ENGINEERING

McMaster University

Project Four – Power in Community:

Some Gardens Grow in Hope

ENGINEER 1P13 – Integrated Cornerstone Design Projects

Tutorial 5

Team: Tues-31

Luigi Quattrociocchi (quattrl)

Ziad Ahmad (ahmadz18)

Avanish Ahluwalia (ahluwa6)

Michael Ferlisi (ferlisim)

Submitted: April 15, 2021

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Academic Integrity Statement

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

Luigi Quattrociocchi 400318027

X Luigi Quattrociocchi

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Ziad Ahmad 400320498

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Avanish Ahluwalia 400314088

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Michael Ferlisi 400307246

Executive Summary

As engineers, we design and test solutions for problems observed in our society. The problem our team was tasked with involved focusing on a real-world issue faced by a client in the community. Our client, Alanna, is a passionate painter and mother of two children. She retired from her profession in midwifery in 2016 and is a recent cancer survivor. She was diagnosed with various autoimmune diseases (fibromyalgia, lymphedema, and ankylosing spondylitis), which affect her daily life and hinder her ability to do what she loves [1, pg. 5]. The task bestowed upon our team was this: come up with a solution that makes the client's daily living better [1, pg. 3]. We focused on solving this problem via the engineering design process [1, pg. 3].

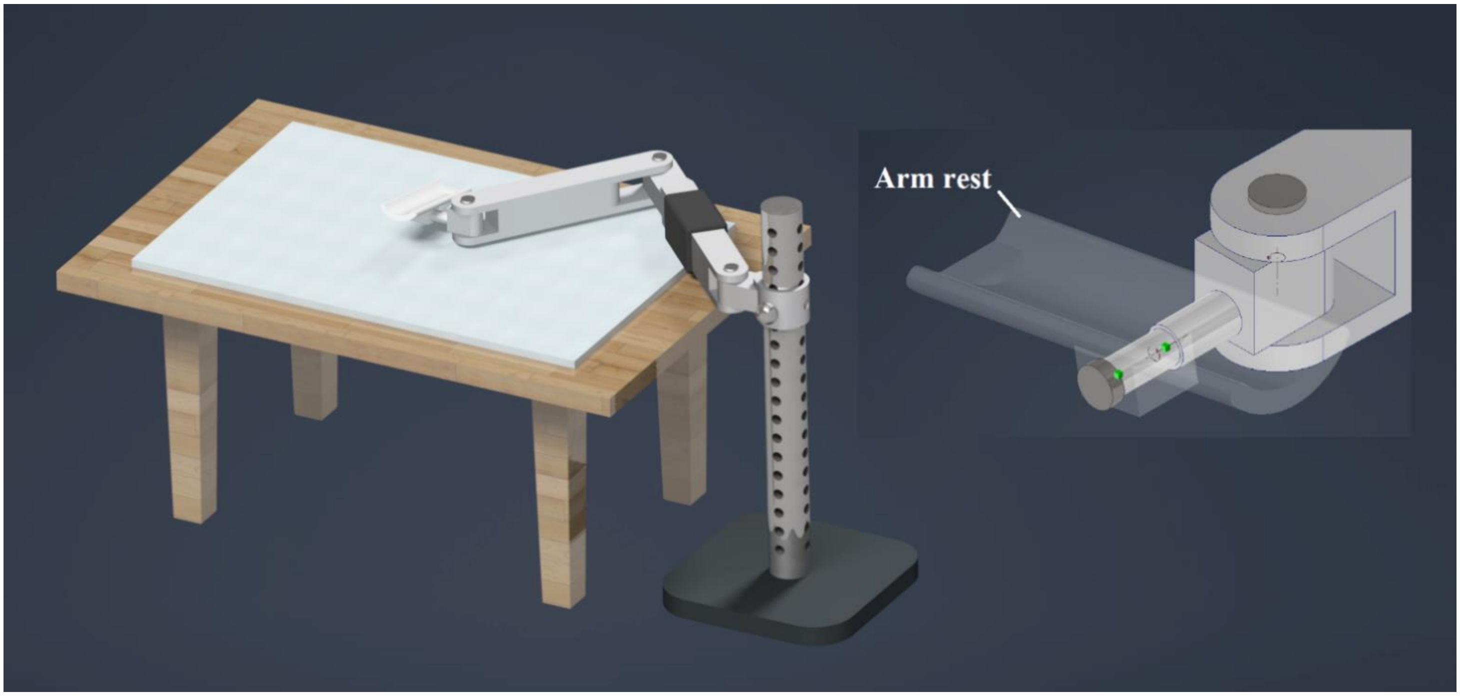


Figure 1 - Final Prototype in Use (Autodesk Inventor 2021)

The primary function of our final prototype (Figure 1) was to support the weight of Alanna's forearm as she paints on a horizontal canvas while still allowing her to reach the entire canvas (i.e. not limiting her natural range of motion). Our final prototype consists of a few different mechanisms which work in tandem with each other. There are two "arm segments," an armrest and a pole attachment, all connected by pins/axles. The entire arm mechanism is connected via these pins, which leaves the arm segments free to rotate. This effectively allows the end attachment to be positioned anywhere along the horizontal plane (within the arm segments' maximum extension).

An armrest is attached to the open end of the arm and can rotate forward and backwards and side to side (also via pins), as seen in Figure 1. This horizontal plane of motion can also be raised or lowered to different heights by inserting the bolt of the pole attachment in the desired slot. Finally, there is a rubber grip on one of the arm segments for easier maneuverability of the end attachment's position.

Our goal was to make Alanna feel comfortable and not concerned about her diseases while continuing her hobbies. We achieved this condition by targeting an area where she finds the most difficulty pursuing her hobbies. We understand that Alanna bears her weight with her opposite arm after a long time, physically holding it up. To prevent this action, the armrest is used to bear the weight of her arm and allow her to rest it in a natural position above the canvas. This armrest is covered in polyurethane foam to absorb any pressure to reduce pain caused by her lymphedema and fibromyalgia. The armrest also provides rotational movement to accommodate slight vertical arm movement, so she will not continuously need to readjust her position. The joints found on the arm segments supply for free range of motion in which she will be able to reach all areas of the canvas. Finally, the adjustable height serves as a benefit to paint at different elevations while frequently changing positions (lying down, sitting, or standing).

If more resources such as time and money were available, the functionality of the device could be improved. Given more time, the design could be further refined to reduce complications involving overall weight, tipping of the device due to a force applied and ease of height adjustment. Other logistical problems (such as the exact specifications of the armrest) could also be worked out. Additionally, suppose a larger budget were allocated. In that case, more could be spent on the materials (a larger and heavier base would reduce tipping issues), and physical prototypes could be manufactured and physically tested under real use-case scenarios.

Introduction

Background

Our client Alanna had a profession in midwifery and worked as a healthcare provider for 15 years. In 2016, she accumulated enough autoimmune diseases that she had to stop being a midwife. Her job required her to work long hours, which resulted in a lack of sleep and affected her body and immune system. Alanna was diagnosed with breast cancer and was treated through surgery. This caused unforeseeable pain throughout her life each day due to chronic illnesses she had. Alanna started to implement lots of hobbies into her daily life to help ease the pain as it allows her to focus on her enjoyment and become less aware of her agony. Alanna mostly enjoys painting, but she faces difficulties throughout it from Lymphedema and fibromyalgia, which causes unpredictable pain in joints and muscles all around her arm as she paints. This causes a shortened painting time interval before she feels any sort of pain, so our goal as a group was to come up with a solution that enhances Alanna's lifestyle [1, pg. 5] [2].

Refined Problem Statement

Our aim was to design a solution to provide comfort and physical support to Alanna's forearm and wrist, while painting at home in her art studio for prolonged periods of time. Given her lymphedema and fibromyalgia, the design solution should be strong, comfortable, and easy to use.

Objectives and Constraints

To create our design solution, we had to come up with primary and secondary objectives as well as constraints that our design should encompass, which we achieved through creating our how/why ladder (Figure 2, Appendix A) [3]. From this we derived our main objectives for creating a successful design; they were strong/durable, comfortable, and ease-of-use. Having a durable design is important because Alanna has trouble bearing her weight such as her arm while painting, so a durable solution is needed to create less effort for Alanna to hold her arm and decrease the pain. The next objective was to provide maximum comfortability to Alanna to increase her painting periods and take breaks whenever she decides, instead of being forced to stop. The edges of the design must be curved so no sharp edges affect the client, and the surface should be smooth so that she does not feel pressure acting back on the arm from the surface. The final objective was to implement an easily usable solution so none of her physical limitations prevent her from creating maximum performability of the solution while feeling minimal pain.

Existing Ideas/Solutions

There are huge varieties of designs we found that provided us with greater knowledge of what we can design, such as the following examples. The first design we found (Figure 3, Appendix A), was a stationary armrest clamped to the edge of a table to bear the weight of a person's arm. The second solution we encountered was a tv adjustable wall mount which we thought can be implemented to provide Alanna with horizontal motion for her arm to easily access the canvas. These ideas had some flaws that would either create uncomfortable movements for her arm and increase pain or are not simple to use as Alanna would not be able to paint across a canvas, which makes the design unusable. Therefore, these ideas gave us insight into use our creativity and create a combination of models into one, which helped us produce a successful design to meet Alanna's requirements.

Conceptual Design

Ideation

After coming up with an initial problem statement and looking into objectives and constraints that might be imposed on our design, we began to brainstorm and discuss potential ideas to incorporate into our design. A morphological analysis chart (Table 1, Appendix B) was created to aid each of us in conjuring our individual initial concept sketches (Figures 4 – 7, Appendix B). Sketches included ideas such as pneumatic lifting armrest (Figure 4, Appendix B), spring-loaded bicep support (Figure 5, Appendix B), compressive glove with brush attachment (Figure 6, Appendix B), and the one we chose to pursue, the "TV-stand armrest" (Figure 7, Appendix B). Each of these designs had some merit to them, but also some concerns.

Initially, we had no design space target in mind, but after each coming up with varying concepts and some discussion about the overlap between our ideas, we agreed upon a single family of design solutions. Our focus was honed to focus primarily on providing some sort of support to Alanna's arm as she paints on a horizontally oriented canvas (as seen in the TV-stand armrest design sketch).

Design Alternatives

Our initial concept exploration began by looking through current solutions and elaborating on them to increase their functionality to cope with our current problem. We searched through designs that may provide Alanna the support she needed and with certain adjustments we can better an already made solution. Our initial concept exploration began by looking through current solutions and elaborating on them to increase their functionality to cope with our current problem. We searched through designs that may provide Alanna the support she needed and with certain adjustments we can better an already made solution. Figure 3, in appendix A displays an armrest that attaches on a desk/table where one can rest their arm, and in our case, would be able to bear Alanna's weight as needed. As a team we decided that we can use this current solution as a starting point and, building off it, we can create a design that is suitable for our client. This design came with flaws that our team wanted to attack to achieve full functionality, one of which was the limitation on movement. One could only move their arm so much when resting on this without the continuous readjustment to a different area. Adding on, this armrest can only be clamped onto a surface which means it will prominently be attached to a desk so our client, Alanna, would struggle to use this when standing or sitting.

Decision Matrices

To come up with the objectively best design among each member's design, the primary and secondary objectives chosen in the previous milestone were ranked in a criterion matrix (Table 2, Appendix B) so that a weighted decision matrix could be created to rank the top candidates (Table 3, Appendix B). This way some objectives could have their importance more accurately reflected, and designs could be scored accordingly [4].

The prioritization order of our criteria was dependant on our client's needs. We selected durable (as in can withstand the forces of our client's weight) as the top priority. After consideration, we realize that this is the most important objective because if it scored poorly in this metric, then the function of the device would suffer. Comfortability is the next highest priority, followed by easy-to-use and lightweight, as governed by the notes taken in the client visits. As per the previous milestone, metrics were mostly subjective rankings of the devices and how applicable each criterion is to that device. An additional consideration that was included noted that the rankings of each device should not be taken at face value, as all the information given was preliminary and some objectives did not make as much sense as they fell out of scope. This led to us taking the results of the matrix (Table 3, Appendix B) with apprehension, as we were aware that the scores were not definitive.

In the end, the design that we selected to pursue was the TV-stand armrest, as it scored the highest in the decision matrix and qualitatively seemed like one of the best concepts of the bunch. This design was selected to be the basis of our prototype, but it would need to be refined through iteration and feedback.

Design Evaluation

Throughout the design process, we received feedback on our design and implemented changes based on the feedback. We attended scheduled design reviews with students from the science department and discussed with IAIs. Their feedback helped catch oversights, flaws, and areas for improvement. We iterated through the design process several times to refine our design. In our first peer design review, all we had to show was our cardboard prototype (Figures 9a, 9b, 10, Appendix B) and initial sketch (Figure 7, Appendix B), but that was enough to demonstrate the intended function of our device. We were reassured that the function made sense through this design review, and no obvious flaws were pointed out at this stage. Minor suggestions were made at this point which was incorporated into the refined prototype; some feedback was taken from the science students, such as foam cushion on the armrest, and material selection was implemented. However, some feedback was not implemented, such as putting locking wheels on the base, as it would not meet the functions and objectives of our design. We presented a preliminary CAD model (Figure 8, 11, Appendix B) during our second peer design review, which painted a clearer picture of our envisioned final design; however, it was still very rough. More features from the science students were incorporated; we implemented the bolt and pole mechanism rather than the clamping one, a rubber grip on one of the arm segments for easier maneuverability, a third pin on the pole attachment piece for a wider range of motion, and round all the edges, so there are no sharp points or hazards. Throughout the project, we took all the feedback given into consideration, which continually improved our design.

Final Proposed Design

How it works

Our client could use the design in her art studio. The client would place her forearm on the armrest to ensure comfort and physical support. She would grab her desirable art tool (paintbrush, squeegee, pencil, etc.) with her fingers and move around the canvas placed on a horizontal surface. If the height of the arm is higher than needed, based on the height of the canvas from the ground, she could tilt the armrest upwards or backwards due to it being connected to a horizontal axle. To accommodate for different elevations the client would prefer to be in while painting, the pole has a set of holes around it where a large bolt could be inserted to lock the arm. Therefore, the device can be used at different elevations and different sizes of canvas, where it can reach all ends of the canvas and allow smooth movement of the client’s arm while painting.

Specifications of the Design

Our final design comprises of an extendable arm, an armrest, a vertical hollow pole, and a heavy base. The vertical pole includes a set of holes on its sides where a peg would be placed to ensure the locking of the arm. This mechanism allows the arm to adjust its vertical position. The pole is welded to the base to ensure structural integrity. The arm is based on a set of linkages joined to each other by pins/axles. It is made of three segments connected by wide pins to allow rotational and translational motion of the arm. It is connected to the pole via the 'bolt and pole' mechanism. The armrest is connected to the arm using an intermediate mechanism (Figure 18, Appendix C) that allows rotational motion about two perpendicular axes. The armrest can rotate about a horizontal axis to allow the arm to move up or down for adding intricate detail to the painting/drawing when required.

Final Drawings

An annotated exploded drawing is made to show how every component in our final design can be assembled (Figure 14, Appendix C). Each component drawing (Figures 15 – 23, Appendix C) has a purpose within the design. The baseplate (Figure 15, Appendix C) is wide and flat to prevent tipping of the design. The pole (Figure 16, Appendix C) attaches to the baseplate. The maneuverable part of the mechanism attaches to the pole with a connecting piece (Figure 17, Appendix C). The connecting pieces for the pole (Figure 17, Appendix C) and the armrest (Figure 18 Appendix C) are designed to allow for rotation of the piece it holds on to while connecting them to the rest of the device. Similarly, the arm segments (Figures 19 and 20, Appendix C) allow rotation about both their endpoints; the armrest can reach the target position via inverse kinematics. The armrest (Figure 21, Appendix C) has a shallow curve and a raised section for wrist support, as well as a hole through the underside so that it can be attached to the connecting piece. The bolt/peg for the pole and rod/pin for the other joins (Figures 22 and 23, Appendix C) are used to affix parts together.

