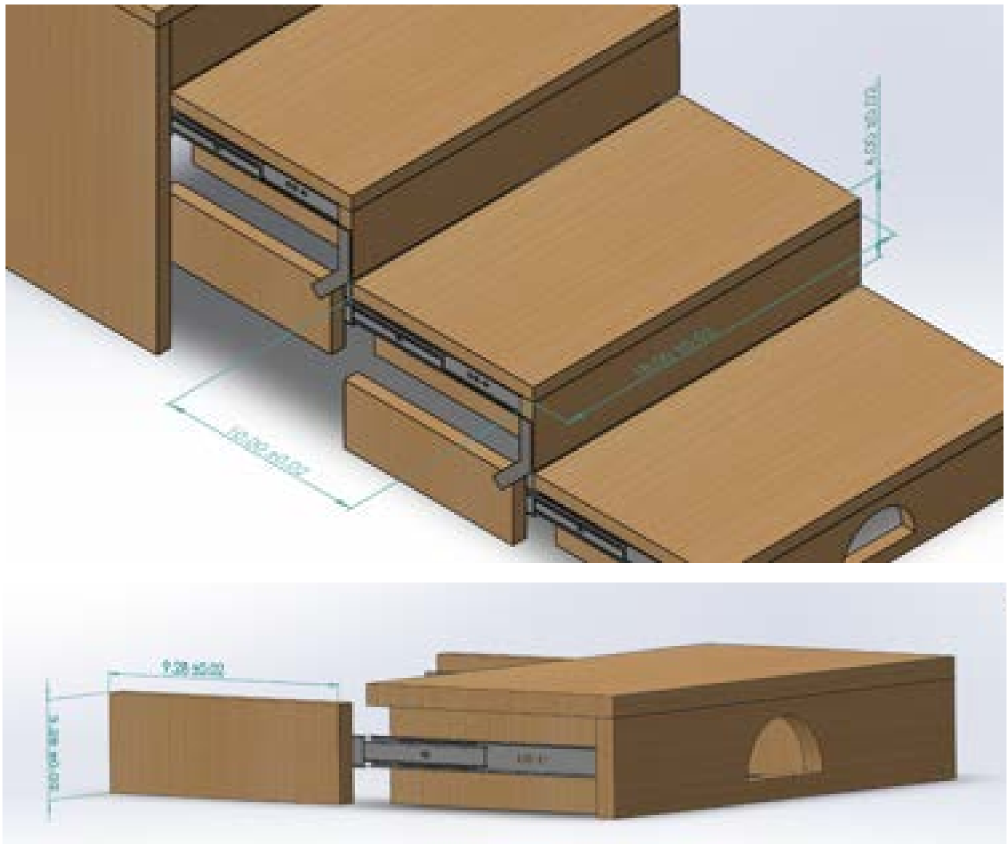

Figure 2: The dimensions of each step

Each step has 10-inch drawer slides attached to it, allowing for each step to slide out further than the step above it. Each side of the slides is attached to a 9.28 x 3.28 in. sheet of wood (Figure 2). The inner piece of wood is secured to the step, while the outer piece of wood is secured to the succeeding step. This allows for the width of each step to be preserved, instead of the width becoming progressively smaller with each step (Figure 3).

Through user testing with our initial mockup, we found that users' clothes tended to get caught on the edges of each step, so we made sure to round out the edges of each step of our prototype to prevent this as well as any potential cuts or scrapes.

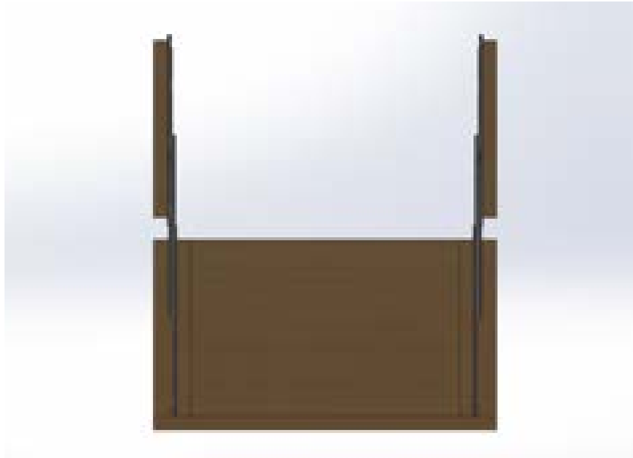

Figure 3: Underside of each step

The top two steps have 135° angled steel braces on the side and straight steel bases on the back of each step connecting the sheet of wood attached to the outside of each drawer slide to the next step, as well as giving support such that the stairs do not give under the user's weight. Initially, we only had the angled brace on our prototype, but after testing with a general user, we found the steps were prone to buckling, after which we added the straight braces on the back of each step which now prevents the buckling.

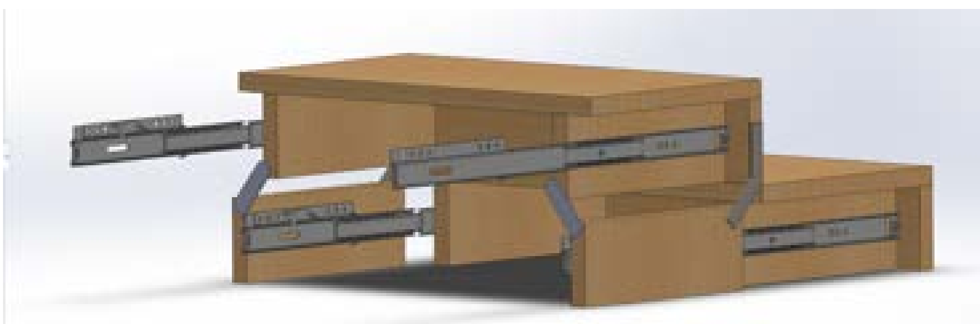

Figure 4: Angled brace and straight brace between steps

Another issue we found during user testing with our mockup was that there was some difficulty pulling out the steps, as users would have to bend down to the ground and grab the edge of the bottom step. To remedy this, the bottom step has a hole in its front face for users to put their foot into so that they don't have to bend over to pull the steps out.

