GNG 2101 Deliverable G

Deliverable G: Prototype 2

Submitted by

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March 1, 2020

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Introduction

Prototyping is a very important stage to developing a product. The first prototypes usually consist of a very simple and cheap design, however, for the second prototype, we decided to produce a more functional design testing the main components (such as joints, and a working model which can withstand weight). The more prototypes to a design, the better the design and the components with them. Having multiple prototypes also allows the developers to obtain more information about their product, refine parts, and test components to further advance their functionality. In the case of our project, we'll only be producing three main prototypes (with testing of side components). Having such prototypes will allow us to explore the various ideas and concepts of the design to find a product that suits the clients desired needs. This prototype is simply determining what the user wants before we spend a lot of time and money into a final product (third prototype).

In terms of our prototype, it consisted of testing the physical dimensions of the product and if they suit the client, as well as many major mechanisms, such as the collapsing mechanism, or more specifically the joints. Producing the second prototype took lots of time to make since it consisted of lots of purchasing of parts, machining of parts, precise measuring and calculations, as well as assembly. By the end of creating the second prototype, everyone had a really good idea of how the main structure would turn out, and the compromises that had to be made so that we achieve the clients' needs, as well as the components and mechanisms that need to be worked on.

Once all the prototyping material has been presented to the client, we will know exactly where the product will progress and most of the major features it will have. In this document, a list of details regarding the second prototype will be found, as well as the client's feedback and changes that may be needed for the next prototype. This prototype is a more accurate design to the final design/product and will resemble its overall shape/ main mechanisms.

Prototype Documentation

Our latest prototype (Prototype 2) is a fully functional prototype made mainly out of PVC pipes. It is a life size model which has our proposed exact angles and dimensions. The prototype was made in order to run more accurate tests on our proposed design, integrate new features into our design (such as clasping and locking) and learn about good construction methods that we will use in the future. This is a medium-fidelity prototype that we will now begin to treat as our base skeleton; we will substitute in better parts for our final prototype.

Figure 1: Improved final concept design.

The PVC tubing was used because it was cheap and it gives us a more stable frame than the cardboard frame in our last one. The prototype implements our new locking and folding mechanism as well as our joint and folding system. The joints consist of a bolt that goes straight through the two pieces of PVC with two pieces of brass bushing in between the pipes and a nut on the other side.

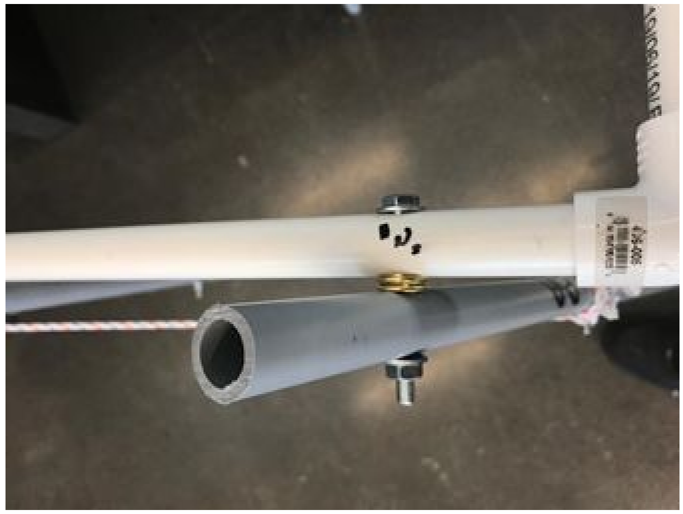

Figure 2: New Joint system showing bushing and bolt

Using the brass bushing prevents corrosion and it also prevents the two components combined from rubbing against each other. Using this system proved to be very effective as all the joints came out really well. This concept will be used in the final prototype. Because of how smooth the joints move the folding mechanism works extremely well and can be activated by just pulling any of the handles upwards. When the handles have been pulled up, the walker is then locked into place by a latch - which was 3d printed - and is attached to the second handle.

Figure 3: Attachable latch

Figure 4: Walker in a folded and locked position

Prototype Testing

With this prototype, we wanted to test several new features that we were implementing such as our joint interfacing, support points, one-handed folding capability and clasping capability. This prototype was also tested for qualities that we hope to optimize in our final design, specifically maneuverability and sturdiness. These tests are described in more detail in the following table; for the sake of spacing, this shorthand is used to classify each set of tests.