Objectives/constraints met

From our initial problem statement, we wanted to make sure our final prototype achieved our top objectives, ease of use, comfortability, durability and lightweight. In constructing our model, these objectives were continuously thought about and were considered feasible. Beginning with comfortability, we achieved this objective through a cushioned armrest, along with keeping her arm in a natural position as she paints. The pin and pole mechanism allows Alanna to adjust the height in any necessary position which also improves the comfortability of the design. Moving on, we met the ease-of-use objective through many joints within the arm segments to create a large range of motion, in which she would not continuously need to readjust her positioning. The design itself consists of retractable movement which makes it very simple for Alanna to use. Next, durability was achieved as the device can bear Alanna's weight as needed in any position. Additionally, the material we decided to use provides long-lasting wear even as Alanna applies pressure on the joints. After discussion, we concluded that we could not obtain a lightweight design due to the weighted baseplate, however different aspects of the device can be considered lightweight. This objective had fallen out of scope after we realized that our solution would not be weighing down on Alanna's arm, which was the initial concern. Regarding the mass felt on her arm, we minimized that completely so no additional stress was applied and was met in our solution. Regarding our metrics, they could not be tested since a physical prototype was not made of our final design, these metrics are provided in Table 4, Appendix B. We were dependent on user feedback which could not be easily obtained due to the pandemic. These metrics would have been useful as we could accommodate for low scores and account for them within our solid prototype to benefit Alanna to the fullest.

To test the durability of our design, a stress analysis simulation is done on the CAD model in Autodesk inventor [5]. The results of this simulation (Figure 24, Appendix C) showed very minimal deflection (a fraction of a millimetre) under a realistic use-case load (25N was used as an approximate value for the weight of an arm). Additionally, extreme values were simulated to get a sense of leaning on the armrest, which still yielded less than a millimetre of deflection. This reassures that our design would be able to sufficiently bear Alanna's weight. The test for the comfortability of our design could not be executed because of the pandemic. We planned to survey a group of participants about which proposed material they preferred given a selection of armrest covers. Due to covid restrictions, however, we could not feasibly survey a substantial enough group to come to a precise conclusion.

Construction/development methods

The construction of our design would be possible if given the resources (materials, machinery and test environment and resources) required. The construction of the vertical pole would require an automated drill press, for which the instructions would be given to cut a set of four holes around a pole till the top of the pole. The arm segments would be made of aluminum alloys to provide strength and would be less dense than stronger metals such as iron and steel. The arm segments would be constructed from aluminum alloy by placing a block of aluminum with the desired dimensions in a CNC machine. The base would be made of cast iron as it is heavy to prevent the device from tipping over. It would be constructed by smelting iron and shaping it into the correct structure and dimensions. The overall cost of the materials and items needed is $160 plus additional costs for the use of a CNC machine, drilling press and other tools needed. The bill of materials (Table 5, Appendix C) includes all the materials, their quantity, unit price and total price for each item.

Conclusion

Looking ahead

Our design turned out to be successful as it covered the objectives we set for this project. If we were provided with more resources and time, we would have made many changes to make the design simpler but still covering all the aspects we had in our design. First, as our design was assembled in inventor, we would have preferred to create a physical prototype with similar materials. Even though we created an initial cardboard prototype, it does not help us test if our objectives are guaranteed to be successful as it is not durable and would break under some small load force. We would have probably at least made our design from wood to get an idea of the design suits the client or not and base our calculations on that. We have no clue how comfortable our armrest would be, and if our arm extender would provide Alanna with smooth motion. The second improvement we could have made is to get feedback from Alanna by providing her with the prototype or just viewing it as this would have allowed us to refine our prototype to suit her arm perfectly. Lastly, if we were offered more time in the early stages of the project, we would have investigated more ideas to sketch and prototype as it would have provided us with more insight into our design. For example, we could have implemented vertical motion in an easier way for Alanna to move it instead of her physically lifting the arm extender upwards. Even though the arm extender should not be heavy for Alanna to lift and cause her agony, we could have implemented some sort of pulling mechanism using a rope or automated system as an example.

Looking back

Project 4 was an exciting and detailed project given the freedom in the design space, objectives, and constraints. The team was provided with several issues in the client's daily life. Our team was given a real client facing several issues due to medical conditions. We began solving this problem individually, and gradually started to gather information as a team. Looking back, it was noticed that the final solution we produced in this project is represented by how well our group worked together. In our case, we assigned roles to each member to achieve the most success and ultimately created a design we were all satisfied with. Due to us being successful, the changes to our design process for next time would be very minimal. The largest change would be the communication within our group, because, at points, it lacked excellence and thorough discussion. Keeping this in mind, it was shown within our initial prototypes as they lacked variety and displayed overlap between concepts. With discussion, we could have created a larger range of prototypes that could have made the section of refining our prototype straightforward. Adding on to this we could have also obtained ideas from each concept to better our focused design. This is something our group would acknowledge if we were to work together again. Overall, the idea of team dynamics is established as a guiding point for group work to create a bond between members so that when they work together to problem-solve, it becomes fluent and natural.

List of Sources (IEEE)

[1] “Power in Community” P4 Project Module, pp. 1-75, class notes for ENGINEER 1P13, Department of Engineering, McMaster University, Winter, 2021.

[2] E. Hassan, R. Fleisig, S. Ebrahimi, Class Lecture, Topic: “Lecture 48 – Project 4 Client Introduction” ENGINEER 1P13, Department of Engineering, McMaster University, Feb. 24, 2021.

[3] S. Ebrahimi, Class Lecture, Topic: “How/Why Ladder” ENGINEER 1P13, Department of Engineering, McMaster University, Mar. 2, 2021.

[4] R. Fleisig, S. Ebrahimi, Class Lecture, Topic: “Lecture 51 – Review from Conceptual Design to Prototyping” ENGINEER 1P13, Department of Engineering, McMaster University, Mar. 8, 2021.

[5] – “Autodesk Inventor Professional 2021.” Autodesk, San Rafael, CA, 2021. (https://www.autodesk.com/)

Appendices

Appendix A – Other Resources

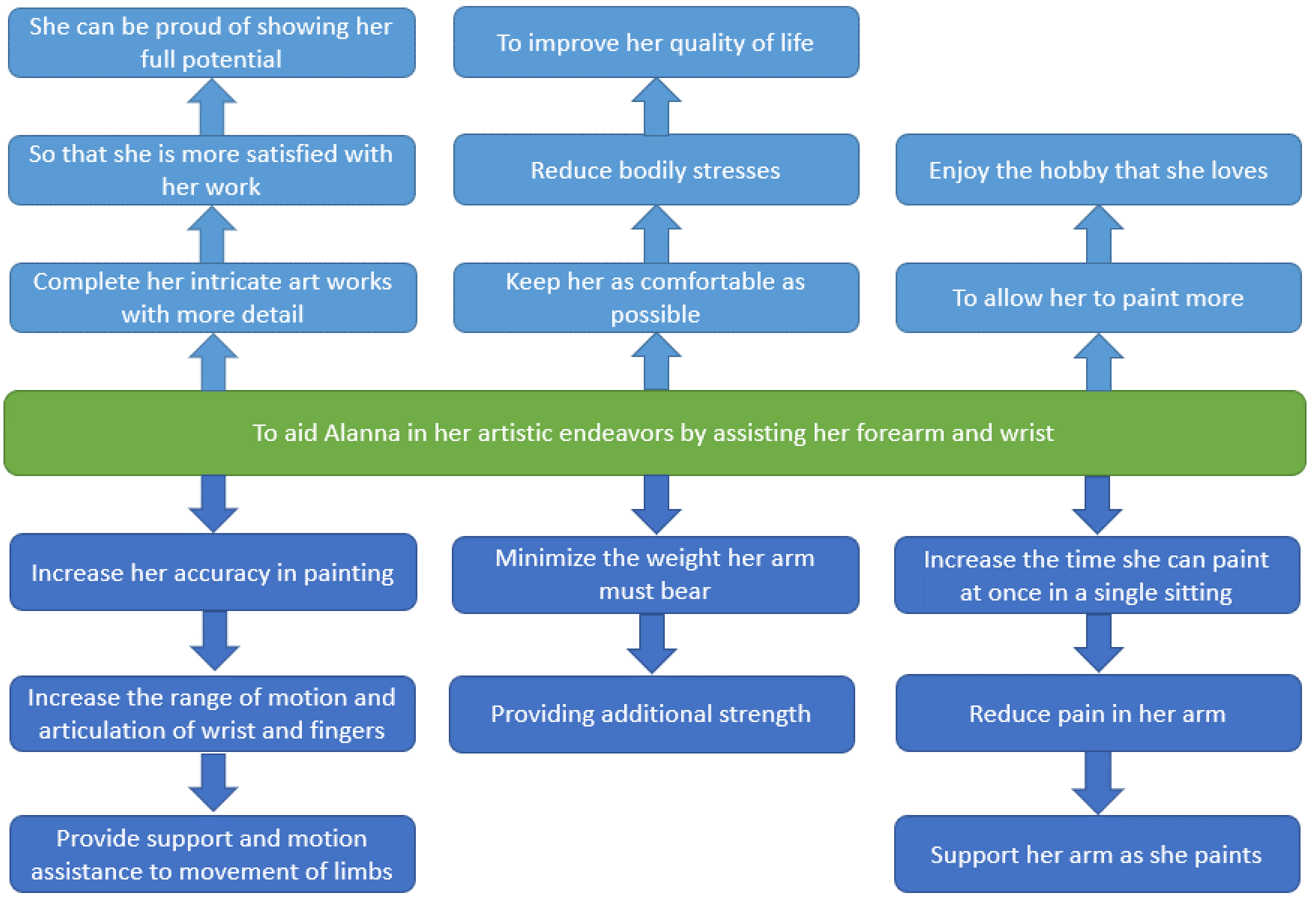


Figure 2: How/Why Ladder created at an early stage of the project

Figure 3: Adjustable Armrest for Desk | MI-7145

Appendix B – Initial Design and Iteration

Morph Chart

Primary function: Should comfort the forearm and wrist
Secondary functions:

- Should bear the weight of and support the forearm
- Should increase effective wrist range of motion without pain

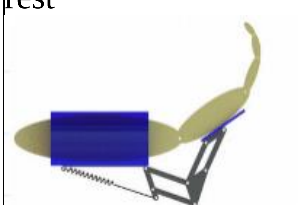
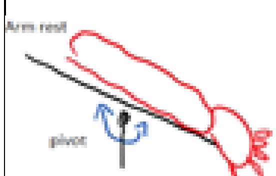
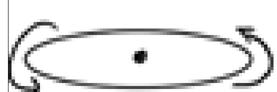
Function	Means (With pictures for visualization)			
Comfort the forearm and wrist	Cushion-like material to rest on (ex. sponge, memory foam …) 	Arm and wrist brace 	Glove and long sleeve	Soft cast / tight wrap 
Bear the weight of and support the forearm	A platform for the arm to rest on 	Pneumatic pump or tube 	Hanging suspension cable 	Weighted pulley system 
Increase effective wrist range of motion without pain	Spring-loaded wrist rest 	Angled arm pivot system 	Swivel base platform 	Set of linkages /joints connected to the ground 