Figure 5: Front face of the bottom step

Housing

The housing consists of five sheets of wood, one sheet for the top, one sheet for the back, two sheets for the sides, and one sheet for the front. The sides are 15.58 x 12 in., the top is 12 x 19.44 in., the back is 18 x 15.58 in., and the front is 18 x 3.28 in (Figure 6). The drawer slides for the top steps are attached directly to the inside of the sides of the housing to assemble the Step'N Stash as seen in Figures 1 and 2.

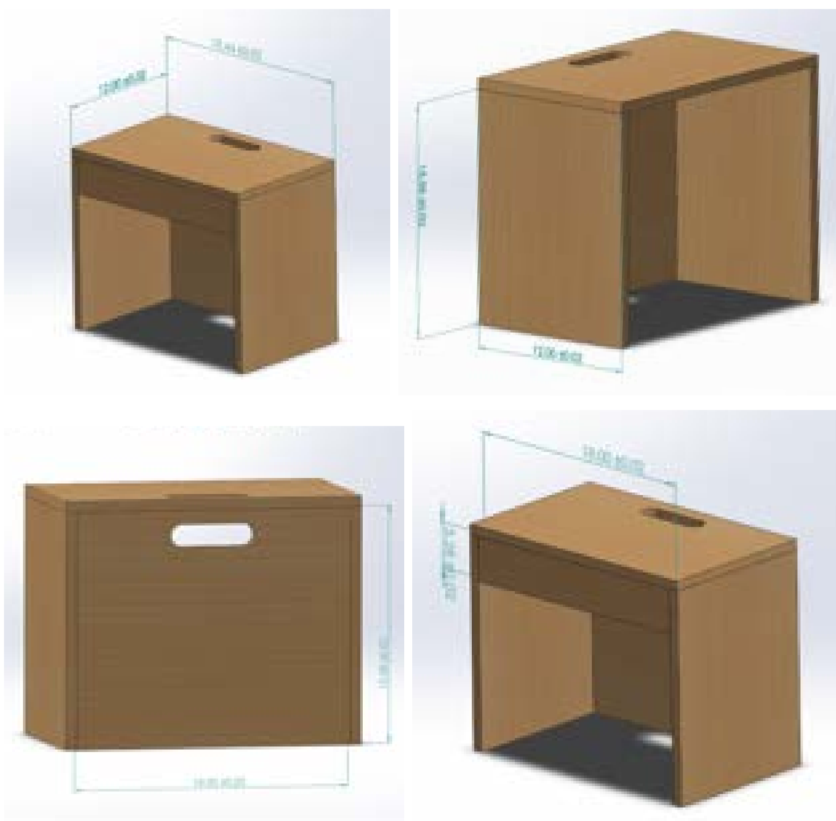

Figure 6: The dimensions of the top (top left), side (top right), back (bottom left), and front (bottom right) of the housing

During user testing, we found that the Step'N Stash was a lot heavier than we had anticipated, and thus transporting it was more of a hassle than we had intended. To alleviate this, we added wheels to the back of the Step'N Stash, and slots in the back and top of the housing to act as a handle. The bottoms of the wheels are a little higher than the bottom of the housing, such that when the Step'N Stash is in use, the wheels do not engage with the ground, which could cause the Step'N Stash to slip. For the wheels to engage with the ground, the Step'N Stash must be tilted at an angle, akin to how a suitcase must be tilted to roll efficiently.

Figure 7: The back of the StepN' Stash prototype with wheels

Limitations

Prototype Testing

The prototype testing was limited in terms of users and environment. We could not conduct prototype testing with the end users in the Shirley Ryan Ability Lab. We also could not find any other target users available for testing that met the key criteria mentioned previously. We instead tested our prototype with fully able bodied users who were instructed to not use their legs while completing their movements when using our prototype. Due to this limitation, we do not have insight from our end users, who would have been able to provide us with important feedback on how successful our prototype would be in its real-world intended use.

Future Developments

Additional User Testing

Further user and performance testing can also be done to test how successful our design is at reducing bodily strain during wheelchair transfer. This would be conducted by instructing users to use the Step'N Stash to first move from their wheelchair to the floor. They would then give a rating on how difficult the movement was from 1 (not difficult at all) to 5 (extremely difficult), along with the reasoning for their rating. They would then repeat this rating after using the Step'N Stash to get back into the wheelchair. This could test any potential hazards, design faults, and measure intuitiveness for the user.

Since the Step'N Stash requires the aid of the caregiver to move it, pull out the steps, and push them back in, testing to gain caregiver feedback should also be conducted. This would allow us to identify potential hazards and strenuous movements caused by the current design. This would allow us to make changes to the Step'N Stash as needed so that caregivers with a wide range of physical abilities could use it with ease.

Production

Additional research would also be conducted on how to manufacture the Step'N Stash on a larger scale while maintaining quality and affordability. Further maintenance research would need to be conducted to see the different weights and stresses that the steps of the Step'N Stash could withstand before deformation. From this research, the lifetime of our device could be identified before the device could be unsafe.

Design Modifications

We can add support for the steps that swing out whenever they are expanded. Visually, our design does not look like it can support heavy weights, which may discourage users from using our product, and it also doesn't hold down as well for weights above 180 pounds. Therefore, in the future, we could develop support with a rubber stopper on the bottom for friction that would swing down whenever the steps are expanded so that weight does not solely rely on the ground support on the housing and bottom step (see Fig. 8).

