Department of Mechanical and Mechatronics Engineering

ME 482 Final Design Report

A report prepared for:

The University of Waterloo

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We the undersigned take responsibility for this design.

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Executive Summary

The objective of Project Cathedra is to create an ergonomic solution to improve spinal health in healthy individuals and mitigate pain in individuals with low back disorders from prolonged sitting. The beginning of this project, the scope of the project focused on maintaining sitting postural health. A need exists to allow customization of a chairs surface to match the ergonomic needs of the individual user. Over the course of the project, the scope was refined through research and experimentation findings. Feasibility of previous scopes were re-evaluated after the fabrication of the validation models. A better understanding of the timeline, fabrication, and skill limitations were recognized to determine the direction of the project. Research of spinal posture, low back disorders, and existing consumer ergonomic products help define Project Cathedra's scope of focus on the Variable Lumbar Stiffness Support (VSLS). The VSLS consists of a mechanical subsystem to variate stiffness and an electrical subsystem for actuation. Guidelines for ergonomic design were incorporated in this project, however ergonomics is heavily subjective and case specific based on the dimensions of the human body. The variations in human body size, spine profile and sitting preferences are typically not accommodated by current ergonomic chairs.

After multiple design iterations, the first half of the project timeline focused on developing and improving the VSLS module. By midterm of the ME482 term, an initial prototype was built to validate design decisions and parameters. This led to some changes in the design of the final prototype. As our final design was developed, considerations for safety, sustainability, and budgetary constraints were acknowledged. Project management tools and techniques such as Work Breakdown structure, Gantt charts and schedule compression were used to ensure timely completion of the project. Completion of this project validated that our VSLS module design is more comfortable than existing lumbar supports and cushions due to the mechanical spring force.

1.0 Project Background

Most people who complain about neck or back soreness or aches do not recognize that the design of the chair contributes to their discomfort. Also, since there are hundreds of chair models, it is difficult to identify what gives them comfort in a chair. Project Cathedra was inspired by people who suffer from low back disorders and experience chronic and acute low back pain. The lumbar support design can help prevent damage to the lumbar back from prolonged sitting and relieve pain of those who suffer from low back disorders. There exist ergonomic chairs on the market from $200 to $2000, yet there is no metric for its ergonomic effectiveness to justify the price. Ergonomic solutions do not have to be expensive. Individuals varies in their body size with different heights, body fat percentage, limb sizes, etc. There is no one-size-fits-all chair, nor is there a one-size-fits-all lumbar support. The variation of anthropometric sizes requires custom fitting for all individuals. We recognized that the lumbar area is a very sensitive part of the human body, as it is the key stone of the human body. Most healthy individuals take for granted the health of the spine, until they encounter an injury. This report will cover the ergonomic design journey of Project Cathedra. Project Cathedra aims to provide a solution for lumbar discomfort from prolonged sitting. The development of the Variable Stiffness Lumbar Support (VSLS) utilizes simple engineering concepts to tackle the complex and ambiguous challenge of ergonomics.

2.0 Problem Definition

2.1 ME 481 Summary

Initial Problem Statement: Customers who are trying to buy ergonomic chairs do not know what features, sizing, customizations are best for their body

Need Statement: Customize a surface of the chair to suit the ergonomic needs of the user

Objective:
- Create optimal individual profile from textile pressure input
- Adjust/morph the chair surface to create optimal individual profile
- User input adjustability

The initial proposal and midterm design of the capstone project was a conceptual design of a chair surface that can change in its topography. The intention of the initial proposal design was to create a topology profile to be fitted accordingly with the dimensions of the user via an embedded textile pressure mat data, then it can be adjusted based on the user’s preference.

Upon further research until the ME 481 midterm review, pressure distribution data from textile pressure mats does not have strong correlations to causation of pain. The textile pressure data did not provide key information to building an optimal sitting profile. The midterm design intention was to variate the topology of the back rest to be able to mimic existing ergonomic chairs via 3D model input or 3D scanning. The need for this was intended to be a retail fitting device for multiple models of chairs, such that the store can promote various models of chairs and save them storage and displace space. A small-scale mechanical prototype of the actuation mechanism to change the topography of the chair back was 3D printed for demonstration purposes. The design is composed of an offset roller to be controlled by a servomotor. The roller axis is offset from the center and the servomotors is used to control the surface displacement of the offset rollers, thus changing the topography of the chair back.