Table 1: Morphological Analysis Chart

Concept Sketches

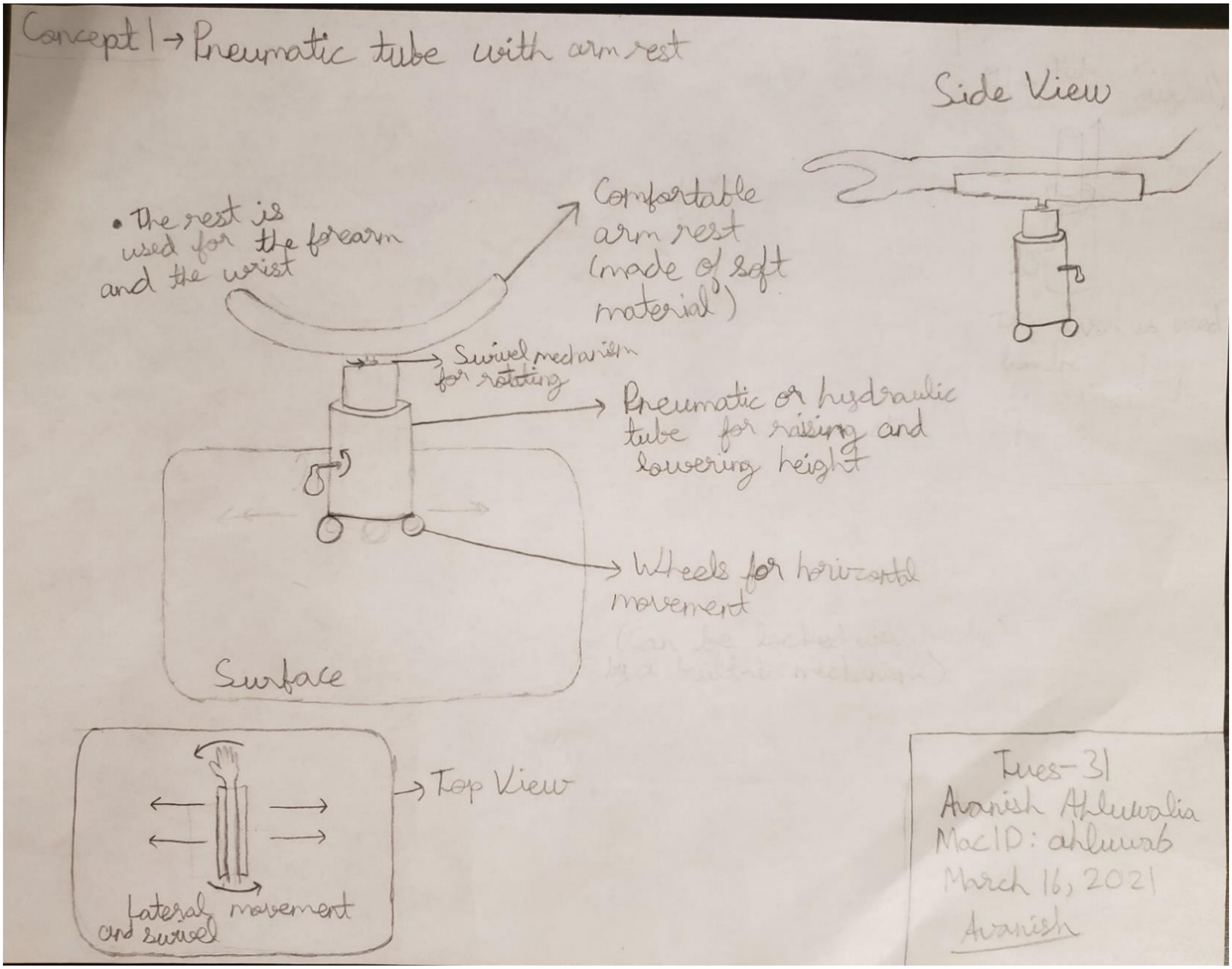


Figure 4: Pneumatic lifting armrest concept sketch

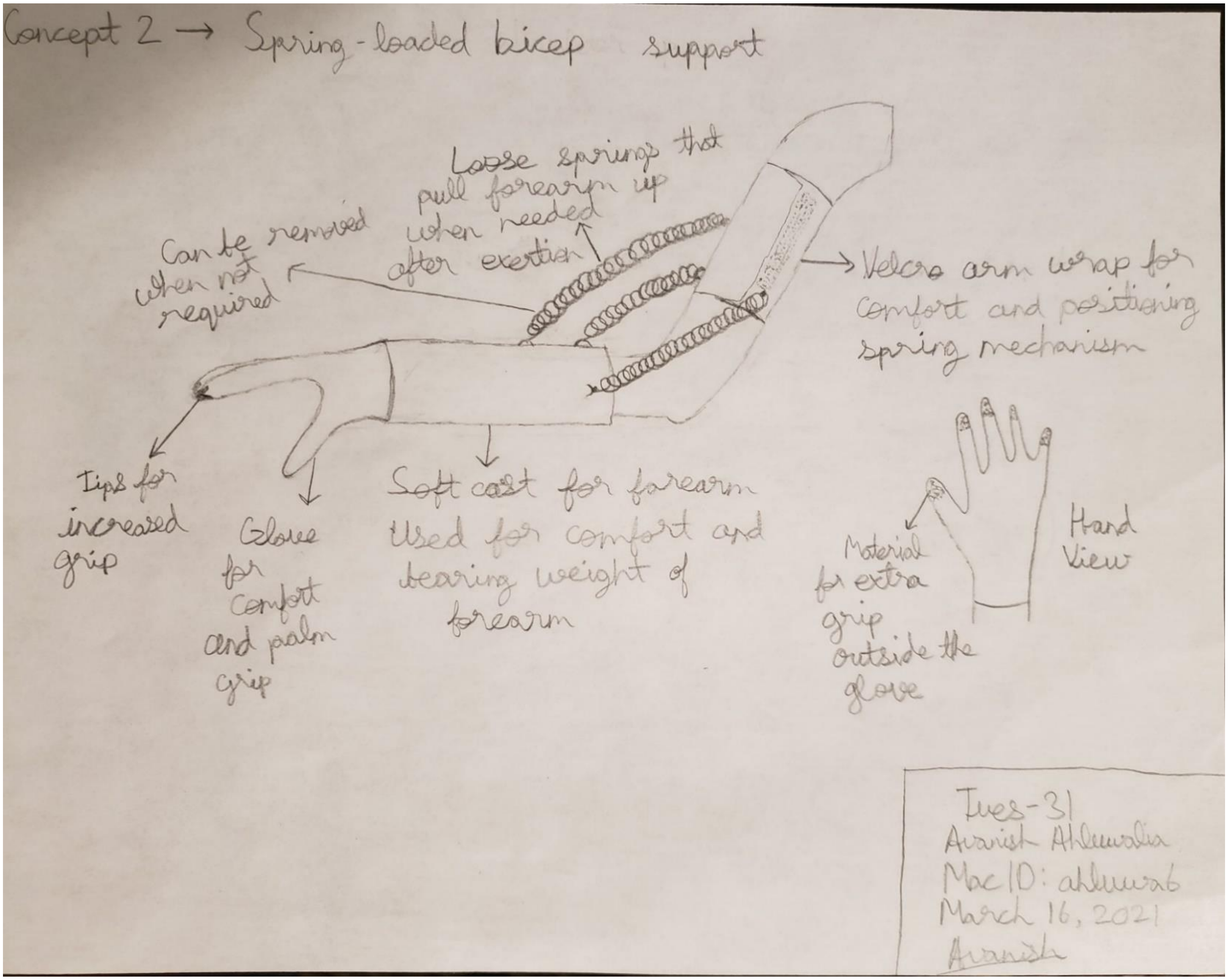


Figure 5: Spring-loaded bicep support concept sketch

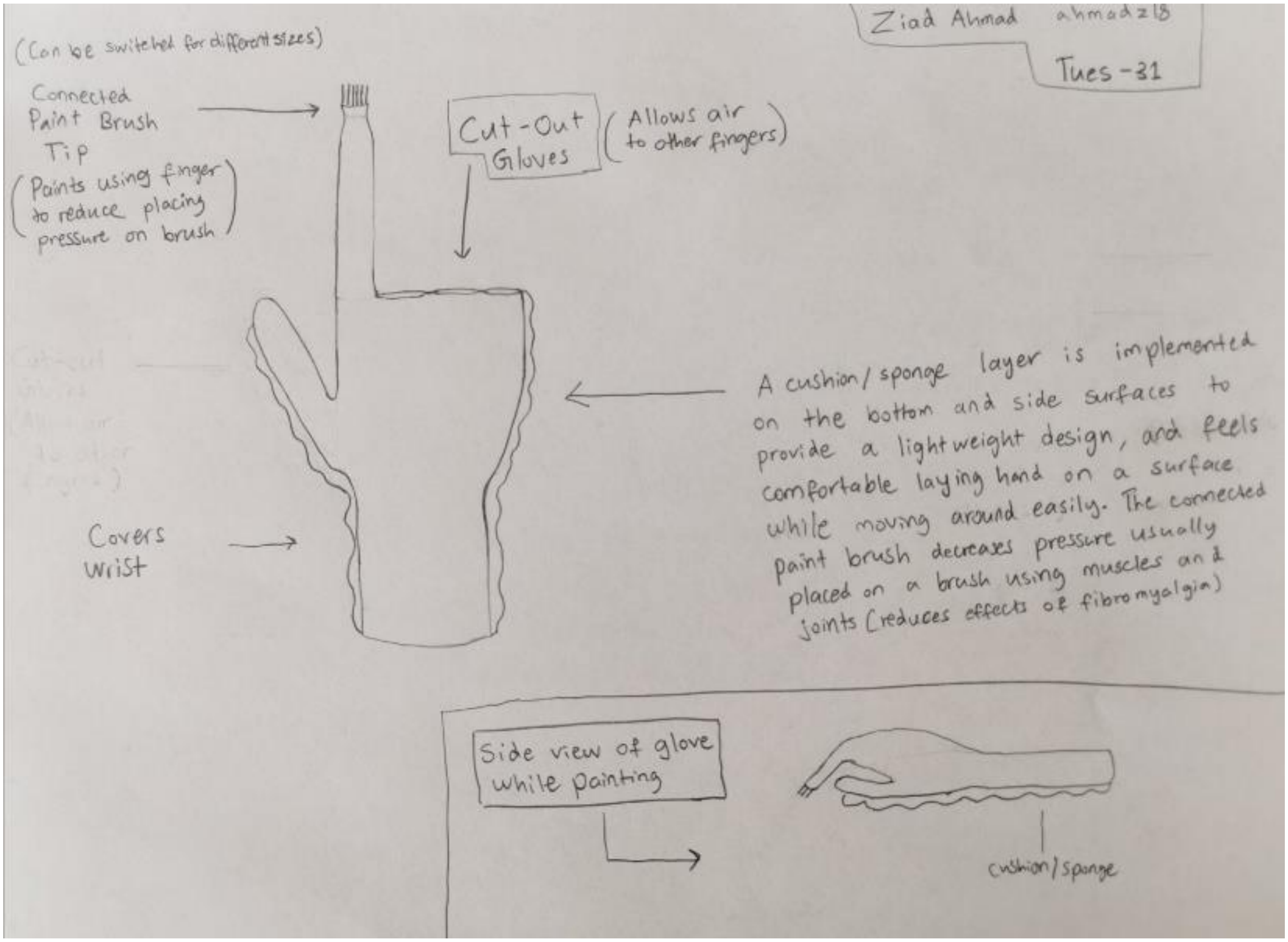


Figure 6: Compressive glove with brush attachment concept sketch

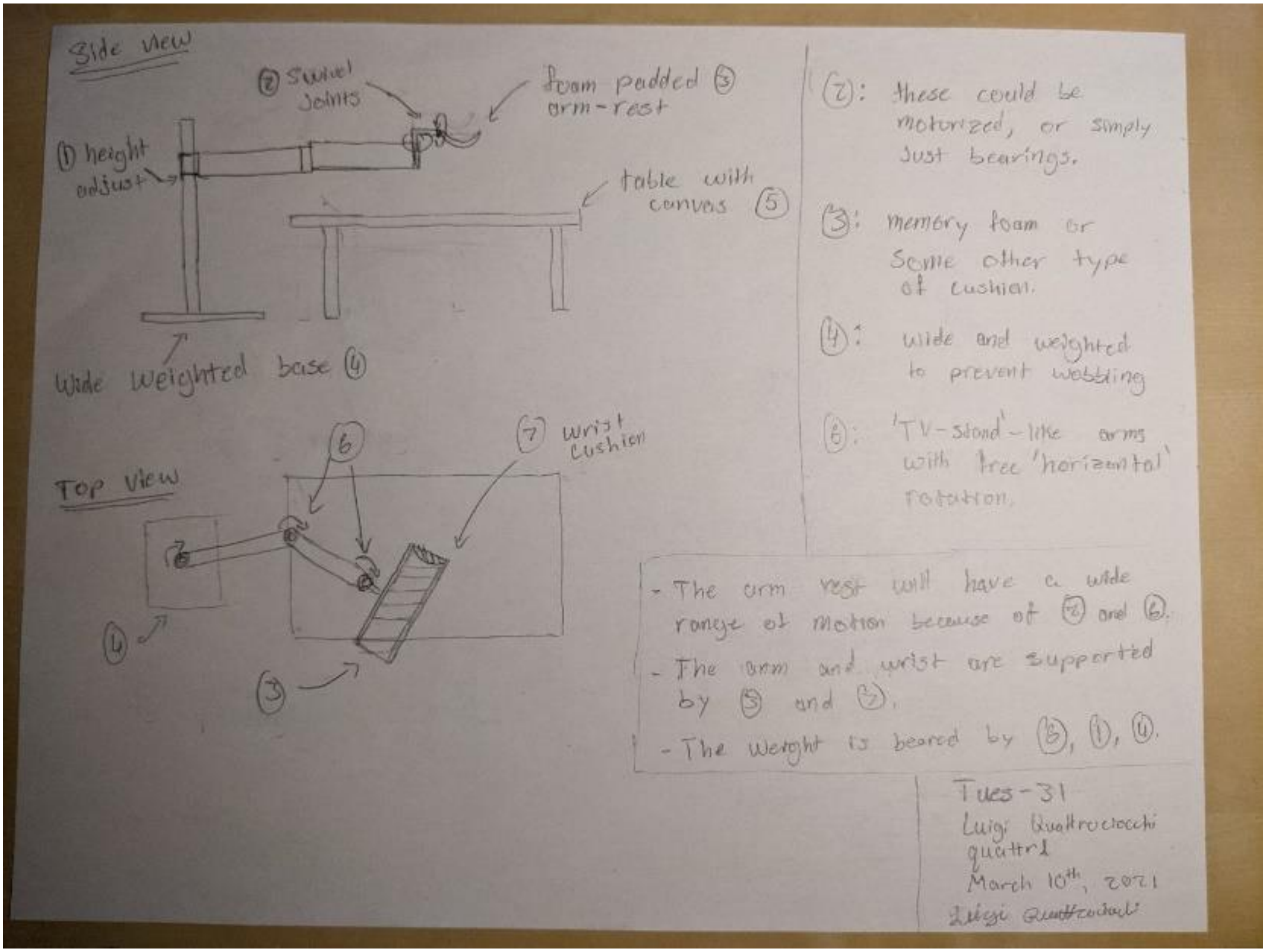


Figure 7: TV-stand armrest concept sketch

Initial Prototype

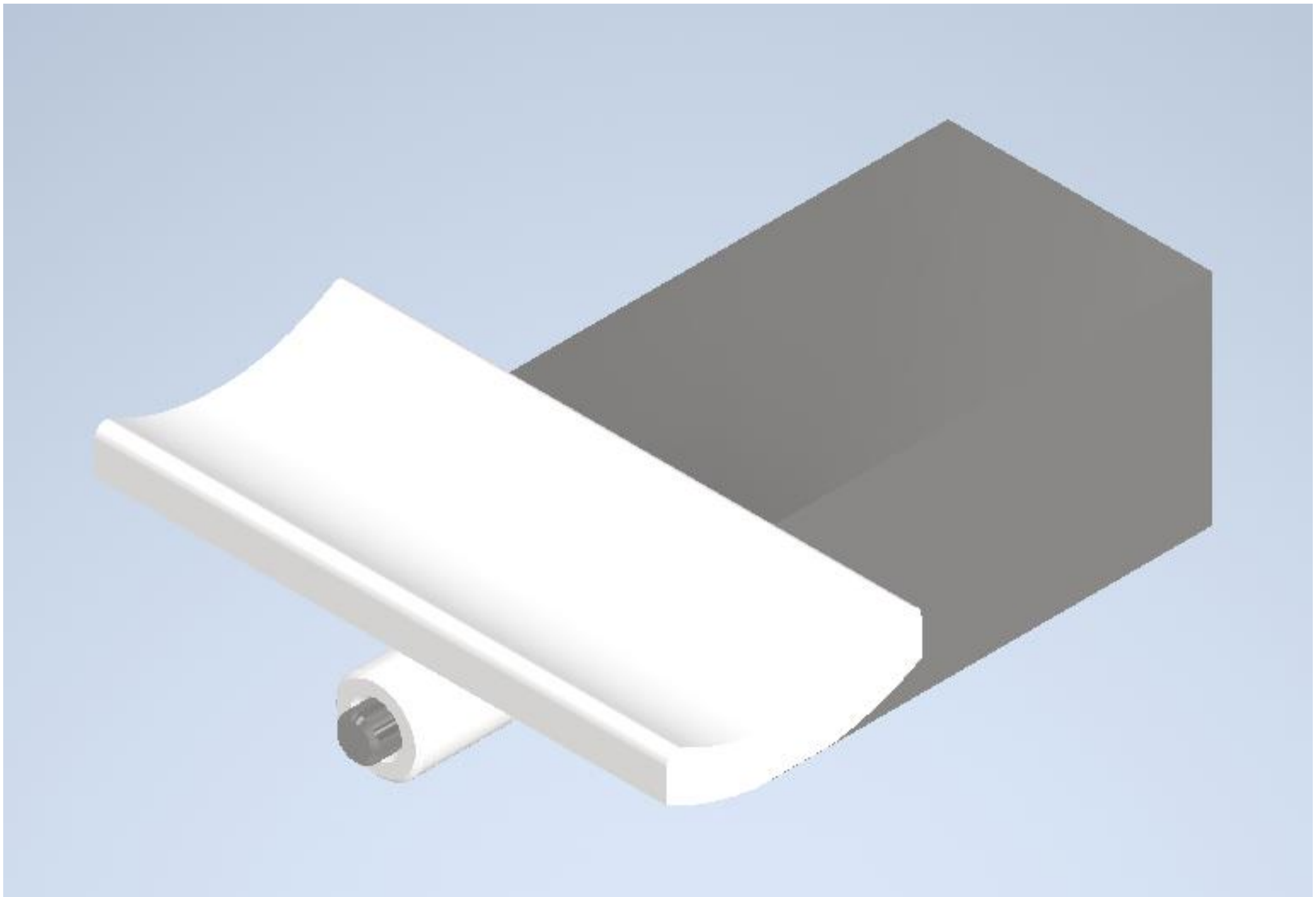


Figure 8: Initial prototype – armrest (Autodesk Inventor 2021)

Figure 9a: Initial prototype – rotating cardboard segment mechanism

Figure 9b: Initial prototype – rotating cardboard segment mechanism

__Figure 10: Initial prototype – cardboard mechanism with pole__

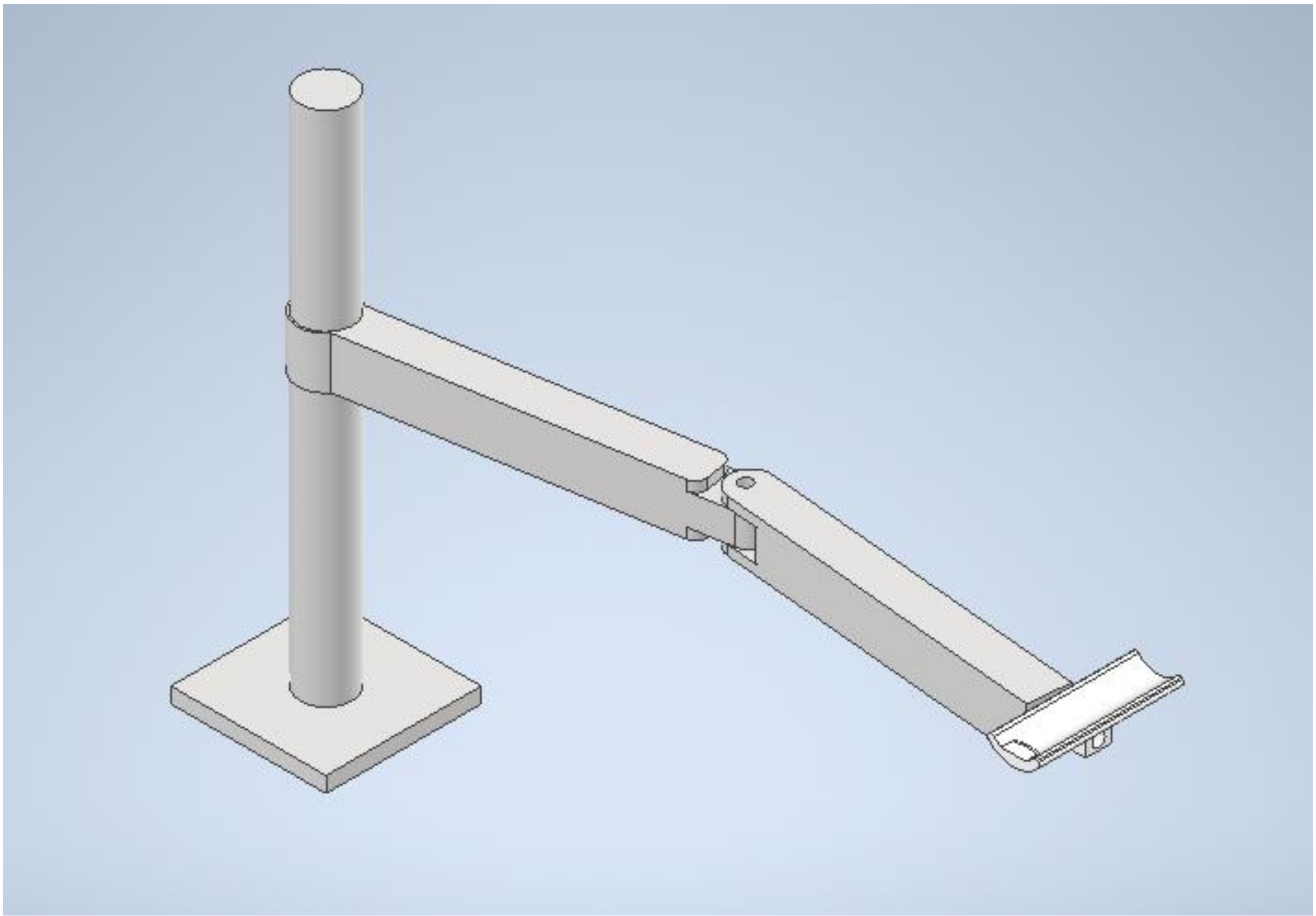


Figure 11: Initial prototype – rough CAD model of design (Autodesk Inventor 2021)