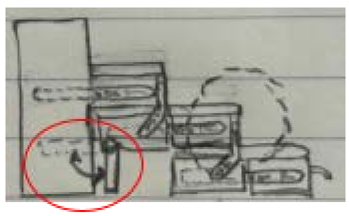

Figure 8. Step support future development

Finally, we would also like to add a collapsible handle like a suitcase to replace the current engraved handle so that people do not have to bend over as much to wheel our device around, which can cause back strain and is not very viable for older caretakers.

Conclusion

To summarize, our design meets the key needs of individuals with spinal cord injury (SCI) and their caregivers who will use the device to safely transfer the user between the wheelchair and the floor. The design uses a combination of:

- Increment of steps to decrease strain on the user's shoulder by distributing the action force into smaller actions.
- Drawer-like design to save storage space while also making the device's aesthetic homey.
- Wheels and foot handlers for the caregiver to be able to transport and assemble the device without causing back pain.

The users and their caregivers need a safe design. Hence, a stainless steel L-bracket and brace are used to ensure that each wood component is securely assembled and to prevent unstable movement. Each railing has a 100 Lb load-bearing capacity, with three pairs of railing being incorporated into the design. In addition, the devices are to be sanded down, including the corners, to prevent users from being injured by sharp edges grazing the user's skin and wood splinter penetrating skin.

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Appendix A: Project Definition

Project Name: Floor-to-Wheelchair Transfer Aid
Client: Lauren Henderson with Shirley Ryan Ability Lab
Team members: Michael Xing, Alyse Playko, Ryan Chung, Rocelyn Young
Date: April 11, 2024
Version: 4

Mission Statement

- Develop a portable device that safely aids wheelchair transfer to and from the floor with minimal effort
- Blends seamlessly with home decor
- For users with spinal cord injuries which prevent them from using their legs

Project Deliverables

- CAD Design / 3D Drawing of the project
- Final prototype
- Project presentation including demonstration of key benefits over existing solution Final report

Constraints

- Budget: $150 to both create initial mockups and final prototypes.
- Time: June 7. Developing a project and ensuring it meets all client requirements may mean that we need to develop several prototypes (which take time) and choose the best one among those.
- Uncontrolled risks: Not being able to test until the device is fully safe for the patient due to FDA regulations and hazards.

Users and Stakeholders

1. Wheelchair users with spinal cord injuries impacting only their lower extremity mobility need aid transferring from and to the floor
2. Patients' families and caregivers who will benefit from the patients' increased independence

3. Shirley Ryan Ability Lab which will benefit from an improvement in solutions for wheelchair patients

User Profile

1a. Wheelchair users with—

- limited to no lower extremity mobility
- Full arm function (low-level injury)
- The ability to move from their wheelchairs to the floor fairly frequently

1b. Some patients may—

- have spinal-cord injuries
- feel unsure about getting out of their wheelchair on their own

2. Caretakers who—

- are unable to lift the patient up
- looking for a way to assist patients onto the ground
- worry about the patient's falling or/and going back up to the wheelchair

User Illustration

David is a father who was in a car accident in which he incurred a serious spinal cord injury that has caused him to lose the function of their lower extremities. David has two young children and a spouse. David's spouse must leave for work or to run errands occasionally, and David is left to take care of their children alone. This includes changing diapers, fixing meals, and engaging with his children. David enjoys playing with his children when he has quality time to be with them one-on-one. His children love to play with their toy train tracks on the ground. Since David's spouse is not present to aid him in moving from his wheelchair to the ground, he must transfer independently. David turns on the brakes of his wheelchair, and though he is aided by gravity, this is still an unsteady process as David slides out of his wheelchair onto the ground. When David is finished playing with his children, he must move from the floor and back into his wheelchair. Without the aid of his legs, the distance to push himself up is too large to be done with ease as he is also acting against gravity. This then becomes a time-consuming process of tricky maneuvering that often causes David shoulder pain.

Needs

Needs Prioritized	Metrics	Units	Ideal Value	Allowable Value
Safety (cannot lead to cuts/falling) From: Ms. Henderson	User goes up and down repeatedly without getting cut by the furniture or falling down	%	100%	100%
Independence (easy to set up by caretakers) From: Ms. Henderson	How fast it takes to set up by caretakers	Seconds	7 Seconds	10 Seconds
Minimal size (as small as possible when not expanded) From: Ms. Henderson	How small it is when not expanded	in^3	18*16*10	18*20*10
Aesthetic (how much it fits in a home) From: Ms.Henderson	How much the material and view blends in with surroundings	%	100	100
Affordability From: Ms. Henderson	How much money the product would cost	USD	50	100

Table 1: Priority project needs and their metrics, units, ideal value, and allowable value.

Appendix B: Background Research

In this project, we are working with Lauren Henderson, an occupational therapist at the Shirley Ryan Ability Lab. The Shirley Ryan Ability Lab is a not-for-profit research hospital based out of Chicago, IL that specializes in physical medicine and rehabilitation.

A key issue that patients with spinal cord injuries face at the facility is transfer in and out of their wheelchairs. According to Henderson, many face difficulty during this transfer, and this leads to shoulder strain in patients. The purpose of the project is to design a product that can reduce injury or strain in patients with spinal cord injuries during transfers between the floor and their wheelchairs. To develop a better understanding of this issue, we have conducted further research on the implications of wheelchair use as well as spinal cord injuries in general. The research conducted led to a greater background that aided in the planning of further primary research. Specifically, the secondary research is broken up into four primary components: spinal cord injuries; users; product standards and regulations; and current products on the market.