Figure A:Midterm Roller Prototype

A frame of the chair was built for housing and validation purposes intended for the roller design. The backrest was made of a stiff fabric that was supported by a tensional force at the top and bottom of the chair. Experimentation was done by applying a pushing force on to the backrest to find comfortable locations of lumbar and mid-back support. Each team member sat on the chair while another member pushed against the backrest in various positions to determine the sitter's position of comfort of where the back support should be administered.

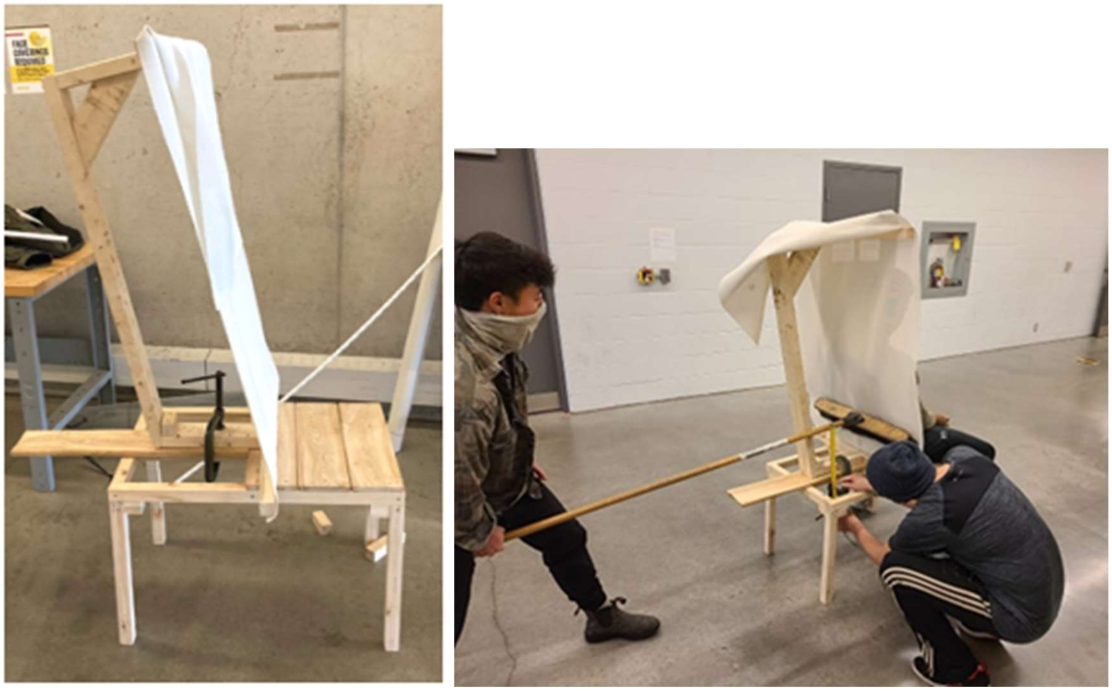

Figure B: Validation Model (left) and Measuring Preferred Lumbar Support Position (right)

This experiment was to determine the optimal locations of where the roller supports should be placed. We found that each member had different preference in the location of the lumbar support along the y-axis shown in figure 2. We found that the lumbar region is particularly sensitive to the applied force. On the other hand, the mid-back was less sensitive to the applied load support. These two conclusions adhere to current ergonomic chair design. The comfort for the mid-back is simply a uniform stiffness support.