Ranked criterion matrix

Criterion	Lightweight	Easy to use	Comfortable	Durable	Final weight
Lightweight	1	0	0	0	**1**
Easy to use	1	1	0	0	**2**
Comfortable	1	1	1	0	**3**
Durable	1	1	1	1	**4**

Table 2: Ranked criterion matrix for decision matrix

Decision matrix

Criteria	**Weight**	TV-stand-arm		Swivel arm rest with pneumatic tube		Memory Foam Glove		Skateboard-type armrest	
Durable	**4**	4	**16**	5	**20**	3	**12**	2	**8**
Comfortable	**3**	4	**12**	3	**9**	5	**15**	3	**9**
Easy to use	**2**	5	**10**	3	**6**	3	**6**	3	**6**
Lightweight	**1**	3	**3**	4	**4**	5	**5**	4	**4**
Total		16	**41**	15	**39**	16	**38**	12	**27**

Table 3: Weighted decision matrix for designs based on criterion matrix

**Scale for rating concepts: 1 to 5 (1 being the lowest and 5 being the highest)*

***Raw score on the left, weighted score on the right (in bold)*

Refined Prototype

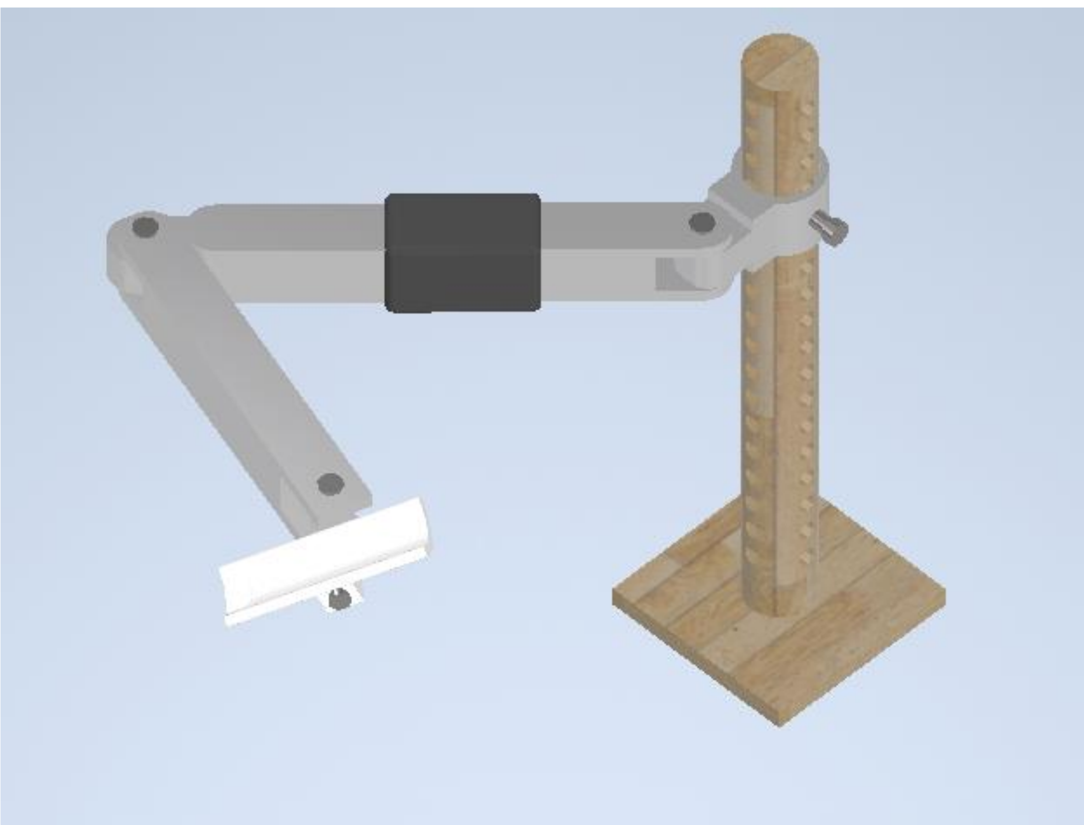


Figure 12a: Refined prototype – isometric view of CAD model

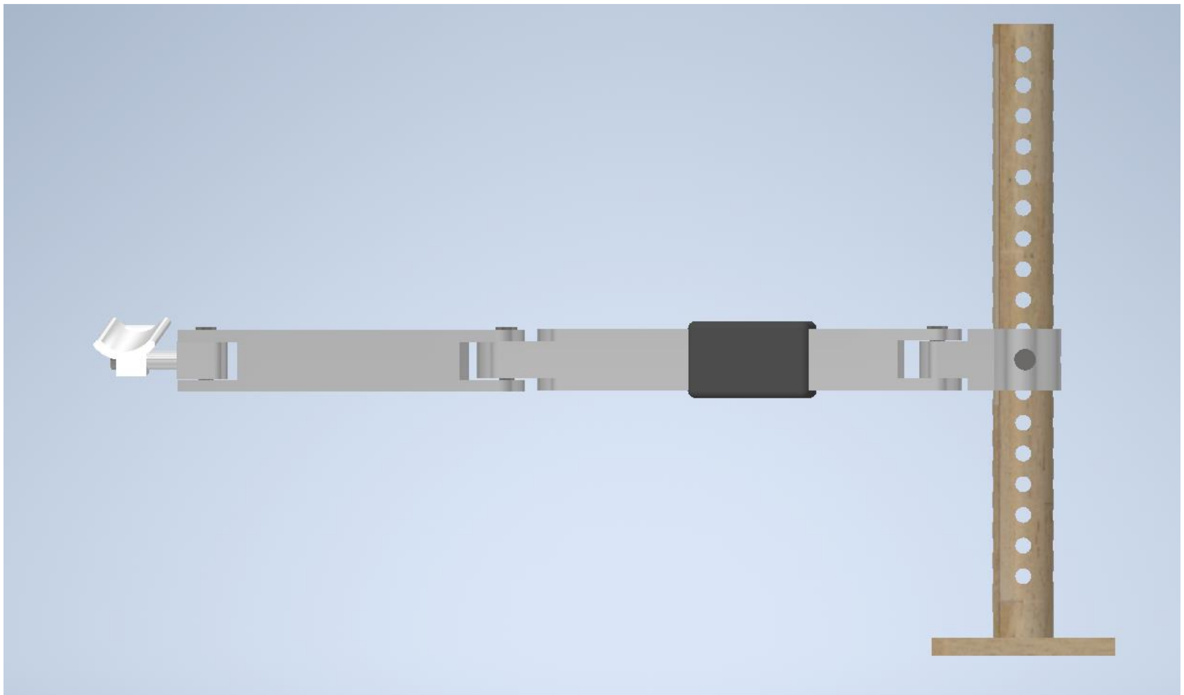


Figure 12b: Refined prototype – side view of CAD model

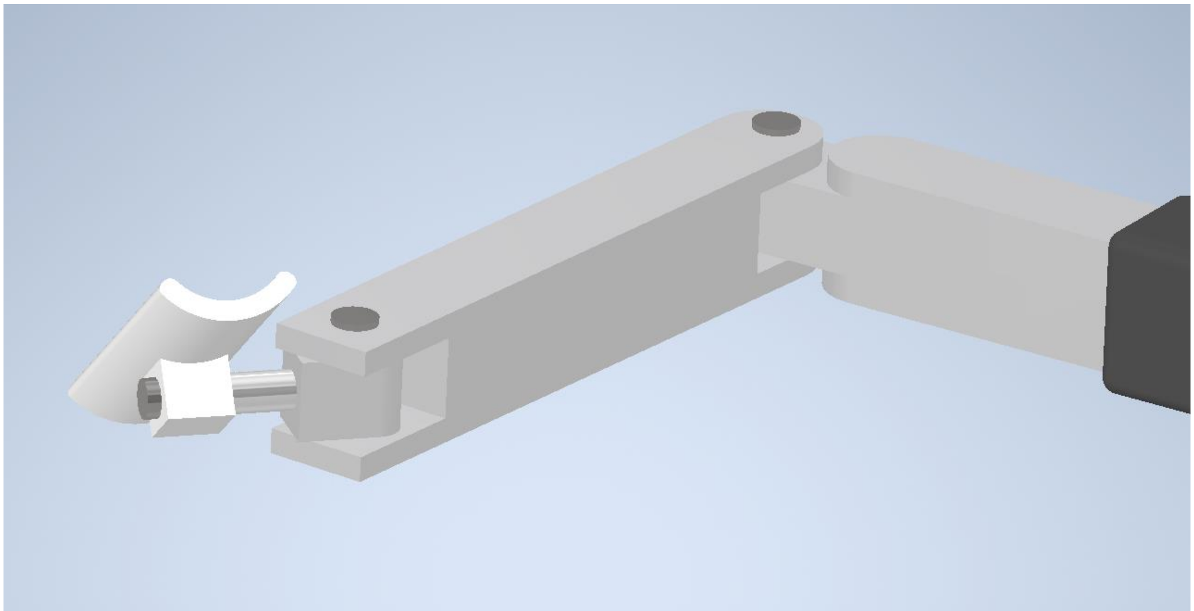


Figure 12c: Refined prototype – enhanced view of rotating armrest mechanism

<u>Final Prototype</u>

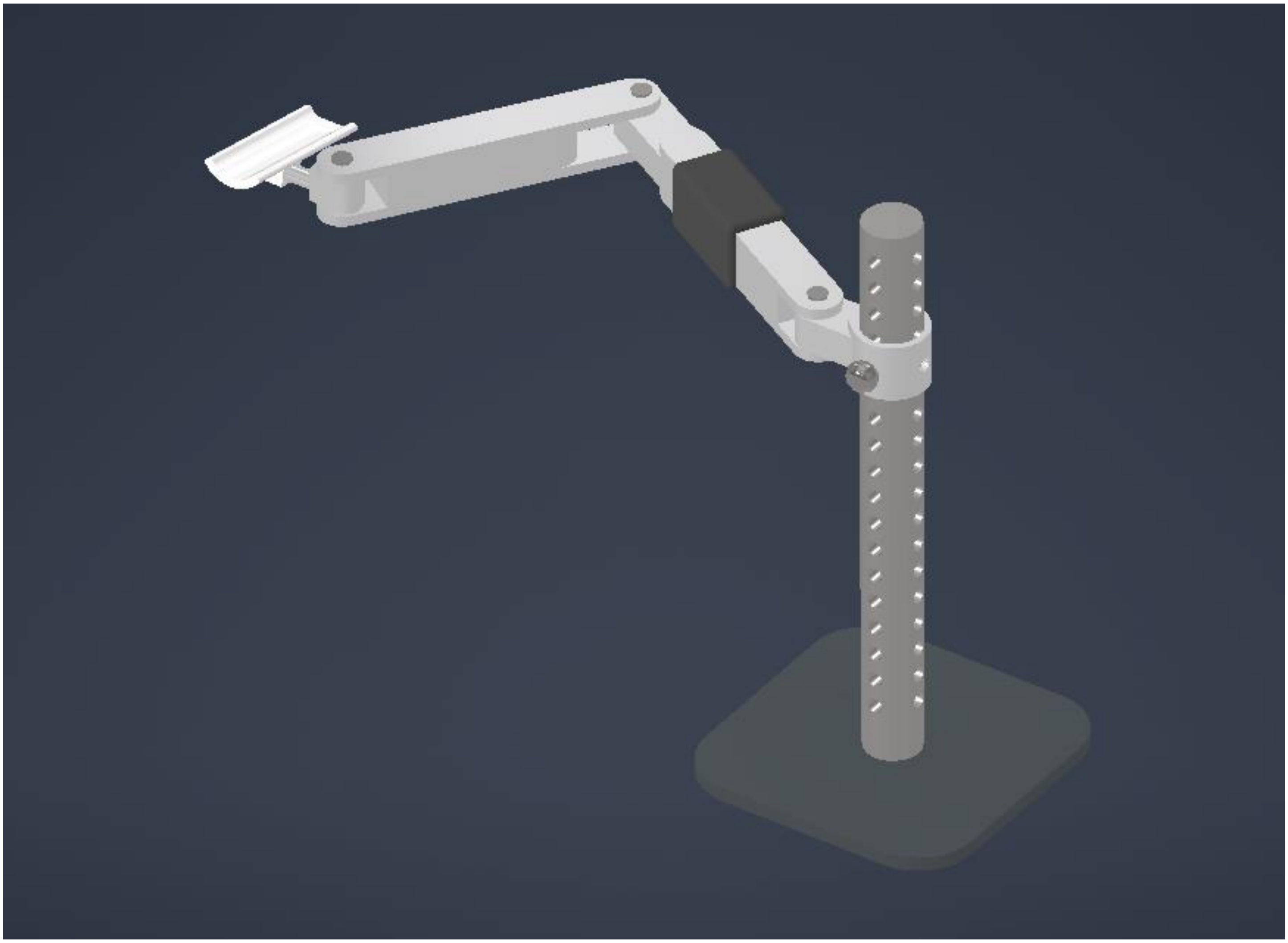


Figure 13a: Proposed final design – isometric view of CAD model

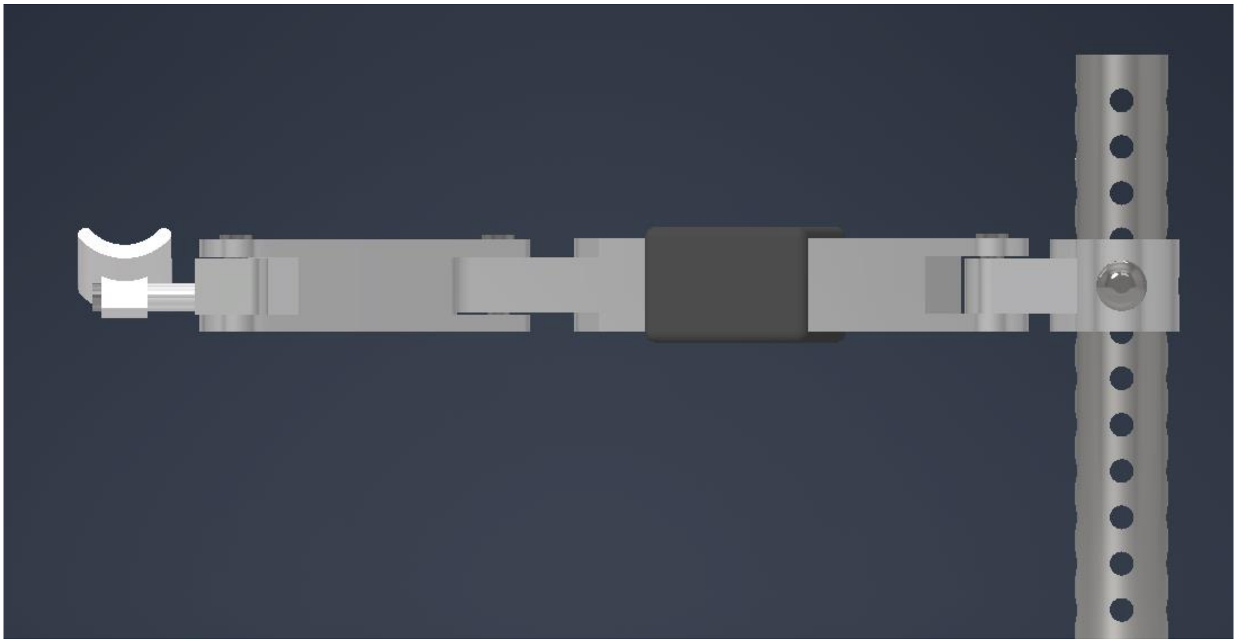


Figure 13b: Proposed final design – side view of CAD model

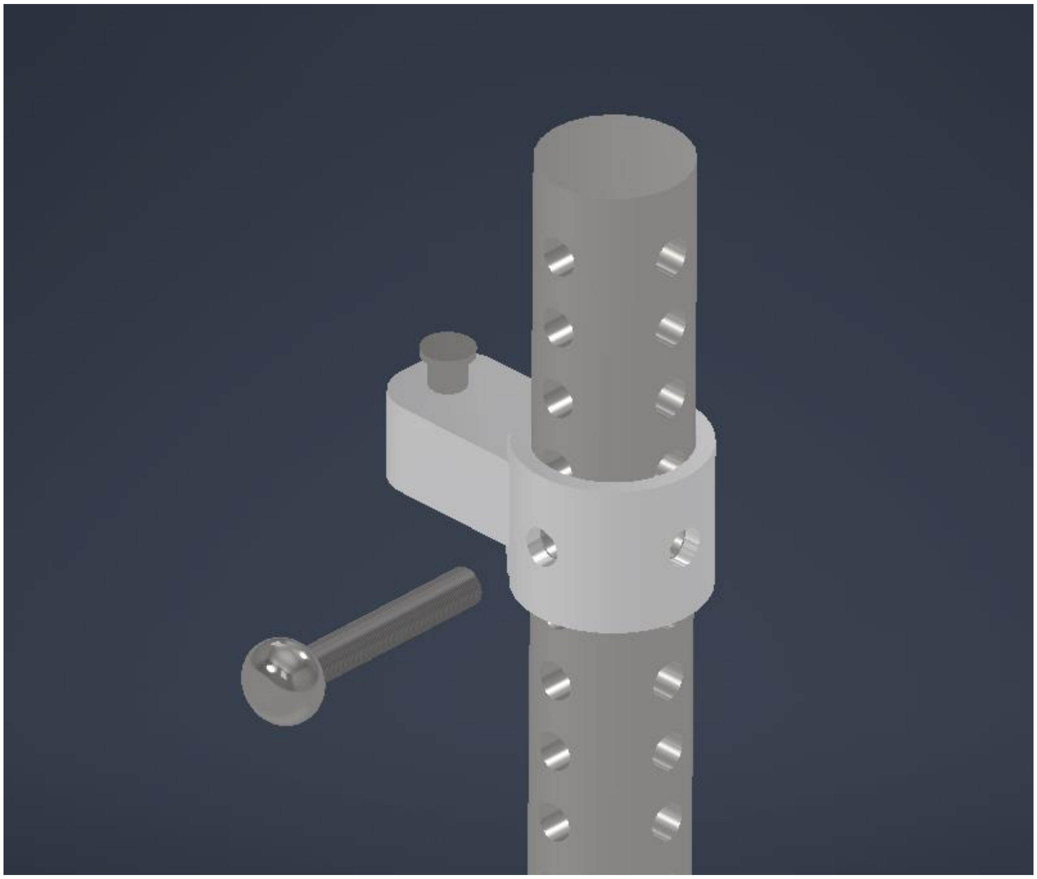


Figure 13c: Proposed final design – bolt and pole mechanism

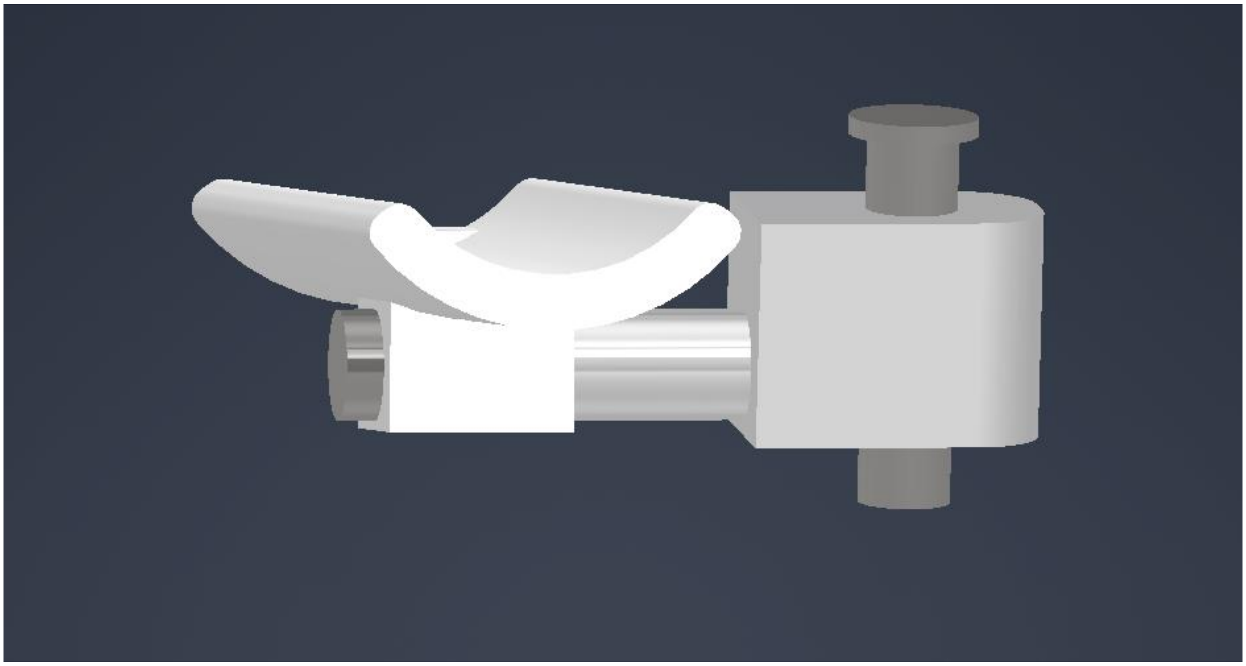


Figure 13d: Proposed final design – rotating armrest mechanism

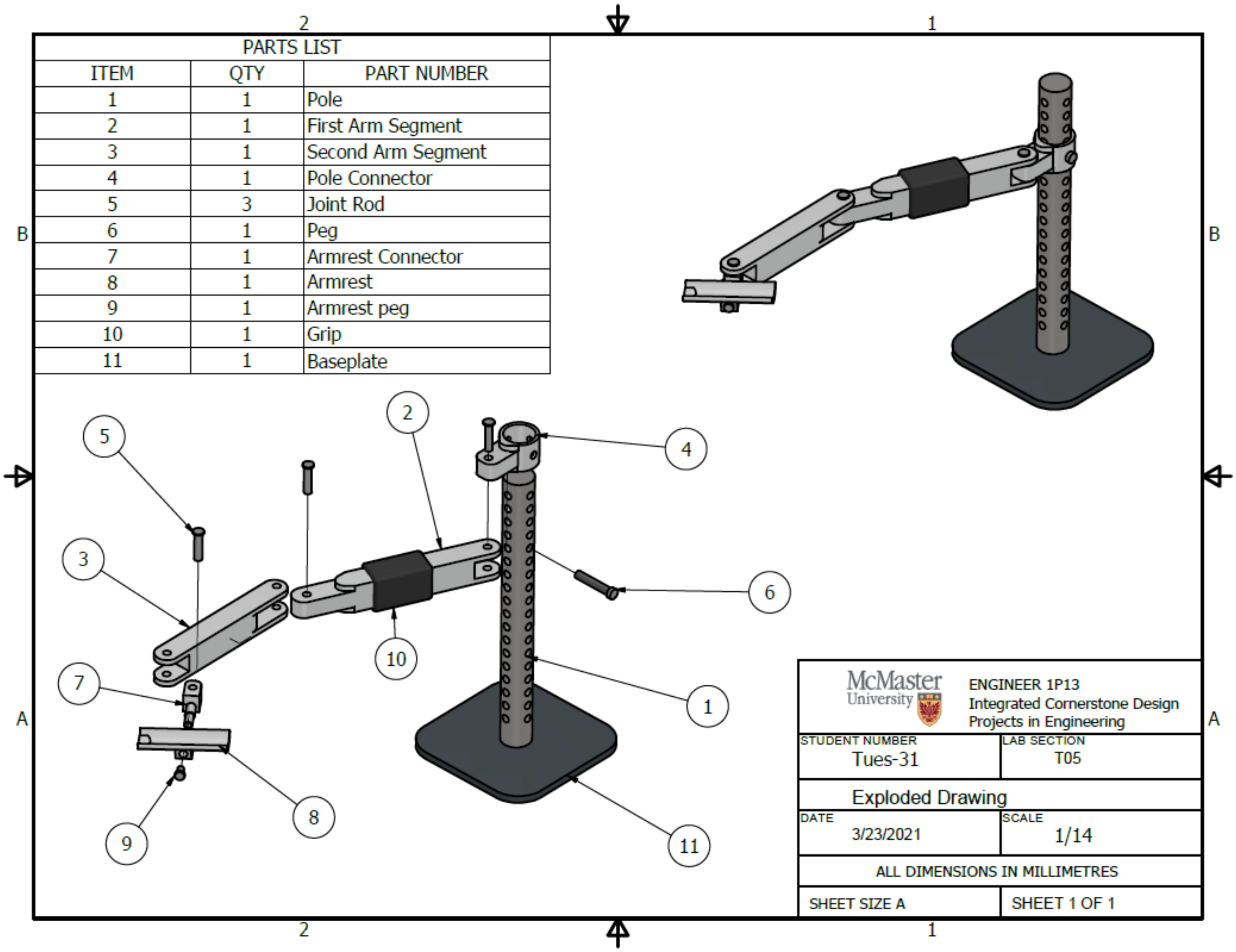
Initial objective metrics

<table>
<tr><td>Objective:</td><td>Lightweight</td></tr>
<tr><td>Unit/Metric:</td><td>Mass (kg)</td></tr>
<tr><td>Objective:</td><td>Ease of Use</td></tr>
<tr><td>Unit/Metric:</td><td>A sample of design testers should be employed to rank their subjective ease of use experience on an objective numeric scale from 1 to 5 as shown below