1) Quantitative (Qn) or Qualitative (Ql)?
2) Selective (S) or Exhaustive (E)?
3) Functional (F) or Non-Functional (N)?
4) Focused (Fo) or Comprehensive (C)?

Table 1 - Prototype Two Tests

Test ID	Scope	Goal	Qn / Ql	S / E	F / N	Fo / C
1	Joint Interfacing	To compare different hole sizes and bushing configurations in order to determine the best way to build our final prototype. Assessment based on the quality of fit of parts.	Qn	S	F	Fo
2	Sturdiness	To assess the rigidity, strength, and form retention of the walker at rest and in motion.	Ql	E	N	C
3	Support Points	To compare different support types and support placements on our walker so that it feels strong and sturdy while still allowing easy one-handed folding.	Ql	S	F	Fo
4	One-Handed Folding	To determine which design parameters are important in order to close and lock our walker with one hand.	Ql	E	F	Fo
5	Maneuverability	To observe how this prototype behaves during normal use. Assessment based on ease-of-movement, ease-of-turning, and starting-stopping resistance.	Ql	E	N	C
6	Clasp	To check that the 3D printed clasp fits onto our walker frame and is strong enough to lock the walker in a folded position. Assessment based on strength and overall fit.	Ql	S	F	F

Test 1: Bushing Interfacing

Since we could not find brash bushings that fit our needs on Amazon or local hardware stores, we decided to purchase brass connector caps from Home Depot and convert them into bushings by 1) drilling through them and removing the threads, 2) cutting the length so that two could fit nicely into the PVC, and 3) drilling holes in the PVC that fit the outer diameter of the bushing. Our initial round of bolts were 2” long to account for the diameters of the PVC pipe.

Test Plan

This test consisted of several iterations of simple tests.

- Drill many sizes of holes in a piece of PVC. Observe the fit of the brass bushing inside of the hole.
- Drill through the bushing and observe the fit of the bolt.
- Sandwich two bushings into one PVC pipe to determine length.
- Sandwich four bushings into two PVC pipes and connect together with one bolt to observe the interfacing.

Observations and Results

Iteration 1

- Our bushings originally fit snugly into holes made with an S drill bit, before holes were drilled into the bushings to convert them from connector caps to bushings. We also tried 11/24 and S, however the former was a little loose and the former was a little too tight to get in comfortably.
- We used B bits to fit our 2” bolt into our bushings.

Iteration 2

- When we put the bushings back into the PVC, we saw that the drilling process deformed the bushing diameter and they now no longer fit properly in the S-holes. However they fit very well into the T-holes.
- The brass bushings provided a nice, frictionless surface for each other when they were rubbing together.
- When we placed four bushings into the PVC pipes and tried to fit our 2” bolt through the whole system, we realized that we had not accounted for the flange of the bushings in our bolt length calculations. We realized that we needed another ½ “ to fit a nut on the end.

Iteration 3

- We came back with 2 ½ “ bolts, however we realized that they were now slightly too thick for the bushings. We switched to a D-bit, however we also used an E-bit in a few rare instances when there was remaining thread in the connector cap.
- The bushing continued to fit well into the T-hole.
- When we placed four bushings into the PVC pipes, the length of the bolt was perfect for our joint.

Lessons Learned

- Our 2 ½ “ bolts will be necessary for our final prototype. This means that the hole through the connector must be a size T to fit cleanly. The hole through the PVC must be size D to fit snugly, however this will need to be double-checked in our aluminum prototype.
- The interfacing between the brass faces of the bushings is very smooth and allows pieces to rotate very easily.
- The joint feels very strong and we feel very confident using it for our final prototype.

Note: To save money on bushings, we used two brass bushings in our second prototype with simple washers on the outside, as seen in Fig. #. We have decided to use four bushings for our final prototype for added strength and durability.

Figure 5 - Our second-prototype joint system, consisting of two brass bushings on the interior and two washers on the exterior of our bolt.

Test 2: Sturdiness

This test was an ongoing experiment while we tinkered with the PVC frame.