Spinal Cord Injuries

The spinal cord is responsible for sending and receiving signals between the brain and the body. These signals trigger movement in the different muscles of the body and are how movement occurs. The spinal cord is made of soft tissue surrounded by bones called vertebrae, and when there is damage to any of these components, it is called a spinal cord injury. Spinal cord injury occurs when someone experiences a sudden blow to the back, often in vehicle accidents and falls. The spinal injuries that will pertain to our design

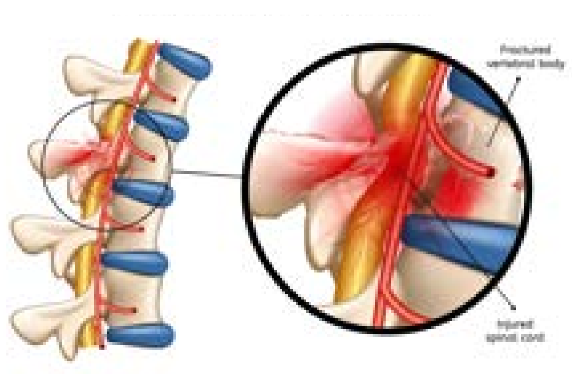

Figure 9: Spinal Cord Injury Diagram

challenge the most are those to the lumbar and sacral spinal nerves that control signals to the lower extremities [2]. Spinal cord injury causes loss of movement and sensation, muscle tightening, lack of circulatory control, and permanent changes in strength [1].

Users

Wheelchair users with spinal injuries come from a variety of different demographics and backgrounds. The age range in which these injuries occur tends to be between ages 16 to 30, and those who are 65 and older [1]. Researchers from the U.S. Department of Veteran Affairs conducted a study to gain insight into the perspective of wheelchair users with spinal cord injuries. Wheelchair users already have limited independence and restricted activity. The study found that due to this when they are injured from an incident caused by their immobility, there are detrimental effects both physically and mentally [3]. For this reason, gaining more independence is very important to users both physically and mentally.

Product Standards & Regulations

For medical devices in general, the U.S. Food and Drug Administration (FDA) monitors and issues recalls for medical devices that are potential safety risks. Recalls can occur for various reasons, such as defects, electrical failures, or risks of separation in devices that could cause harm to patients [4]. For a recall to occur, only one accident has to take place. When it comes to more specific laws surrounding wheelchairs, there are the Assistive Device Lemon Laws. These laws protect consumers who purchase defective mobility aids such as wheelchairs [5]. They also hold the company accountable by requiring that manufacturers provide a warranty guaranteeing that devices will be free from defects that substantially impair their use, or will be repaired, replaced, or refunded [5].

Current products

After researching a variety of current solutions on the market to ease wheelchair transfer, we were able to come up with three products coming from a wide range of prices. These products are made from a variety of materials, have different dimensions, and have varied online reviews.

Figure 10: Power Hoyer Lift

The most expensive product, the Hoyer Lift, is popular primarily due to its simplicity and ease of use for caregivers. There are a range of different kinds of Hoyer Lifts based on the kind of "power" used to operate them. The most popular type is the Power Hoyer Lift. This device is either plugged into an outlet or battery-powered. The caregiver then can press a button to raise or lower the lift. The wheels on this design also make it easy to transport within the home. This device also works for users with various disabilities, from those who may have no mobility whatsoever to users who may still have mobility in their upper extremities. However, this product falls short on the accessibility and portability scale. A typical Power Hoyer Lift will cost about $3,000 and cannot be easily transported to different locations [6].

Figure 11: The Paraladder

Next, a lower-cost device has also been popular. The Paraladder by Living Spinal is a portal step-ladder-like device that is used during wheelchair transfers to and from the floor. A non-wheelchair user unfolds the collapsible Paraladder and places it in front of the wheelchair [7]. The user can then use the handles and scoot their way up the stairs and into their wheelchair [7]. This device reduces the upper body strain that may occur from going directly from the floor into the wheelchair by breaking down the process into steps. Through this process, the user does not have to lift their entire body weight during the transfer as contact with the steps is held at all times. The Paraladder is portable and relatively easy for caregivers to transport. However, the price of the Paraladder is $700, so still very expensive and not widely affordable for users [7].

Figure 12: The Assist Handle

Lastly, the most affordable and simplest design is the Assist Handle. The user first attaches the Assist Handles to the left and right frontmost bars of the wheelchair. The user can then grip the handles to provide stability while using their arms to push themself up [8]. This device is portable, lightweight, and costs only $9.79 to produce, making it very convenient as well as accessible to users from a variety of socioeconomic backgrounds [8]. However, this solution still relies on the user being able to lift their entire body weight unsupported from the ground and into the wheelchair. Therefore, upper-body muscle strain is still highly likely, and the user would have to be relatively in good physical shape to complete this action.

Implications

After conducting secondary research, we have gained insight into the complexity that comes with wheelchair transfer. Since the different conditions held by wheelchair users have a variety of implications affecting areas of muscle mobility, creating a general solution for all wheelchair users is a complex task.

Looking at existing solutions has shown us that common issues with devices that aid in wheelchair transfer are cost-effectiveness and accessibility. There are helpful devices currently on the market, but they are so expensive that the average person would not be able to afford them. A lot of the devices that would solve the issue of muscle strain during wheelchair transfer were very large and not portable so could not be used in most environments. There is room for more improvement in the areas of portability as well as affordability of these devices. Potential limitations our design might face include generalizability and cost. We will have to balance the pros and cons of each aspect of our design, as many aspects of the solution to one problem will likely enhance another. Our design needs to be relatively low cost so that users can afford them, while also maintaining safety and longevity. Additional questions that have arisen from our research are mostly surrounding the daily lives of our end users. How often do they need to get in and out of their wheelchairs from or to the ground? In what environments must these transfers occur? What methods are working best for them right now versus what methods do they least like?