<table>
<tr><td>User feedback</td><td>Numeric score</td></tr>
<tr><td>Not easy to use at all</td><td>1</td></tr>
<tr><td>Slightly easy to use</td><td>2</td></tr>
<tr><td>Easy to use</td><td>3</td></tr>
<tr><td>Moderately easy to use</td><td>4</td></tr>
<tr><td>Very easy to use</td><td>5</td></tr>
</table>
The mean score of the sample should be taken as the final metric for ease of use.</td></tr>
<tr><td>Objective:</td><td>Comfortability</td></tr>
<tr><td>Unit/Metric:</td><td>A sample of design testers should be employed to rank their subjective ease of use experience on an objective numeric scale from 1 to 5 as shown below
<table>
<tr><td>User feedback</td><td>Numeric score</td></tr>
<tr><td>Not comfortable at all</td><td>1</td></tr>
<tr><td>Slightly comfortable</td><td>2</td></tr>
<tr><td>Comfortable</td><td>3</td></tr>
<tr><td>Moderately comfortable</td><td>4</td></tr>
<tr><td>Very comfortable</td><td>5</td></tr>
</table>
The mean score of the sample should be taken as the final metric for comfortability.</td></tr>
<tr><td>Objective:</td><td>Durability</td></tr>
<tr><td>Unit/Metric:</td><td>Stress Analysis Test subjective ranking scale
<table>
<tr><td>Test result</td><td>Numeric score</td></tr>
<tr><td>Can withstand up to 5kg</td><td>1</td></tr>
<tr><td>Can withstand up to 10kg</td><td>2</td></tr>
<tr><td>Can withstand up to 15kg</td><td>3</td></tr>
<tr><td>Can withstand up to 20kg</td><td>4</td></tr>
<tr><td>Can withstand more than 25kg</td><td>5</td></tr>
</table>
The design solution would be stress tested under various loads; the highest score would be taken as the metric.</td></tr>
</table>

Table 4: Preliminary objectives and associated metrics

Appendix C – Final Design

Exploded View of the Final Design



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	Pole
2	1	First Arm Segment
3	1	Second Arm Segment
4	1	Pole Connector
5	3	Joint Rod
6	1	Peg
7	1	Armrest Connector
8	1	Armrest
9	1	Armrest peg
10	1	Grip
11	1	Baseplate