Test Plan

We tested sturdiness in the following ways:

- Putting a downward force on the walker at the handle positions.
- Shaking the frame (laterally, head-on, etc.)
- Lifting the frame from various points, shaking in mid-air, etc.
- Putting pressure on the frame to change the pitch, roll and yaw.
- Pulling pieces apart and pushing pieces together to observe flex.
- Swinging the walker around and moving it across various surfaces (wood floor, tile, concrete) to observe leg position.

Observations and Results

- We had originally hoped that PVC would be a suitable option for our final prototype, however it was immediately clear that the flexibility of PVC made it too bendy and too weak to support a person safely without adding in many more supports that would add undue weight to our prototype. Our original test goal then changed from “make a sturdy PVC frame” to “maximize sturdiness in a PVC frame”.
- The PVC flex meant that the legs moved easily and flexed outwards when the walker was swung around.
- We did not cement the elbow joints, and so our frame had a tendency to come undone at certain points during the testing process. However it was strong enough to stay together when held on the side while walking to and from campus.

Figure 6 - The flex of the walker legs can be seen in this side-by-side comparison of width at the top and bottom of the walker before a support bar is installed. The tape measurer is fixed.

Lessons Learned

- PVC is not a suitable material with our current frame. Rather than change the frame and add weight, we have chosen to upgrade our material for our final prototype to aluminum.
- We need support at the bottom of the legs to prevent outward flexing, however once this support is in place, it feels much better.
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Follow-Up Thoughts

- We did not try cementing the PVC inside the elbow joints. This might have improved the sturdiness of our frame at the elbow joints, however it would not have changed leg flexing or our confidence in its ability to support our weight.

Test 3: Support Points

This test became necessary once we realized that we overlooked how our walker would stay up in ‘use’ position. We did not catch this with our cardboard walker because we used zip ties to tie our joints together and these zip ties limited the motion of the walker to only collapse in one direction. When we assembled the walker for the first time, it collapsed in both directions and we began brainstorming new support systems.

Test Plan

This test involved putting support systems in various places and observing sturdiness.

- Supports were placed at the bottom of the legs to limit collapsing motion to one direction.
- Supports were placed between the back two legs to limit flexing.
- Supports were placed in between existing joints to limit collapsing motion in one direction.

Observations and Results

- We began by using zip-ties like we did with our cardboard walker. Even though we used heavy-duty zip-ties, these were stretching, and it did not feel sturdy.

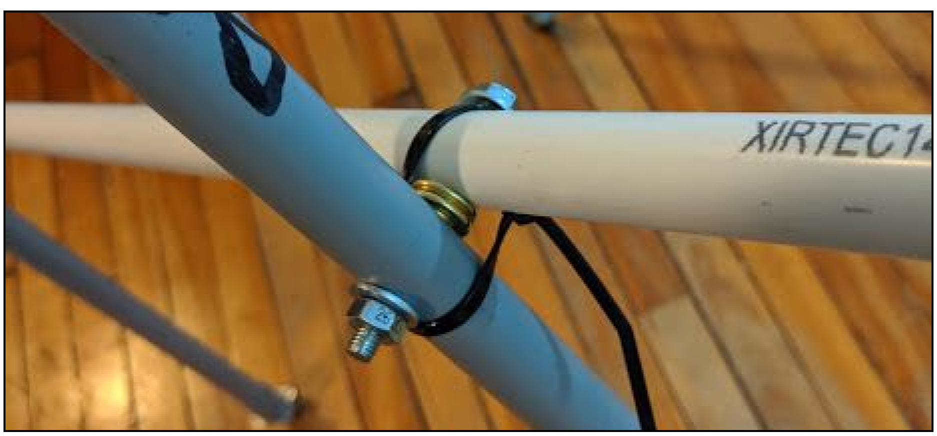

Figure 7 - Zip tie supports.

- Next we used string as our support material because we only wanted to observe what would happen with tension forces at different points on the frame. This worked really well and it allowed us to keep an open mind about what we would use as support for our final product.

- We used string at the bottom of the walker between all legs, as seen in Fig. #. This increased stability somewhat, however it did not feel sturdy at the top of the walker near the handles, which we felt was very important.