<u>Final Design from ME 481</u>

FDR Project Objectives:

- Fabricate Variable Stiffness Lumbar Support mechanism and validate comfort and effectiveness
- If time permits, incorporate arm, neck, and other supports
- Build an overall comfortable chair
-

New Project Deliverables:

Mechanical: Variable Stiffness Lumbar Support, adjustment in height of lumbar support, fabricate chair
Electrical: Arduino controlled automated stiffness adjuster and lumbar support height

With the new findings from experimentation, the scope of the project was re-assessed. We moved away from the design of the mid-back rest and focused on the lumbar region. Each group member has a different preference on the force applied to the lumbar region. We realized that the functionality of the roller design was not the best design to fulfill the comfort criteria. The human sitting posture is subjected to frequent changes, which makes the static topography ineffective. Based on the findings from the validation model, the roller design was scrapped to focus on developing a mechanical variable stiffness lumbar backrest.

3.0 Design Solution

Needs Statement: Customize a surface of the chair to suit the ergonomic needs of the user
Project Objectives:

- Improve Variable Stiffness Lumbar Support
- Incorporate arm rests
- Build an overall comfortable **and aesthetic** chair

Project Deliverables:

- Mechanical: Design and fabricate chair seat and mid-back rest, housing and framing for VSLS
- Electrical: Arduino controlled automated stiffness adjuster and lumbar support height

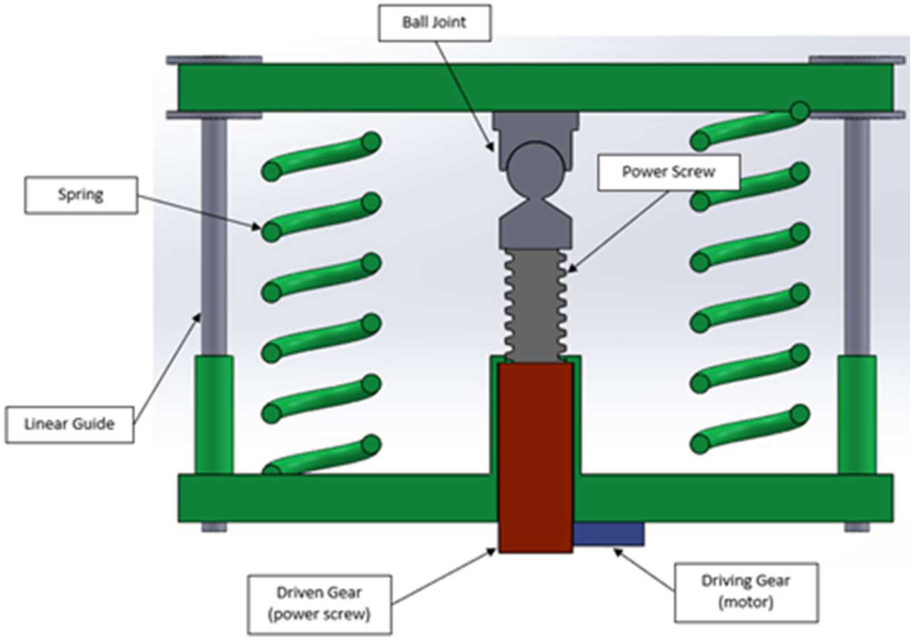

Figure C: CAD of VSLS Mechanism

The variable stiffness lumbar support (VSLS) allows the user to adjust the stiffness of the backrest to their preference. It is noted that lumbar supports exist on the market. They are usually a cushion with uniform material stiffness and the location is not adjustable. The fixed position and undesired stiffness can be problematic and unfit for some users. Pneumatic designs, such as the ones that exists in luxury cars, has the same issue as the cushion in terms of comfort. Pneumatic cushions are not comfortable over a prolonged time due to the distribution of force. Thus, the intention of the VSLS can be positioned anywhere along the seat back and to be adjusted to any preferred stiffness.

3.1 Engineering Design Analysis

A second validation model jig was fabricated to test the optimal location of the VSLS and to find the spring rating for a comfortable support. The optimal location for the lumbar support was found to be at the approximate location from the L1-L4 in healthy individuals of this FYDP team. Due to the lockdown protocols, additional feedback from other individuals was not possible. Several iterations to select a comfortable stiffness rating were made. The springs were selected based on the lowest rating preferred, since the actuation of the stepper motor can compress the VSLS to a stiffer setting. The validation and final iteration of the VSLS was completed at the midterm of the ME 482 term.