Appendix C: Project Partner Interview Summary

We had our initial interview with Dr. Lauren Henderson from the Shirley Ryan Ability Lab on Zoom on Tuesday, April 9th, 2024 at 5:00 pm. The interview aimed to discuss Dr. Henderson's proposal for a device to aid wheelchair users with spinal cord injuries with transferring independently from the ground to their wheelchairs, her expectations for this device, and its impact on its users.

Problems

While the problem statement supplied by Dr. Henderson was very descriptive, we wanted to reaffirm a couple of details during our interview. Some of these details include:

- The intent behind this device is to aid specifically in ground to wheelchair transfers, and not other types of transfers.
- The intended users for this device are people with spinal cord injuries who have good upper-extremity mobility and usage.
- The goal of the device is to eliminate the need for users to get help from family or caretakers to get from the ground to their wheelchairs, both as a way to increase independence for users and also to alleviate the potential mishaps from an improper attempt to help users up. Dr. Henderson also mentioned some cases where her patients had to call the fire department to help them up because there was no one else home to help them: "If someone falls, calling the fire department is sometimes necessary as it's not safe for family to help you up."

Requirements

During our interview, a major topic we wanted to cover was Dr. Henderson's requirements for our design. Throughout our interview, we narrowed down her requirements to those below:

- Safety: General safety will always be a concern in the design of any product, but Dr. Henderson emphasized the importance of safety for her patients in particular. Due to the nature of their injuries, the users have no sensory feedback in the lower half of their bodies, meaning any cuts, scrapes, or bruises sustained on the lower extremities of the users' bodies may go unnoticed, leading to these otherwise small injuries becoming much more dangerous. Dr. Henderson suggested padding/cushioning to avoid injury, but she noted that any smooth material with no rough edges should also work fine.
- Independence: As mentioned in the problems section, the ultimate goal of the design is to let users independently transfer from the ground to their wheelchairs. As such, our design

should be easy to maneuver around the floor and set up for a transfer in the case that the user is alone when initiating the transfer.
- Aesthetic: Dr. Henderson noted that her patients' medical equipment is often unappealing to the eye, and that ideally our design would look aesthetically pleasing in users' homes.
- Minimality: As these devices will be used primarily at the AbilityLab and in users' homes, they should be minimal in size, and be able to be stored when not in use, hence Dr. Henderson's proposal for steps that can nest inside each other, in a manner reminiscent of Russian nesting dolls. We should consider her idea but also consider other mechanisms, perhaps a way for our device to fold or collapse into itself for storage.
- Affordability: Dr. Henderson noted that lots of medical equipment for people with disabilities is often overpriced, and that ideally our design would be relatively cheap to produce to drive down the retail price for our design. While we can't predict whether production costs or the manufacturer's pricing decisions will influence the retail price more, using cheaper materials certainly couldn't hurt.

While Dr. Henderson did note that portability wasn't much of a priority for our design, she also stated that it would be nice if users could use the device while camping, meaning some degree of portability is required. A follow-up session/clarification on this contrast may be necessary before going forward with designing/prototyping.

Users Testing

As mentioned before, our users will be patients from the Shirley Ryan Ability Lab with spinal cord injuries that primarily affect their lower extremity mobility, meaning our users will have use of their upper extremities. It is important to note that Dr. Henderson mentioned that she currently does not have any patients that have the upper extremity mobility that she had envisioned for users of our design to have, so our observations will most likely come from videos, while any contact we have through Dr. Henderson with any patients with spinal cord injuries will give us insight on the emotional side of living with a spinal cord injury.

Equipment

Through the interview, we found that patients currently do not have any devices to aid with ground-to-wheelchair transfers apart from the Hoyer lifts, a type of electric or hydraulic lift that lifts patients via a sling. Dr. Henderson noted that one of her patients had made wooden steps that nestled into each other like Russian nesting dolls and that it was a success. Another thing to note is that the height of a typical wheelchair from the ground to the seat is 22 inches, not the 19 inches previously found during research.

Appendix D: Mockup Testing and Feedback Summaries

Introduction

Floor-to-wheelchair transfer is a complex movement that heavily strains users' shoulders and often can only be done with the help of a caretaker or heavy-duty Hoyer lift. Users are wheelchair users who have spinal cord injuries and have lost use of their legs. Sometimes, if users are on the ground and can't get back to their wheelchairs, firefighters are called to help. Our team devised multiple solutions to enhance the floor-to-wheelchair and wheelchair-to-floor transfer methods to make this process possible without external help and lessen the strain on users' shoulders. The device should also be optimized for storage in a home – it can't be as bulky as a Hoyer lift nor look out of place. To accomplish this task, we worked with therapists at the Shirley Ryan AbilityLab to ask questions and evaluate our initial ideas.

Overall, the mockups should create a method to transfer from the floor to the wheelchair that is as safe and timely as possible while being conveniently and aesthetically stored within a house for patients of the SRA lab. Our team expected to receive feedback on our two mockup designs: Tetris-like assembled stairs and a multi-level shelved staircase. Each sought to create small increments for the users to climb up and down and optimize for home storage. Our aim for testing was to get overall feedback and find new features we could integrate into an enhanced design.

Initially, we planned to have an in-person session with Ms. Lauren Henderson at the Shirley Ryan Ability Lab sometime in early May, which included hands-on testing of the mockups and interviews with her patients who struggled with spinal cord injuries. However, unforeseen circumstances led to Ms. Henderson's inability to host our group as initially arranged. We then contacted AccessibleNU to talk to people in wheelchairs but received no response. Thus, our testing was limited to testing among ourselves and friends while simulating the loss of the use of our legs.

Methodology

To prepare for the testing, we sketched different design concepts and discussed what we thought were the top two best ideas as a group. These ideas consisted of Tetris stairs and and multi-level shelf stairs.