Figure 8 - String as supports on the bottom of the walker.

- We used string in between existing joints. This felt the sturdies of all and it limited the amount of material we needed to add to the walker. It also allowed us to easily adjust the angle of the walker legs until we found a configuration that felt good.

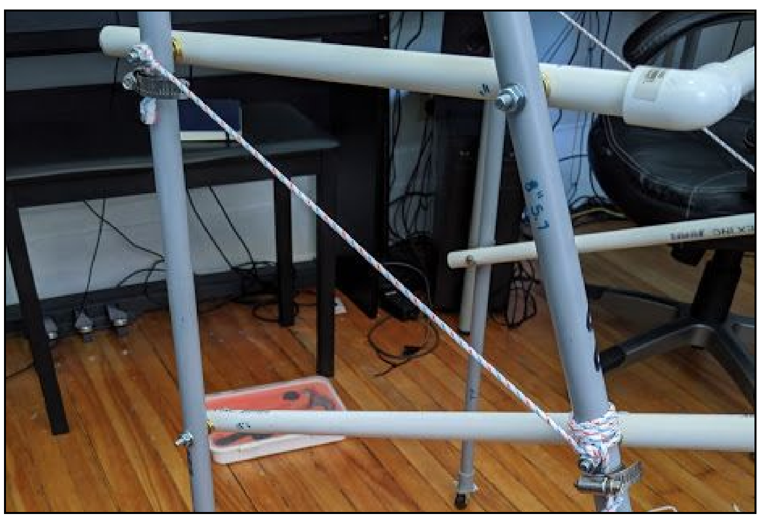

Figure 9 - String as a support between existing joints.

- We then used a scrap piece of PVC to anchor the bottom two legs using clamps. This increased the sturdiness even more.

Figure 10 - PVC support beam at the back of the walker.

- While the joints felt very sturdy, the nuts we used for this prototype did not have a locking mechanism and so they came loose after some use. We found that sturdiness increased the more we tightened the nuts.

Lessons Learned

- The walker seems just as stable with short supports between existing joints as it does with long supports at the bottom of the legs.
- The walker had a dramatic increase in sturdiness when we put a support between the two back legs. This would probably also increase with a support between the two front legs, but it would completely rule out usability.
- We will need locking nuts for our final prototype.

Follow-Up Thoughts

- We will now need to determine a good way to limit motion as the walker opens. We will need to compare locking vs. non-locking methods.

Test 4: One-Handed Foldability

Test Plan

This simple test involved attempting to fold the walker with one hand and tweaking walker parameters until it was as easy as possible.

Observations and Results

- After weighing the walker, we found that it weighed approximately 5 lbs in its current state.
- For the most part, the walker could be collapsed easily by vertically lifting either of the back support bars with one hand. Gravity would pull the walker into a folded position.
- Although tightening the nuts increased the sturdiness of the walker, we found that the collapsing became difficult to do with one hand when they were too tight.

Lessons Learned

- We will need to find a sweet spot of joint tightness to balance the sturdy feel of the joints with how easy it is to fold.
- We will need some kind of locking nut for our final prototype.

Test 5: Maneuverability

Test Plan

This was another ongoing experiment that we did while conducting other tests. We were primarily interested in the following points.

- How easily could the walker turn? What radius did it need?
- How easily could the walker move forwards / backwards?
- How much space did the walker take up?
- Did the walker impede normal ranges of motion?

Observations and Results

- When the walker was in its most sturdy state, it was quite easy to move forwards.
- It was more difficult to move the walker backwards; this caused the front legs to flex at an unintended angle.
- The walker required a wide turning radius, especially when turning from stillness. This seemed to be because our rear casters were installed at an angle, however it could have been because of the type of caster we picked.

Figure 11 - Our rear casters were installed at an angle, which made the turning radius large.

- The walker did not respond well to jerky movements. This is probably due to a combination of unsteadiness from the PVC construction (particularly the loose PVC joints) and the lack of locking in ‘use’ position.

Lessons Learned

- We will need to be very choosy about our wheels. It is very important that they turn well so that our client does not need to struggle with motion and potentially lose her balance.
- We may need to be creative in how we install the back wheels if we continue to use an angled leg.