Figure 14: Final design drawing – Exploded assembly

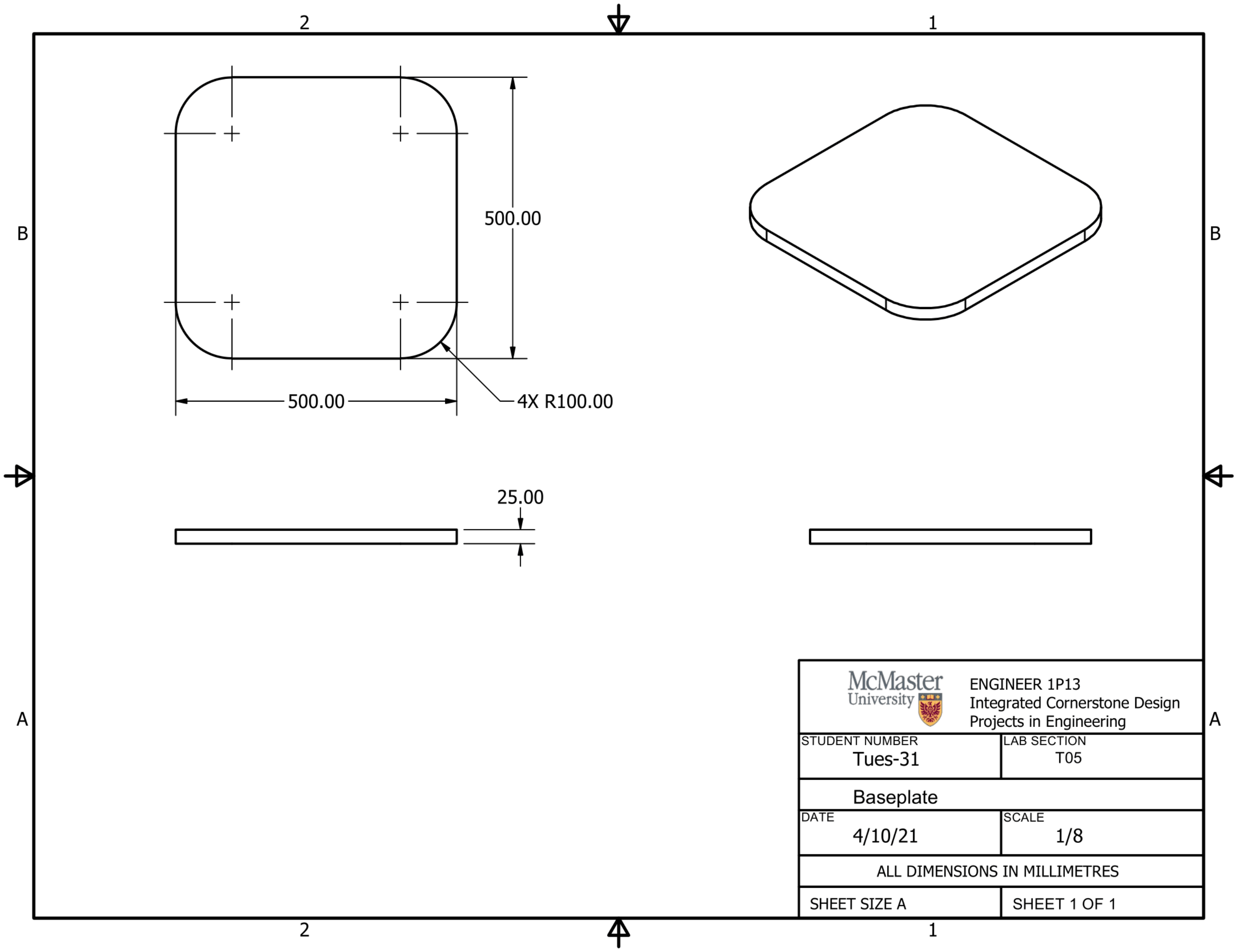


Figure 15: Final design drawing – baseplate

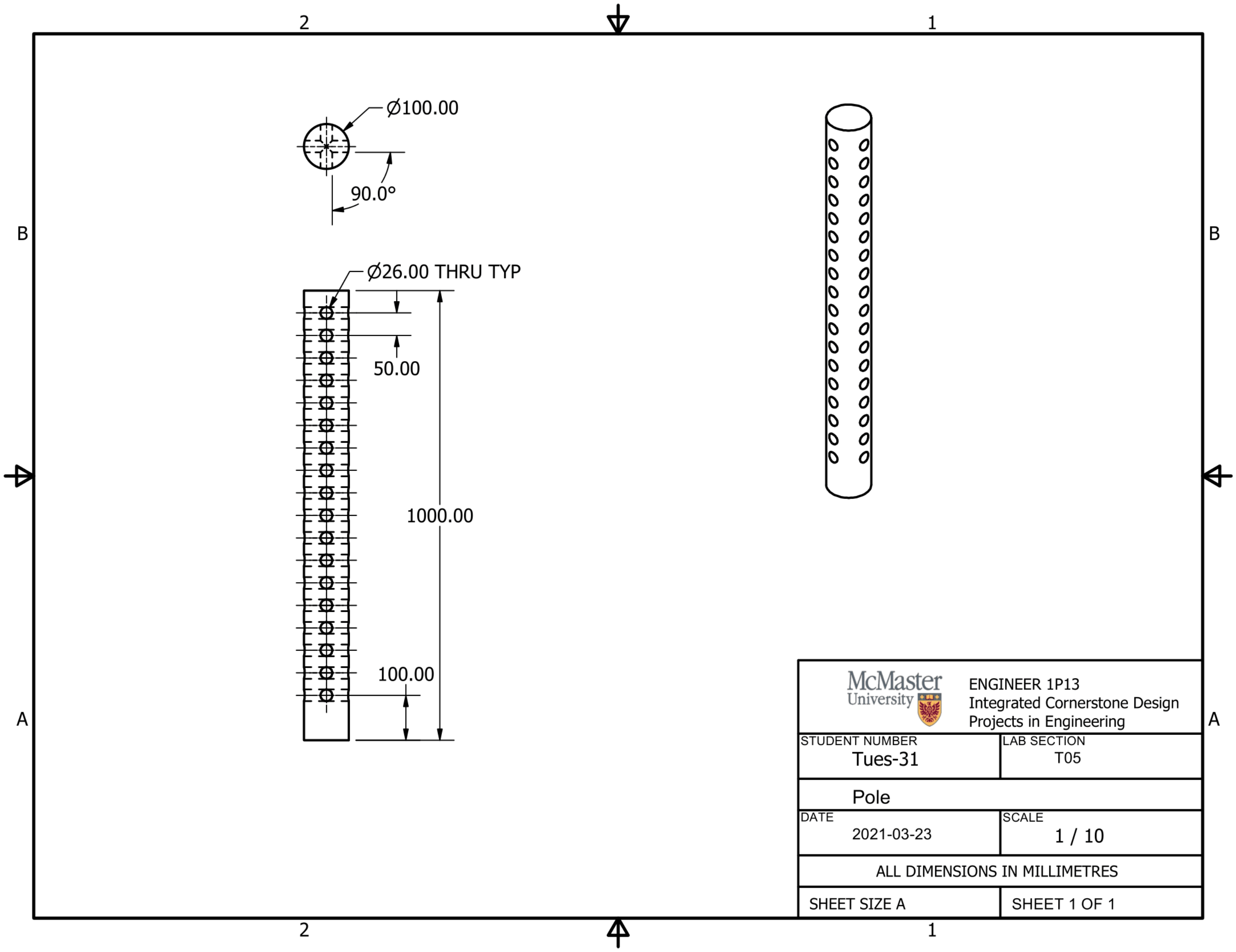


Figure 16: Final design drawing – pole with holes for connector

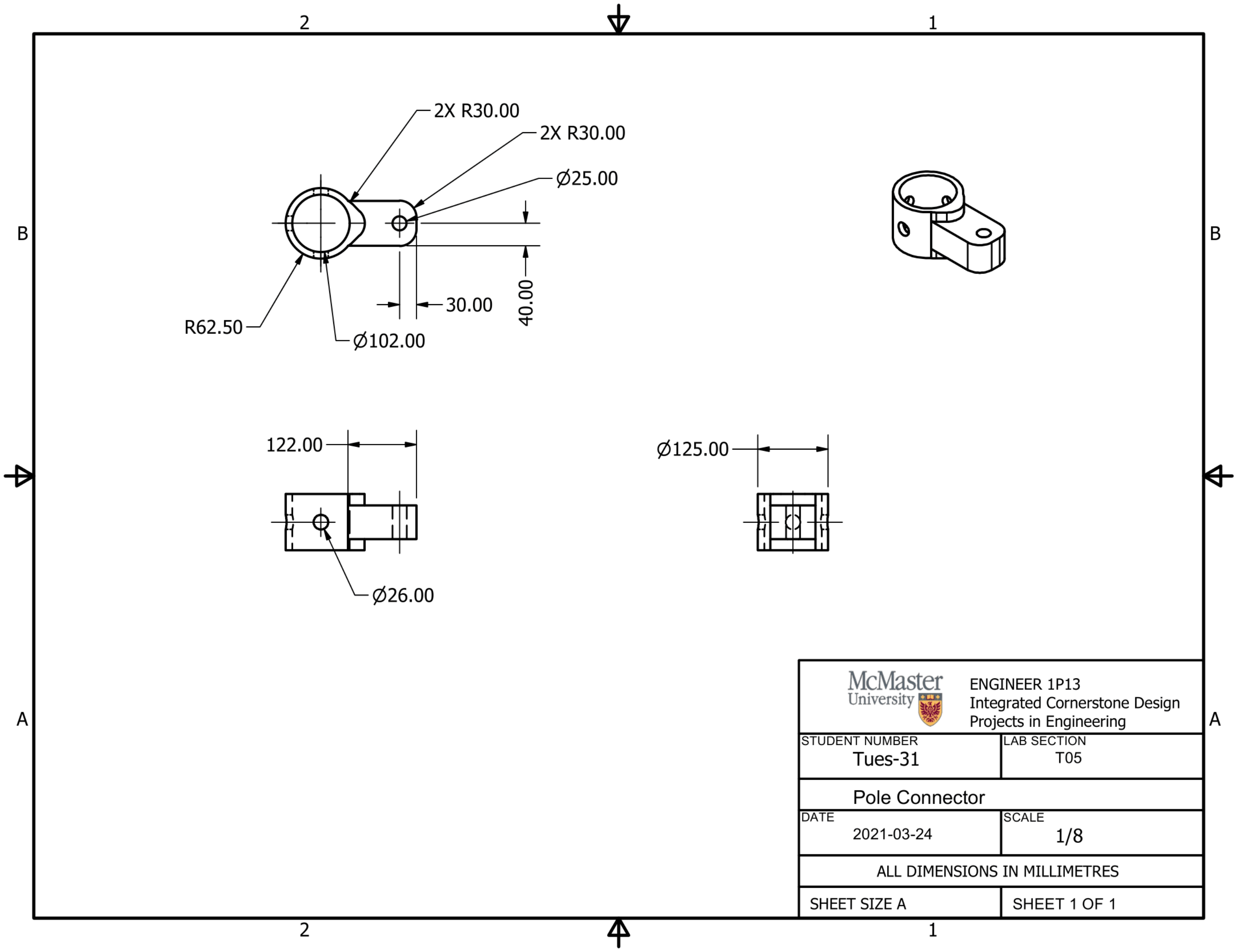


Figure 17: Final design drawing – Pole connection attachment piece

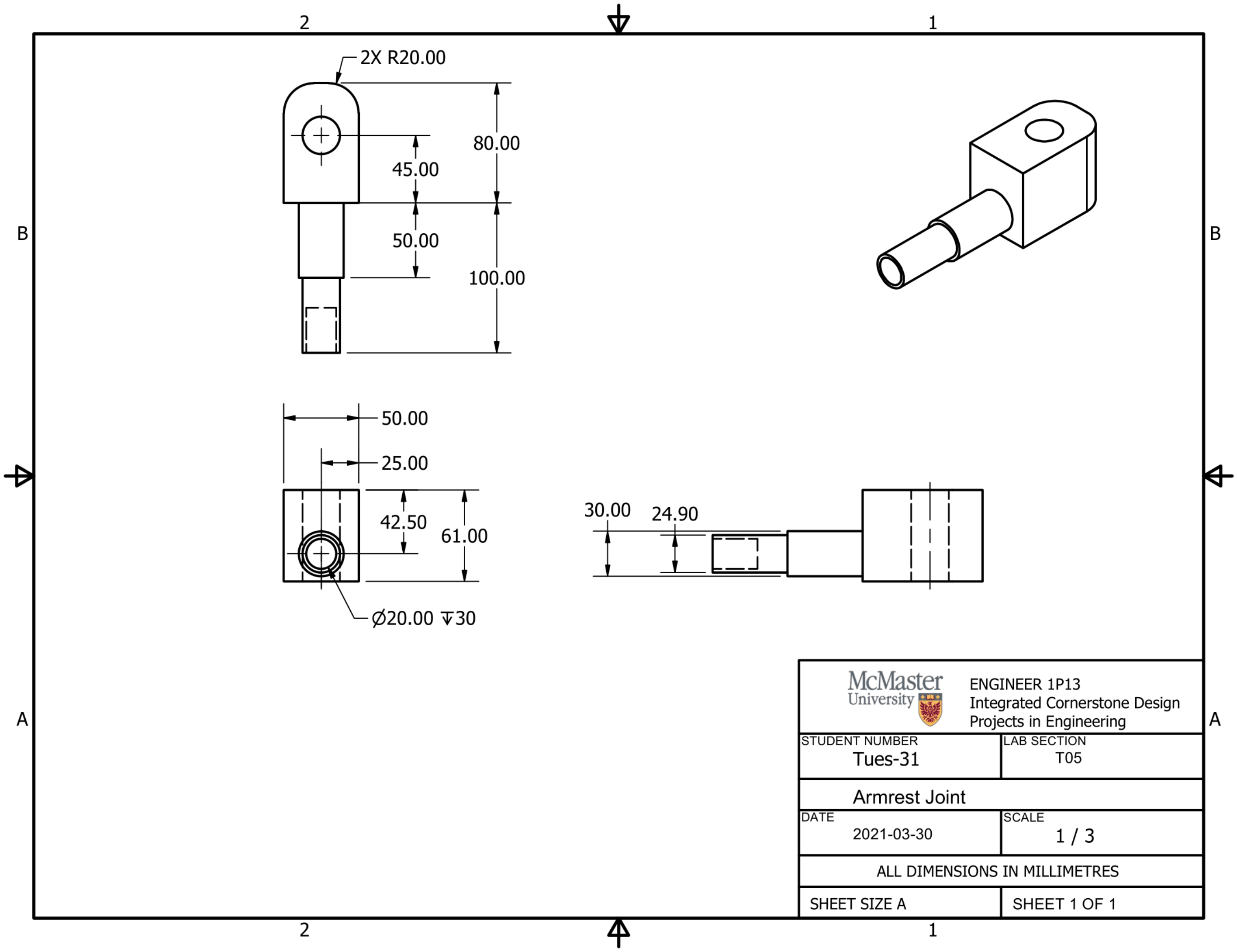


Figure 18: Final design drawing – arm segment and armrest connecting piece

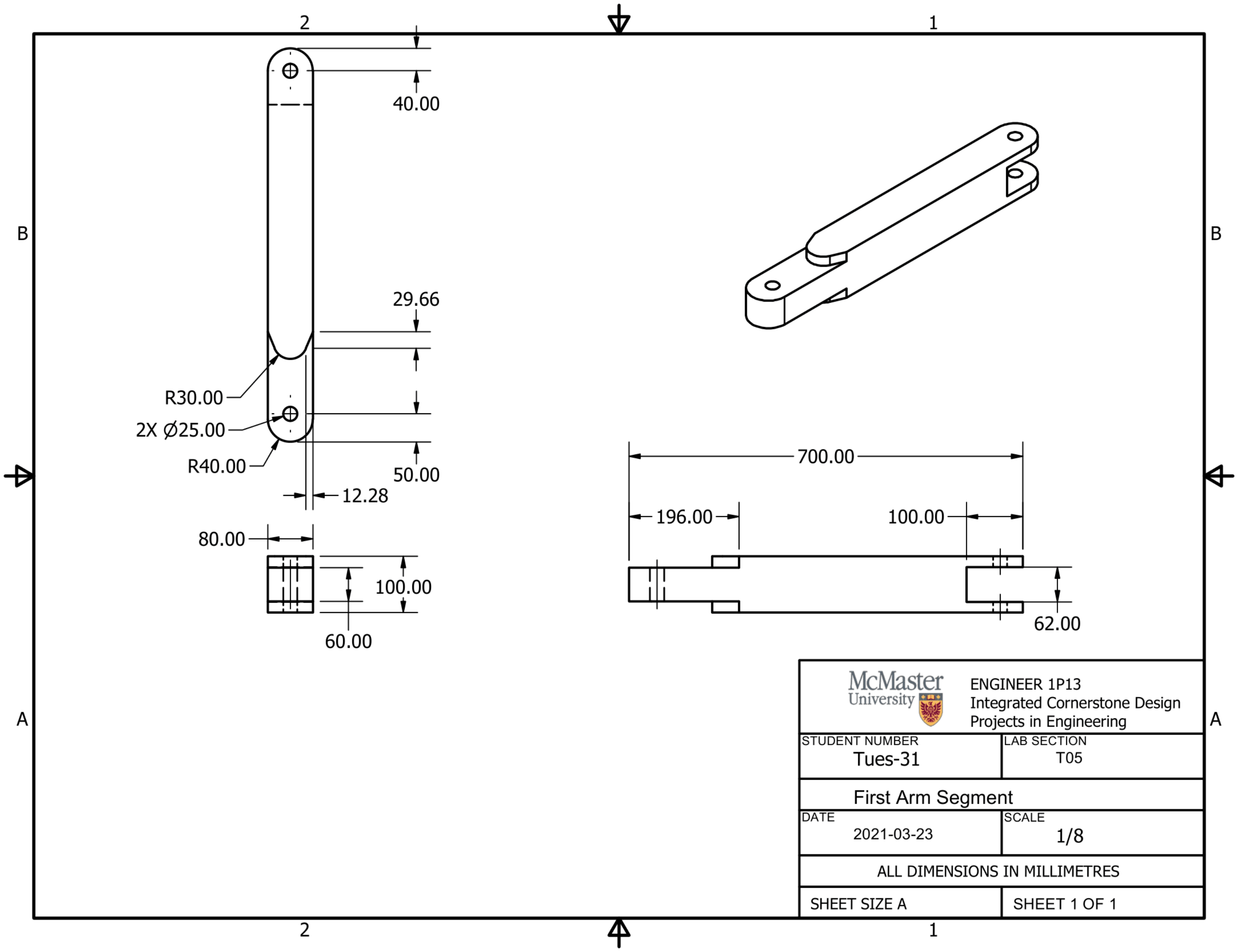


Figure 19: Final design drawing – first of two arm segments

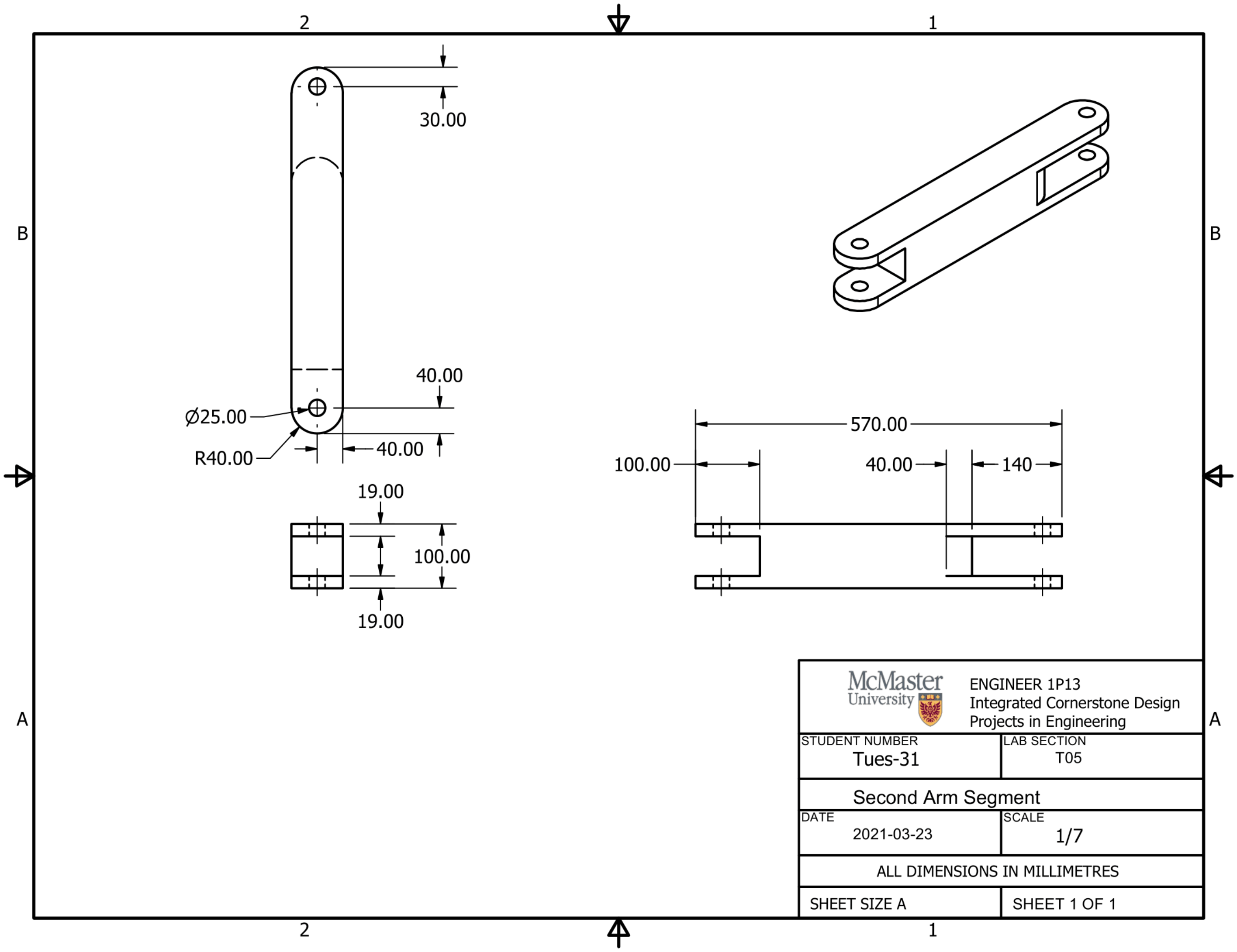


Figure 20: Final design drawing – second of two arm segments

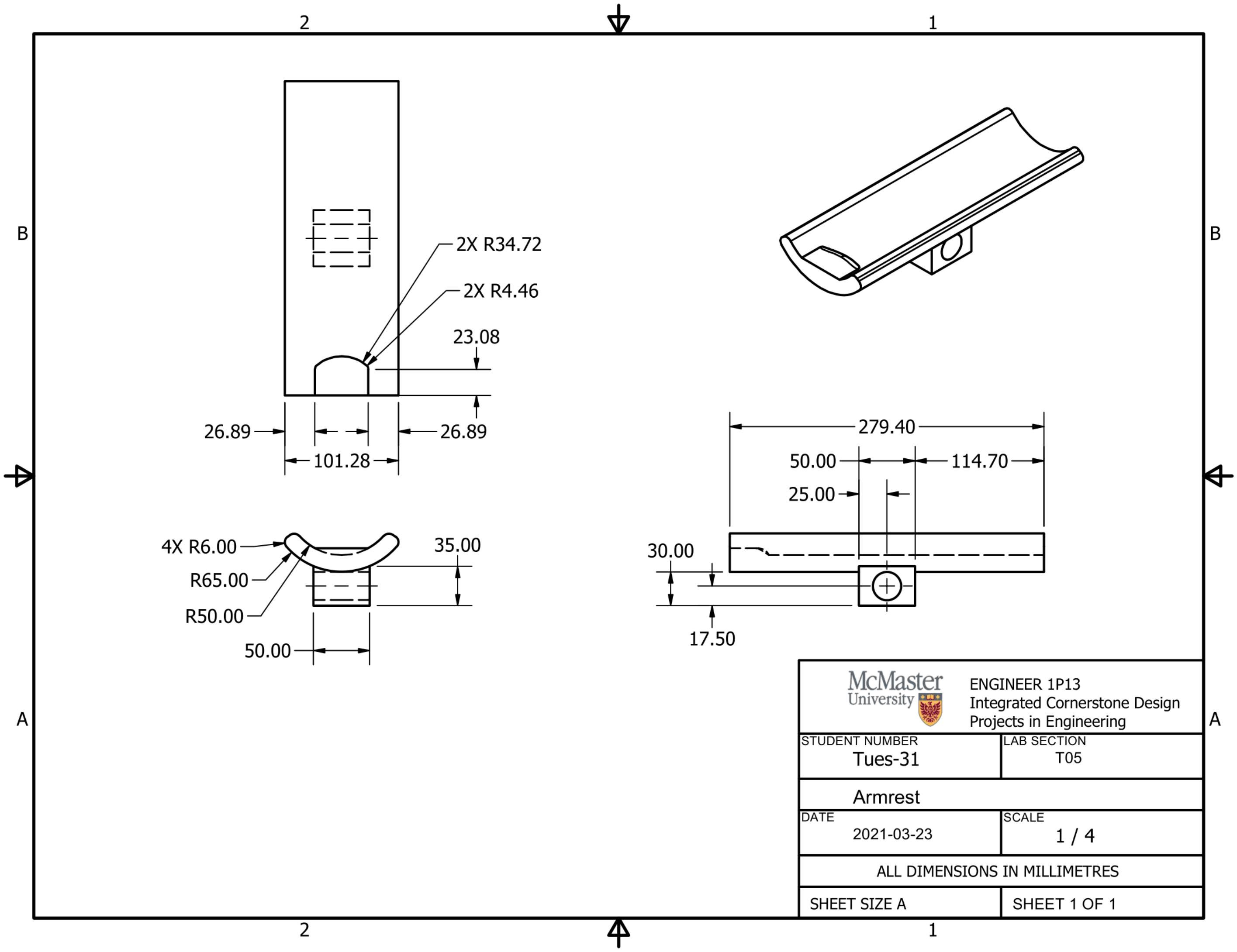


Figure 21: Final design drawing – armrest

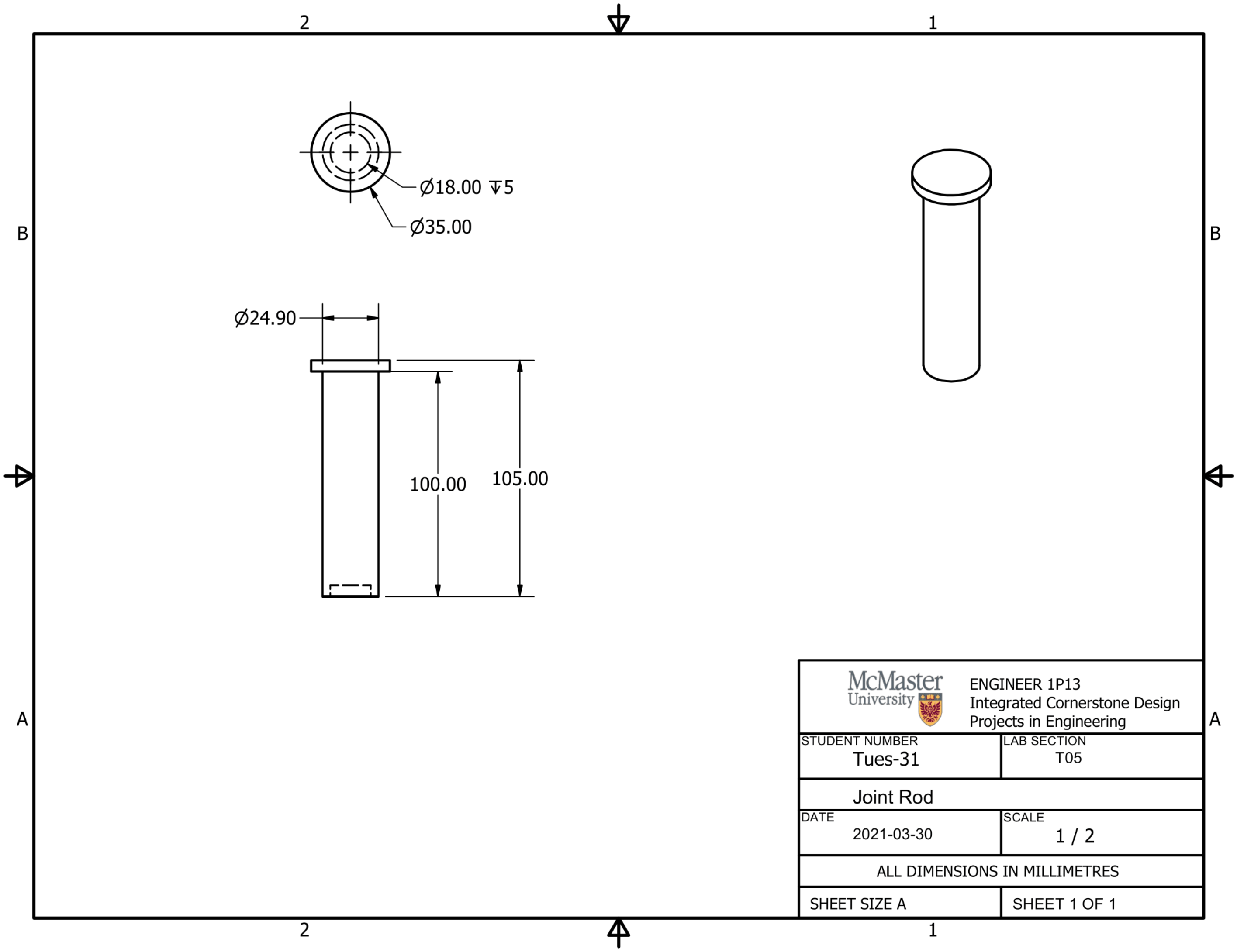


Figure 22: Final design drawing – rotational joint connecting rod/pin

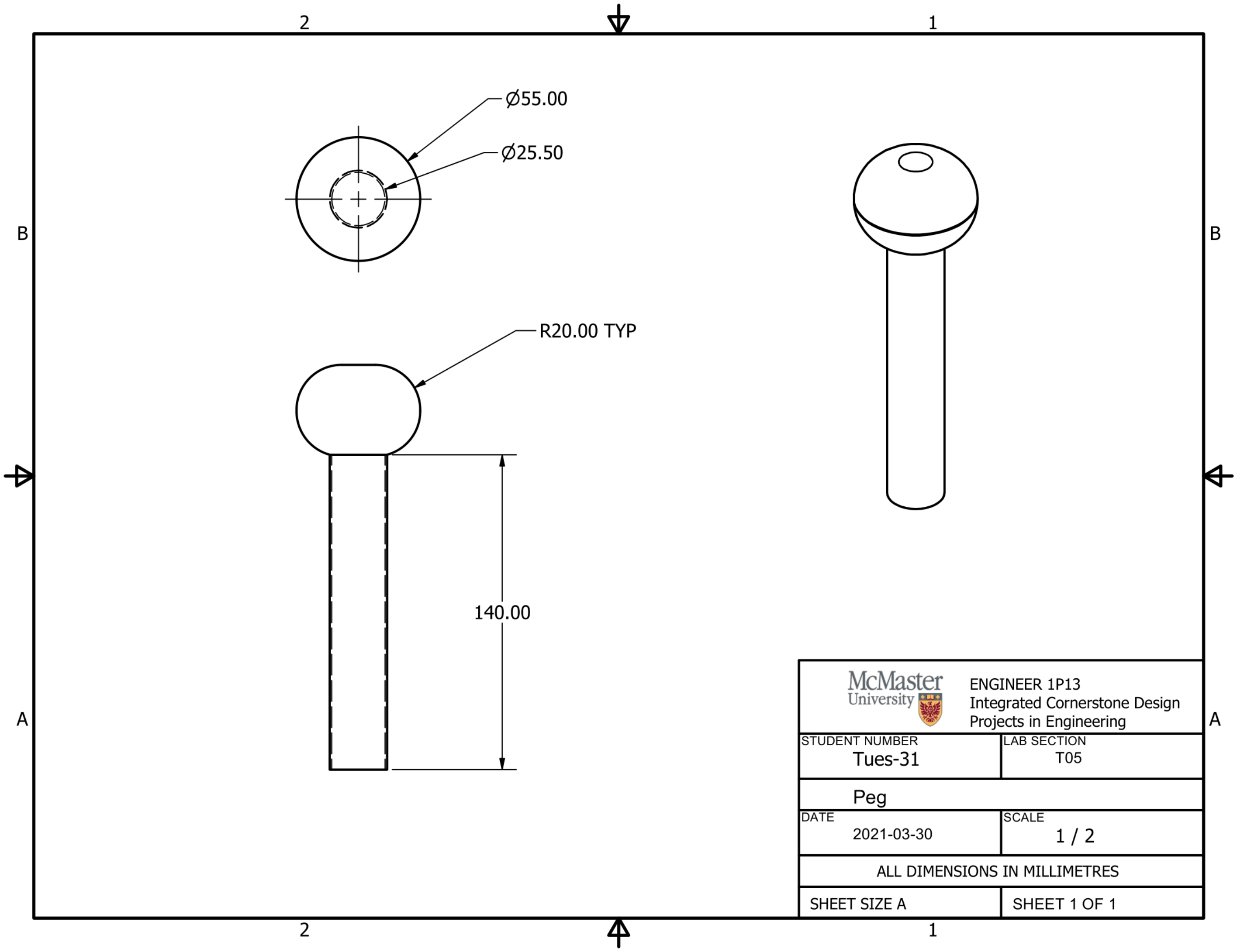