Tetris Stairs (Name inspired by the fitted block shapes in the video game Tetris)

Our initial mockup aimed to provide small, manageable steps to help wheelchair users climb up and down while also being easy to fold and store in a home. We wanted to create something we were sure could hold the user's weight, so we used 1-inch thick wood for each step without reducing weight. At the same time, the steps are solid and wide, creating a comfortable fit for people of any size—a good baseline for our final prototype.

The Tetris stairs mockup—
- Consists of four open rectangles: each 18 inches wide, 4 inches tall, and with depths of 36, 27, 18, and 9 inches
- Has two pieces (the base and the upper stairs), each made of plywood boards fastened together with wood screws.
- Configured into a staircase with all four stairs stacked on each other when the upper stairs are stacked onto the base (See Fig. 14).
- When stacked, the stair pieces fasten together with velcro.
- Can be reconfigured as a narrow rectangle (See Fig. 13) for storage.

Figure 13: Tetris Stairs in storage &
Figure 14: Tetris Stairs in action during transfer

During the mockup test, Ryan unfolded the Tetris device by placing the upper stairs onto the base while assuming no use of his legs. Then, he tried slowly lifting each of his legs with his arms while going up and down the stairs to simulate transfers both up and down (see Fig. 14). He sat down on each step and pushed slowly up each step and made sure that his legs were not going to be injured. We tried this same testing method with multiple people of different strengths and sizes.

Multi-Level Shelf Stairs

Figure 15: Multi-Level Stair Shelf storage &
Figure 16: Multi-Level Stair Shelf transfer in action

Our second mockup aimed to deviate a little from the sturdy steps and experiment with a method that would reduce the weight and make the device easier to store by allowing all of the steps to be pushed back into a shelf (see Fig. 15). As this was only a mockup, we built only the first step of the shelf to receive feedback and test before building the entire thing. Overall, the device had one step that could be pulled out using shelf railings. The whole device is made with wood and L-brackets, and the user has to pull out the steps to use the small increments needed to push themselves up slowly toward the wheelchair and back down to the floor. The entire device is only as wide and deep as each step, making it ideal for storage.

The Multi-Level Shelf Stairs (envisioned full version)—
- Consists of four steps (each 18*4*10 in)
- Plywood boards fastened together with wood screws, L-brackets, and drawer railings.
- Configured into a staircase when the bottom drawer is pulled all the way out (example in Fig. 16).
- Configured into a compact device (18*16*10 in) when drawers are pushed all the way in (See Fig. 15).

During the mockup test, we each tried lifting the device out of storage and expanding the shelf mechanism without using our legs. We lifted our legs to go up and down each consecutive step to transfer repeatedly. We tested for various weights and different-sized dimensions for each step to evaluate which was most comfortable.

Results

Tetris Stairs Results

When considering the Tetris stairs, it was hard for us to set up while in a wheelchair and not able to push off using our legs. Due to its size, it was also bulky and hard to lift. However, the steps and their dimensions proved to be very effective in making it easy to transfer in and out of a wheelchair.

Multi-Level Shelf Stairs Results

Regarding the multi-level shelf stairs, we found this to be most effective for moving around due to their minimal weight. Even with the reduced wood support, they still worked just as well as the Tetris stairs. It became evident that a storage method where the device would only have to be as large as each step is much more practical for storage and transportation.

New Requirements for the Design

While testing, we noticed several needs we needed to address with our prototype. The first was that it needed to be able to be taken out of storage by users with minimal strength. We also noticed that users' pants could get caught. Therefore, for the final prototype, we need to implement a method for the user to pull the device out of storage easily when needed for usage and ensure the device cannot catch clothes.

Below is a table of the new requirements for the final design:

New Requirements	**Explanation**
Ease of Storage Transfer	The device needs to use wheels or be lighter and more compact to be transferred out of storage
Catch-proof	There should be no rough edges or spaces between steps so that the device cannot catch clothes easily

Smooth Edges	Edges should be rounded to ensure that users' fingers cannot be cut while going up

Table 2: New requirements for the design and their explanation.

Discussion

Following the mockup testing, we obtained several crucial insights. We became particularly interested in the multi-level shelf prototype due to its minimal weight and ease of setting up. In contrast, the Tetris stairs were very heavy and would likely be hard to set up for users in wheelchairs.

Our group has chosen to move forward with the multi-level shelf prototype. To optimize this design, we will incorporate the new features we noticed we needed during our mockup testing and engage in research to understand its safety further.

Mockup testing was very valuable in guiding us toward our final design and looking forward, we are eager to test the final prototype with either users from the Shirley Ryan AbilityLab or AccessibleNU students on campus. User feedback would be very useful, which is something we missed during our mockup testing and will hopefully be able to gain later, but overall, this mockup testing proved significantly valuable in guiding us on the path toward refining our design.

Appendix E: Bill of Materials

Material	Source	Quantity	Total Cost
6 pairs of 10 in Drawer Slides	Amazon	1	$39.99
4* 2" Caster Wheels	Amazon	1	$13.99
4* Stainless Steel Straight Brace, 6.1 x 0.7 x 0.08 in	Amazon	1	$8.79
135-degree linking brackets	Amazon	1	$16.29
1.5 in Wood Screws	Any	~50	Varies
0.5 in Wood Screws	Any	~25	Varies
0.7 in Wood Components	0.7" wood pieces cut with water jet / CNC	1	Varies

	router		

Table 3: Bill of Materials

Appendix F: Ethical Considerations

Introduction

As described in the provided NSPE code of ethics "2. Engineers shall at all times strive to serve the public interest," which include following regulations such as the Consumer Product Safety Commission (CPSC) and Americans with Disabilities Act of 1990 (ADA), thus many considerations are taken in the ideation and development of the device. In the Ethics summary, the team named the top three ethical concerns: safety, client privacy, and accurate representation of the limitations of the research.