Test 6: Clasp

Test Plan

This was a very simple test.

- The closed loop fit onto one bar and the open end was latched onto the adjacent bar.
- The walker was picked up in different places, held at various angles and shook in order to determine if the clasp would keep the walker locked without breaking or unclasping.
- The clasp was tested at the top of the walker (where our client would lock it immediately after folding) and near the bottom wheel on the side (where our client would lock it once the walker was tipped over and sitting in the car).

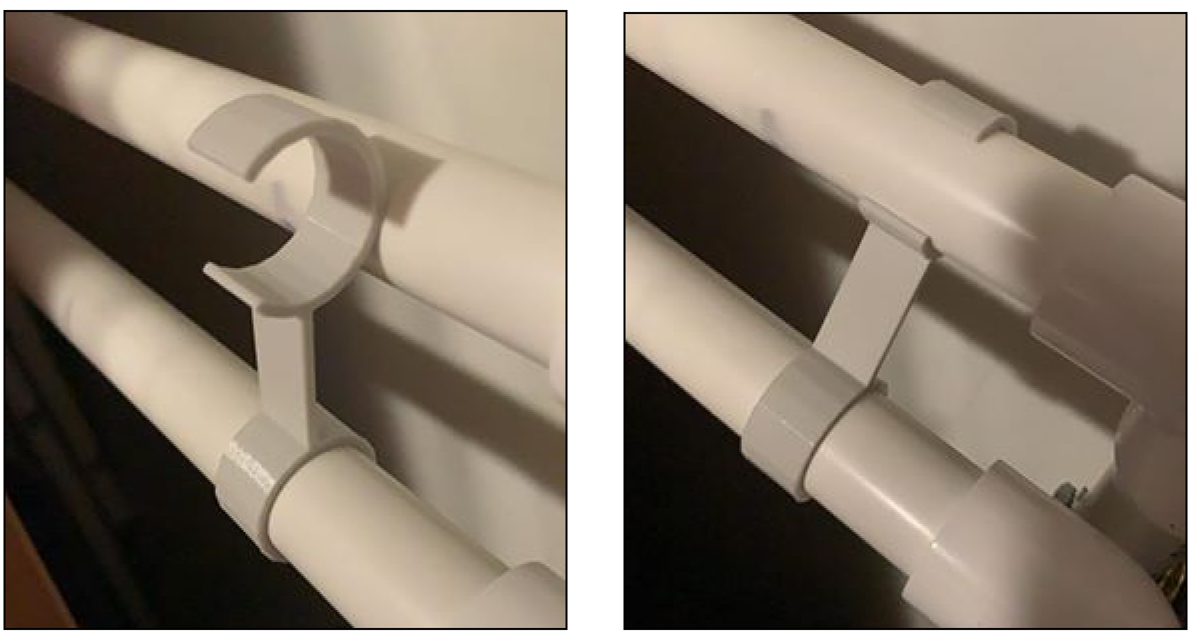

Figure 12 - The 3D printed clasp fit over the bar (left) and clasped over both bars (right).

Observations and Results

- The closed clasp loop fit snugly over the bar, enough that it can stand up on its own. This made it slightly finicky to clasp at first because often it had to be rotated first.
- The clasp was easy to click on the second bar and strong enough that it held after shaking.
- The stem was slightly too long, however this was not a big deal because the PVC was flexible enough to still get a flat fold with the clasp on.

Lessons Learned

- This shape was perfect for our needs.
- The clasp length will need to be tailored to be a more precise distance for the final prototype.
- The closed clasp loop can have a slightly larger diameter than the open loop.
- We can improve the quality and strength of this clasp by making the width longer.

Follow-Up Thoughts

- How will this material hold up after many snaps? In different temperatures? How much force is needed to break or deform it?
    - It might be a good idea to print this clasp in nylon or APS.
- We might want to include extra clasps with our final product if we do not exhaustively test the durability of this part.

Summary

As a reminder of our original client needs, we are including a comparison of our original target specs and our current specs.