Figure 23: Final design drawing – bolt/peg for pole insertion

Material/Item	Quantity	Price per Unit (CAD)	Price of Quantity (CAD)
Polyurethane foam	1 sheet (1.3m x 2.3m x 0.006m)	$1.70 - $2.00 per sheet	Approx. $2.00
Cast Iron	31.725 kg	$0.48 - $0.80 per kg	Approx. $15.00
Aluminum alloy block	1 block (2.5 m x 0.15m x 0.15m)	$2.75 - $5.49 per kg	Approx. $20.00 - $40.00
Aluminum alloy pins and bolt	4 pins	$2.75 - $5.49 per kg	Approx. $11.00 - $22.00
Aluminum alloy pole	1 pole (1m long x 0.1m diameter)	$2.75- $5.49 per kg	Approx. $50.00
Polyvinyl chloride (PVC)	1 pipe (0.05m x 0.15m)	$15.50 per pipe	Approx. $15.50
Nitrile Rubber	1 piece (0.5m x 0.5m x 0.025m)	$21.00 per piece	Approx. $21.00
Total Price (Tax Exclusive)			$160.00 + Manufacturing/ Construction Costs

Table 5 - Bill of Materials/Construction

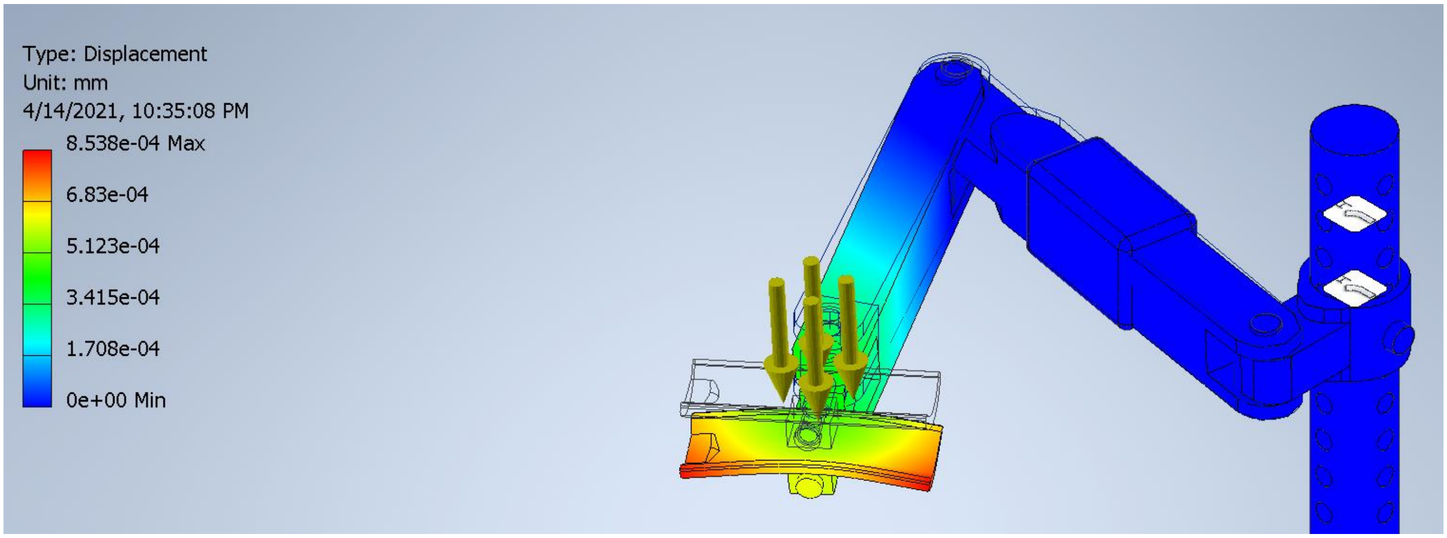


Figure 24: Stress analysis simulation (Autodesk Inventor 2021)