Ms. Lauren Henderson, an Occupational Therapist at Shirley Ryan Ability Lab and the project partner, tasked the team with finding a solution for individuals with spinal cord injuries (SCI) who struggle with transferring between their wheelchairs and the floor. This process currently puts a considerable strain on their shoulders or requires assistance from a caregiver. The need for such transfers arises from activities like playing with children or pets on the floor and undergoing physical therapy. While hoyer lifts are available, they are costly, bulky, and impractical for transportation. Ms. Henderson's proposed solution is a wooden four step approximately 4", 9", 14", and 19" that have some padding over them for skin protection and are hollow inside to nest inside one another due to its low cost and ease of transport. Still, Ms. Henderson is open to other solutions and possibilities.

Due to the health concern within the Shirley Ryan Ability Lab related to a virus, the team is unable to directly observe live wheelchair users with spinal-cord injury (SCI), eliminating the concern for client privacy. Instead, we observed by watching videos online of wheel-chair users transferring between their wheelchairs and the floor. With this, notes were taken on user experiences, along with the previous background research. Furthermore, we interviewed Ms. Lauren Henderson, a physical therapist. Based on the research. a made-up user was created for the user illustration, giving the team an idea of how to tackle the issue from within a given circumstance. The team also tried imitating the process of transferring by only using their upper bodies to further gain personal insight to the experience. However, it is also important to note that none of the team members have SCI, to once again point out the limitations of the research.

Development

After taking all the information into consideration, the team considered the weight and portability of the material to prevent back injury from having to carry it around. In addition, the weight capacity and durability of the device is considered to ensure that users can safely put their weight on the device without it collapsing and causing an injury.

In terms of safety, the team implemented a stainless steel L-bracket and brace to ensure that each wood component is securely assembled and to prevent unstable movement. Each 10 inch drawer metal slide has 100 Lb load bearing capacity, with three pairs of railing being incorporated into the design. In addition, the devices are to be sanded down, including the corners, to prevent users from being injured by sharp edge grazing user's skin and wood splinter penetrating skin.

Resource

As the device isn't being used on live patients and is still in the prototype stage, the materials used to manufacture the product do not need to meet the safety requirements. However, once it moves past the prototype stage, a serious and careful consideration of the material is necessary to ensure that it meets the safety requirements. For the current prototype, the material we used is wood, inexpensive, readily available, and sustainable.

Other considerations of material are:
Plastic: common, light, inexpensive, non-biodegradable
Metal: durable, recyclable

User Impact

The device aims to decrease, if not prevent, shoulder strain in wheelchair users by facilitating movement in smaller, manageable increments from point A to point B, rather than requiring one large movement.
This approach reduces the high risk of experiencing fatal falls and shoulder strain, as well as the psychosocial effects associated with these challenges for the wheelchair user, such as limited independence, restricted activity, and negative emotions. Furthermore, it can alleviate the impact on caregivers who witness such falls and/or strain their bodies from assisting in transfers.

Additionally, the cost is constrained to $150, rendering it affordable compared to other existing solutions, both for individuals and physical rehabilitation facilities. Furthermore, the aesthetic of the design was considered as requested in the interview to make the appearance not too similar to a medical device and for it to blend within the user's home, adding a level of comfort in it.

Social Impact

The device will allow wheelchair users with varying levels of SCI who have upper-extremity mobility to be able to ease in and out between the wheelchair and the floor, increasing independence and self-esteem. The caregiver and rehabilitation facilities also benefit through a cost-efficient device that can be used anywhere as needed without the need for specialized facility nor skills.

End of Life

As the device is mostly wood, a biodegradable material, the natural end of most of the device's life will not have any environmental impact. For the metal component, proper disposal at a municipal pickup program, which varies on the user's location, and metal recycling company ensures the recycling of the metals, thus reducing the carbon footprint produced during the manufacture of goods. However, the device can end prematurely if not taken care of properly as it is susceptible to rot, rusting, decay, pests, and fire, which might cause environmental concerns within the user's surrounding area.

Appendix G: Instructions for Constructing StepNStash

StepNStash is a device that aids in wheelchair transfer between the floor and wheelchair for users who have limited use of their legs. Our device will be portable around the user's home and easily rolled into storage using attached wheels. The design is designed to fit in seamlessly within the user's home with other home decor.

Our design is a multi-level wooden step shelf that can be extended and retracted using drawer slides. The steps break the large distance from the floor to the chair into smaller distances, making it easier for the user to climb these steps and get into their chair without shoulder strain. After use, the stairs can be pushed back into the drawer and wheeled back into storage. The box appears to be a typical side shelf rather than a medical piece of equipment.

In these instructions, you will learn how to build StepNStash securely. The instructions for construction are divided into the following sections: putting together a step, connecting the steps together, and assembling the housing. These instructions assume you have some basic experience in woodworking (using a drill and panel saw/CNC router/water jet). This process will take approximately 2 hours to complete, excluding the time needed to cut the wood pieces.

Materials List

To fully assemble this device, you will need the wood components, screws for fastening, linking brackets, drawer slides to create the pull-out shelf functionality, straight braces for extra support of the drawer slides, and caster wheels for the transport mechanism. The fully detailed components chosen are detailed in Appendix F.