Table # - Comparison of Target Specs and Current Specs

	Metric	Unit	Marginal Value	Ideal Value	**Current Value**
1	Total Weight	lbs	>8	8	**5**
2	Width of Collapsed Walker	in	>14	>13	**5**
3	Wheel Movement	deg	<180	360	**360**
4	Load Exerted	lbs	<120	140	**<20**
5	Loading Time	s	>40	25	**10**

6	Front Wheel Width	in	>8	>7	**1**
7	Ideal Walker Height	in	>40	>35	**35**
8	Maximum Back Wheel Width	in	>10	>8	**1**
9	Maximum Wheel speed	cm/s	>25	>20	**30**
10	Brake Efficiency	%	>30	>20	**--**
11	Handle weight	lbs	>2	1	**--**
12	Compact Lock Strength	N	>10	5	**~2**
13	Weight of Wheel	lbs	>3	>2	**~1**
14	Ideal Walker Width	in	>25	23	**22**
15	Length of Handle Grip	in	>5	>4	**--**
16	Maintenance Time	min	>20	>15	**--**
17	Unit Manufacturing Cost	$	<100	100	**40**

Client Meeting Feedback

Our client meeting went very well. Erica and Fahad were impressed and happy with our second prototype. Fahad liked the overall simplicity of the design and how light it was. It reassured them to know that we have some breathing room for weight, as our current walker with PVC weighs 5lbs and we still have to incorporate the wheels, brakes and aluminum (which is not that much heavier than PVC).

We asked Erica if she would like us to reduce the size of the bottom back horizontal bar as it sticks out slightly and she said that it would be beneficial in order to move around in tighter spaces. As a result, if the bottom back bar is brought closer inwards it would cause the distance between the two back bars to increase when the walker is collapsed. We would need to keep that in mind when considering the folding motion would be more difficult with one hand and that we are going to need to increase the length of the clamp.

They commented on the fact that it is easier to lift both horizontal bars at the same time to collapse it rather than to lift a single bar. Previously Fahad said he would need one arm to brace himself while lifting the walker into the car, leaving only one arm to actually lift the walker. He said he would be able to lift this walker with both hands as it is considerably lighter than their previous Nexus walker and he would not have to brace himself for balance.

We asked Erica and Fahad about where we would need the brakes to be and if we should have slow down brakes on all of the wheels. They said that for most walkers they have had, the slow-down wheels and brakes have been on the back two wheels and that it was not really necessary to have them on all four. Therefore we will look into having front wheels with no brake and back wheels with manual brakes and slow-down brakes.

When discussing the wheels, we found that we would need to make sure that they are good enough quality for the side-to-side motion to be comfortable. If the motion is not smooth in the 360º range, Erica would need to jerk the walker upwards to move sideways and this would increase the risk of her falling over.

Also, they asked about how we would prevent it from closing on her when she is using it which is a problem she has had in the past with other walkers. If when using the walker she is jerking backwards too much it might close. We decided that we will make the front vertical posts at around a 255º angle in order to make it more stable, as the posts for this prototype are at 270º. We will also look into making the support bar lock in place or perhaps incorporate a similar clamp to the one that we use to keep it together in the collapsed position.

Next Prototype Improvements

For our next and final prototype we will be focusing on making adjustments based on feedback given by our client as well as looking into what wheels and brakes we can use. We will be incorporating the aluminum as our material for the overall structure and keeping all of the same joints, bolts and washers that we have on the PVC walker.

Plan for Design Day

For design day, we will mainly be presenting the prototypes we've created throughout the project, as well as physical representations of the mechanisms in our product. We'll explain to the spectators or interested people our process of designing the product and how it will improve the life of our user, as well as why the user needed this product in their life and how hard it can be. We will also talk about the challenges or issues we've faced throughout the designing, planning, and production/testing of components. Most of us will describe our experiences working with the team and what we've learnt from this project. It's best to have as many visuals for the people interested in our design day presentation, we want to make sure everyone has a clear and sharp understanding of what we are doing and how we did it.

Conclusion

To conclude, this prototype has been an overall success, and we've learned a lot from creating the different mechanisms and what needs to be worked on. The client did like the prototype as well as it's development and weight. Some components do need improvement, and these will be made for the final (third) prototype. This prototype has been a great improvement from the first concept prototype. Our group has lots of content to present on Design day which is approaching very fast. However, at this rate, we will have a final well developed product for Erica, our client.