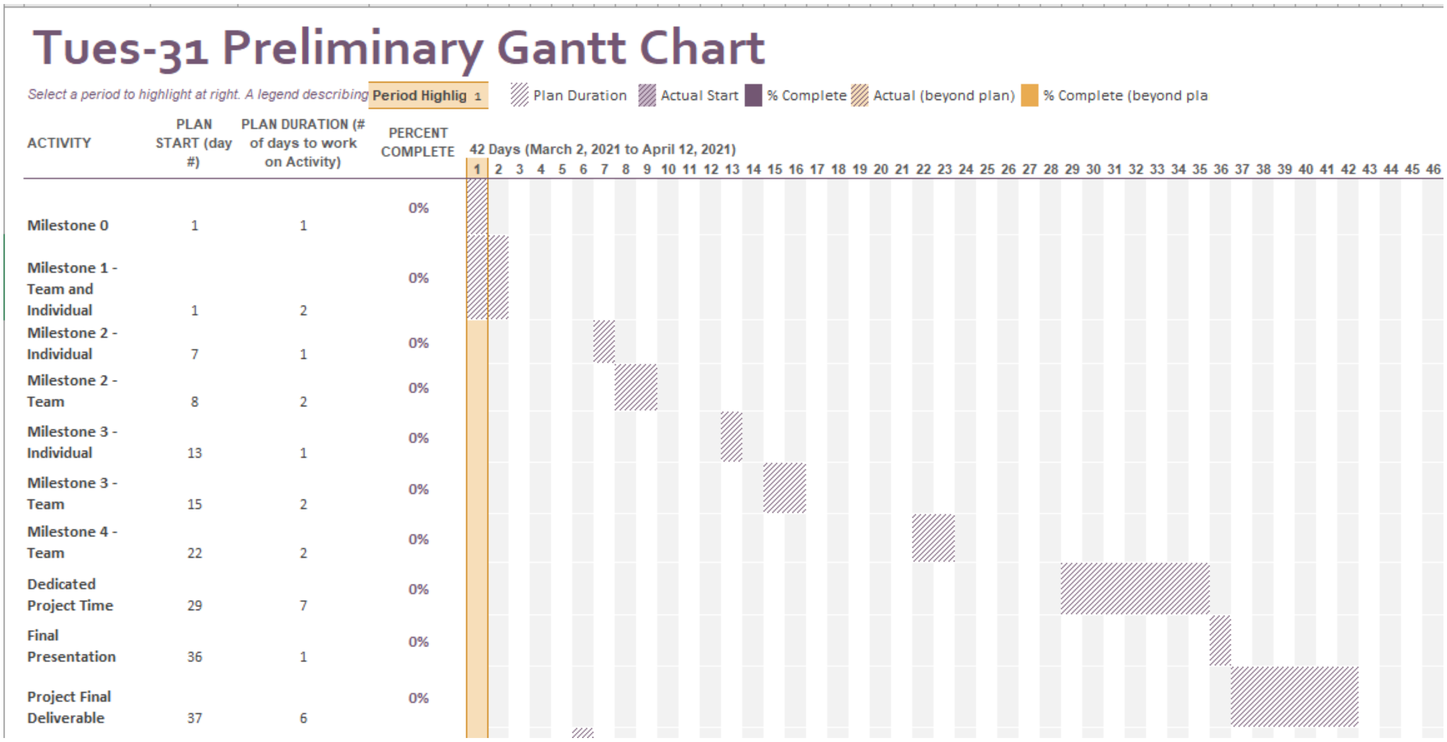
Appendix D – Gantt Charts and Logbook

Logbook

Date (EST timezone)	Discussion Content
Tuesday March 2nd: 12:30pm – 2:30pm	Milestone 0 – team meeting and role selection Begin Milestone 1 – write the initial problem statement, being how-why ladder
Wednesday March 3rd: 11:30am– 2:40pm	Milestone 1 – complete how-why ladder and justification, objectives and their rationales/metrics, project planning (resources, previous experiences)
Monday March 8th: 8:30pm – 9:30pm	Complete Milestone 1 – add fourth objective to ensure level 4 (based on rubric). Discuss general project ideas, look forward to Milestone 2
Tuesday March 9th: 12:30pm – 2:30pm	Milestone 2 – write refined problem statement, come up with primary and secondary functions for the morph chart
Tuesday March 9th: 9:50pm – 10:20pm	Attendees: Luigi, Avanish Final review and submission for milestones 0 and 1
Wednesday March 10th: 11:30am – 2:30pm	Milestone 2 – complete functional analysis, concept exploration and sketches
Tuesday March 16th: 12:30am – 2:30pm	Milestone 3 – initial prototypes and thoughts, discussion, and preparation for design review.
Wednesday March 17th: 11:30am – 12:30pm	Milestone 3 – Peer design review, taking notes on science student feedback
Thursday March 18th: 3:30pm – 4:15pm	Attendees: Luigi, Avanish, Ziad Milestone 3 – Create decision matrix
Saturday March 20th: 3:15pm – 4:00pm	Attendees: Luigi, Michael Milestone 3 – Write rationale. Looking ahead and discussion for milestone 4.
Tuesday March 23rd: 12:30pm – 2:30pm	Milestone 4 – Discuss logistics of design, begin CAD modelling parts.
Tuesday March 30th: 12:30pm – 2:00pm	Milestone 4 – Work on remaining sections. Assign work to be done individually before submission deadline.
Tuesday March 30th: 7:30pm – 10:00pm	Milestone 4 – Finish milestone.
Wednesday March 31st: 11:30am – 1:00pm	Final Deliverables preparation, understanding what needs to get done in the next two weeks (video, report). Set up PowerPoint and report template.
Monday April 5th: 1:00pm – 3:30pm	Finalize model and motion simulation, discuss video presentation and PowerPoint, plan to meet again later in the afternoon.
Monday April 5th: 6:00pm – 11:59pm	Complete PowerPoint presentation, record and rerecord video many times, finalize and submit video.
Tuesday April 6th: 1:20pm – 1:30pm	Final video presentation.
Monday April 12th: 6:15pm – 8:15pm	Work on final deliverable – complete executive summary and introduction sections.
Tuesday April 13th: 8:00pm – 10:00pm	Work on final deliverable – appendices, conceptual design.
Wednesday April 14th: 6:00pm – 11:59pm	Work on final deliverable – tidy up appendices, finish main body of report.
Thursday April 15th: 1:00pm – 4:00pm	Finish final deliverable – re-read body, tie up loose ends

- **Dates in red were outside of scheduled class time*
- ***Entire group was present if Attendees was not listed*
- *Conversation took place via an Instagram group chat in which we discussed the project and when to meet up.*
- *Individual direct messages on Teams were exchanged if Instagram was not accessible.*

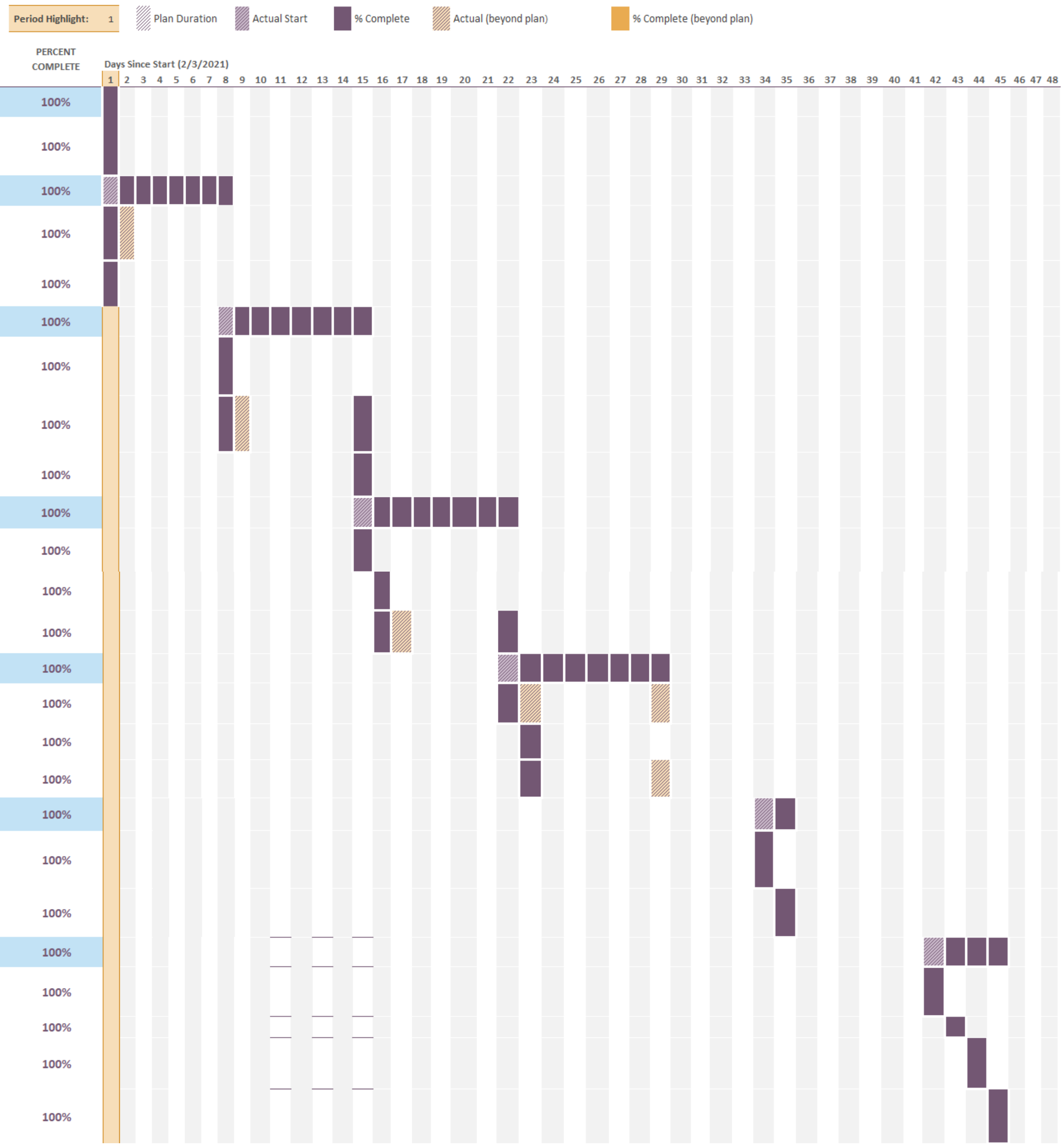
Gantt Charts



P4 - Power in Community (Final Gantt Chart)

Team: Tues-31

ACTIVITY	PLAN START (DD/MM/YYYY)	PLAN DURATION (Days)	ACTUAL START (DD/MM/YYYY)	ACTUAL DURATION (Days)	PERCENT COMPLETE
Milestone 0	2/3/2021	1	2/3/2021	1	100%
Completed Team Charter Worksheet and Preliminary Gantt Chart	2/3/2021	1	2/3/2021	1	100%
Milestone 1	2/3/2021	2	2/3/2021	3	100%
Completed Problem Statement, How/Why Ladder and Objectives	2/3/2021	1	2/3/2021	2	100%
Completed Metrics and wrote individual experiences	2/3/2021	1	3/3/2021	1	100%
Milestone 2	9/3/2021	2	9/3/2021	5	100%
Completed Refined Problem statement and functions for Morph chart	9/3/2021	1	9/3/2021	1	100%
Completed functional analysis section and concept sketches	10/3/2021	1	10/3/2021	3	100%
Reviewed second client meeting notes	11/3/2021	1	16/3/2021	1	100%
Milestone 3	16/3/2021	2	16/3/2021	5	100%
Completed Intial prototypes and justification	16/3/2021	1	16/3/2021	1	100%
Attended Design Review 1 and recorded feedback	17/3/2021	1	17/3/2021	1	100%
Competed Criterion and Decision Matrix	17/3/2021	1	17/3/2021	3	100%
Milestone 4	23/3/2021	2	23/3/2021	6	100%
Completed Intial prototype and justification	23/3/2021	1	23/3/2021	3	100%
Attended Design Review 2 and recorded additional feedback	24/3/2021	1	24/3/2021	1	100%
Completed Present Testing plan and Future Testing plan	24/3/2021	1	30/3/2021	2	100%
Final Presentation	30/3/2021	2	4/4/2021	2	100%
Completed final design assembly and dynamic simulation for video	30/3/2021	1	4/4/2021	1	100%
Completed powerpoint presentation and recorded pitch video	5/4/2021	1	5/4/2021	1	100%
Design Report	10/4/2021	4	11/4/2021	4	100%
Completed Executive Summary and Introduction section	10/4/2021	1	11/4/2021	1	100%
Completed Conceptual Design	11/4/2021	1	12/4/2021	1	100%
Completed the Final Propose design and Conclusion sections	12/4/2021	1	14/4/2021	1	100%
Completed the appendices and reviewed the entire report	15/4/2021	1	15/4/2021	1	100%



Appendix E – Source Materials Database

M. D. Melissa Conrad Stöppler, "What Is Lymphedema? Treatment, Therapy, Causes, Symptoms, Pictures," *MedicineNet*, 12-Dec-2019. [Online]. Available: https://www.medicinenet.com/lymphedema/article.htm. (Accessed: 08-Mar-2021).

"Living with Lymphedema: Susan O'Brien's Story," *The James - OSUCCC,* 02-Jun-2016. [Online]. Available: https://cancer.osu.edu/blog/living-with-lymphedema-susan-obriens-story. (Accessed: 08-Mar-2021).

"Fibromyalgia: Symptoms, causes, and treatment." https://www.medicalnewstoday.com/articles/147083 (accessed Mar. 08, 2021).

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D. Furnace, *Lymphatic Education & Research Network*, 2020. [Online]. Available: https://lymphaticnetwork.org/living-with-lymphedema/lymphedema-and-lymphatic-diseases-affect-millions-and-concern-us-all#:~:text=More%20people%20suffer%20from%20these,are%20susceptible%20to%20developing%20lymphedema. (Accessed: 13-Mar-2021).

S. Phan, S. Crowhurst, and P. Hammond, *How to Self-Bandage Your Hand(s) and Arm(s) to Reduce Lymphedema*, 2019. [Online]. Available: https://www.uhn.ca/PatientsFamilies/Health_Information/Health_Topics/Documents/Self-bandage_hands_arms_to_reduce_lymphedema.pdf. (Accessed: 13-Mar-2021).

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"Lymphatic drainage massage: How-to guide and benefits," Feb. 22, 2019. https://www.medicalnewstoday.com/articles/324518 (accessed Mar. 15, 2021).

"Compression treatment for lymphoedema | Coping with cancer | Cancer Research UK." https://www.cancerresearchuk.org/about-cancer/coping/physically/lymphoedema-and-cancer/treating/compression (accessed Mar. 15, 2021).

"The Role of Gender in Fibromyalgia | Everyday Health." https://www.everydayhealth.com/fibromyalgia/101/the-role-of-gender.aspx (accessed Mar. 15, 2021).

"20 Products People With Fibromyalgia Swear By | The Mighty." https://themighty.com/2017/08/fibromyalgia-pain-relief-products/ (accessed Mar. 15, 2021).