As a reference, if you prefer not to use a water jet or CNC router to cut the wood pieces, here are the dimensions of the wood components for simplicity. Additionally, the following component names are used to reference pieces of each of these dimensions throughout the instructions:

Name of Component	**Quantity**	**Dimensions**
Housing Top	1	19.44" x 12" (Note: must cut handle hole)
Housing Side	2	12" x 15.58"
Housing Back	1	18" x 15.58" (Note: must cut handle hole)

Step Top	3	18" x 10"
External Step Side	4	9.28" x 3.28"
Interior Step Side	6	9.28" x 3.28"
Step Front	4	18" x 3.28" (Note: must cut hole for foot to grab onto)

Table 4: Component Specifications

Directions

The following steps are outlined with a short textual description followed by images if they are more complicated.

Note #1: Every reference to fastening is to describe the

Note #2: Before screwing in wood screws, always draw out where you are going to screw in and drill a smaller hole first to ensure the wood doesn't break.

Note #3: Whenever fastening two wooden pieces together, always use three screws with two on the sides and one in the middle to ensure adequate support.

Note #4: Make sure to sand down any protruding and sharp wooden edges while assembling, especially in the interior, which is hard to sand at the end.

Note #5: The above table distinguishes between the external and interior step sides. The interior step sides attach to the extension side of the drawer railings and to the current step. The exterior step sides attach to the previous step and are fastened to the base side of the drawer railings.

Putting Together A Step

Figure 17: Complete Bottom Step with Pull-Handle

1. Line up the step front and side so that they're flush on a 90-degree clamp.

2. Fasten the step top and front together securely.

3. Measure the placement of the interior step side piece so that when a railing and exterior step side piece is put on top, the exterior step side piece is flush.
4. Fasten the interior step side piece into the step top and front.
5. Repeat Steps 1-4 for the three different steps.

Connecting Steps

Figure 18: Complete step connection

1. For the second and third steps, use the 135-degree linking brackets to fasten the side of the step front piece to the external step side so there is space between them for the next step to slide in between the empty space of the linking bracket. Do this on both sides.

Note: Test that the next step slides easily through the gap provided by the linking bracket. Otherwise, sand the next step down until it fits or increase the linking bracket gap.

6. Add the drawer railings in between the external step side and the interior step side of the next step. Fasten both sides of the railing to each corresponding step side.

7. Repeat for the second and third steps until you have three steps connected together. Note: Test to make sure that when you pull out the bottom step, the second step should also pull out from the third. Otherwise, debug to track the issue.


8. **OPTIONAL**: For extra weight support, the steel straight braces can connect the external step side to the internal step side of each given step to add extra support to the external step side.

Assembling the Housing

Figure 19: Complete housing and assembly for Step N' Stash

1. Fasten the housing side and top together with a 90-degree clamp.

2. Measure the placement of the final railing so that it lines up with the middle of the interior step side of the third step. Fasten the final railing to the housing and the third interior step side.

3. Fasten the back of the housing to the rest of the assembled housing.

4. Finally, add another railing to the other housing side and fasten it to the other side of the third step.

5. Fasten the final step front to the housing top.

6. **OPTIONAL**: Paint the entire device with wood finish to give it a homey look.

7. Screw in the wheels to both sides of the housing in the back so that they are the only thing in contact with the ground when the device is tilted using the handle. You may have to sand down the housing's back side to get this effect.

8. **OPTIONAL**: If the housing is moving while pulling out the drawer steps, add some form of grip (rubber, roughness, etc) on the bottom to increase friction with the floor.

9. Slide the drawer steps in and out and begin using!

Appendix H: Instructions for Using StepNStash

The following are steps to follow when using the Step'N Stash.

Initial Set Up (Set up should be done by an able-bodied caretaker)

1. Tilt the Step'N Stash over until the wheels are engaged with the ground (Figure 1), and roll the Step'N Stash over to the user.
2. Pull the steps out with your foot using the hole in the front face of the bottom step (Figure 2).
3. Lock the wheels of the user's wheelchair in place before they attempt to use the Step'N Stash.

Figure 20: Tilt over until wheels engage

Figure 21: Foot in bottom step hole

Going Up

1. Scoot yourself in front of the Step'N Stash and brace your arms on the first step (Figure 3).
2. Push yourself off the ground and place yourself on the first step (Figure 4 & 5).
3. Repeat this process until you are on the top step of the Step'N Stash.
4. Similarly to scooting yourself up the Step'N Stash, brace your arms on the seat of your wheelchair, and then push yourself off the step and onto the seat of your wheelchair.

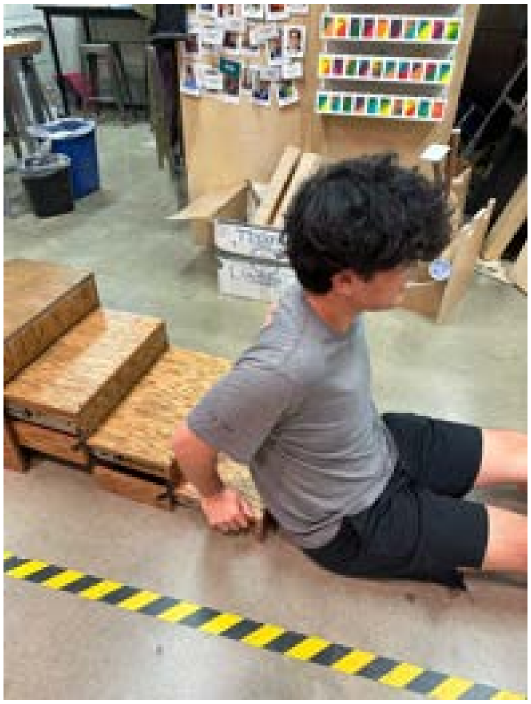

Figure 22: Bracing arms on previous/next step

Figure 23: Pushing up off of step

Figure 24: Positioning on step

Going Down

1. Place your legs on top of the Step'N Stash.
2. Push yourself off of the wheelchair and place yourself on the top of the Step'N Stash.

3. Repeat this process until you are on the floor, readjusting the placement of your legs as you see fit.