3.1.1 Mechanical

3.1.1.1 VSLS

The design for VSLS modules were designed to allow the users to control the stiffness of the module and to allow the slight shifts in user's sitting posture. The mechanical springs and adjustment with a power screw were selected for minimal maintenance of the modules and simplicity of the design. Swivel joints and circular slots were implemented in the design to meet the criterion of allowing slight shifts in user's posture. The validation model design for a VSLS module is as shown in the figure 4. The preload of springs is adjusted by loosening and tightening the nut, which is replaced by flange with motor connection for prototype. Guide rods are fixed to the swivel joints and keeps the springs in-place.

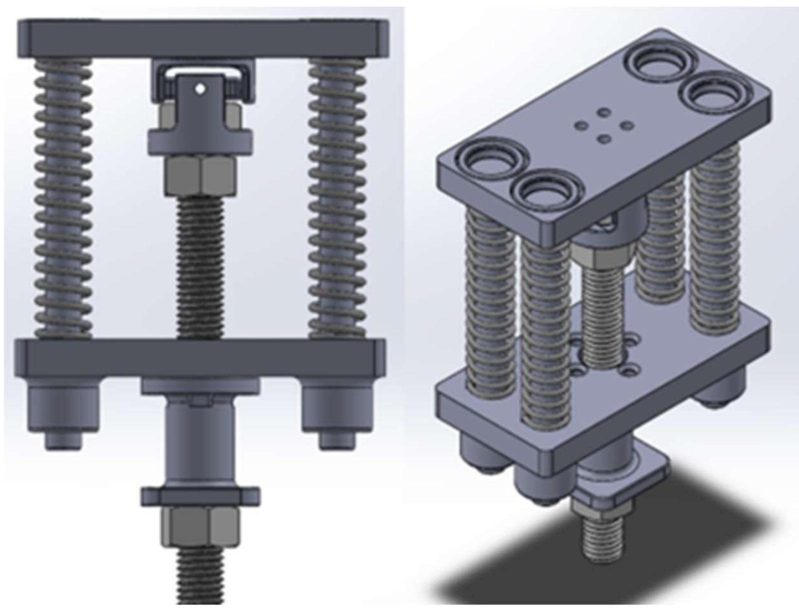

Figure D: VSLS assembly for validation model

The load of the spring was calculated based on the maximum loading scenario that the heaviest user within the criteria leans on the back support. The total weight of upper body was used for the calculation, which includes a head, shoulders, a trunk, arms, and hands and is approximately 69% of the total body weight [1]. In addition, the spring should allow wide range of compression accounting the distance for adjustment and user's shift. The initial selection of the springs was 22 lbs/in (3.94 kg/cm) with 2" range of compression.

The dimension of the top and bottom plates was decided with the consideration for the comfortable contact surface and the minimal deflection due to fully compressed springs. Experimented with different sized blocks to find the suitable size for the lumbar support, the dimension of the plates was decided to be 5 x 10 cm for the validation model. The thickness of 1 cm was decided to keep lower than 2mm of the maximum deflection of the plates with the assumption that the plates are isotropic. The reason for the tight limit for the design is to avoid unexpectedly large deformation due to 3d printing the plates.

Figure E: Validating and identifying for VSLS design and its orientation

Several trials were performed to prove the VSLS concept and to collect the data for further iterations of the VSLS design, with the validation fixture mimicking back support of chair. It was validated that the VSLS design provides the adjustability to fit personal comfort level, but the initial selection for springs was too stiff to provide comfortable feeling to users. The initial assumption of 69 % of body weight did not take the consideration of muscular involvement to sit upright. Therefore, the ratio of body weight acting against VSLS modules was updated from the data collected during the validation: the average spring compression at the posture that users feel comfortable and the other at the posture that user forced to lean against VSLS. The updated body weight ratio was ~20 % at the comfortable posture and ~40 % at the forced-to-lean posture.

The spring selection was updated iteratively with the loading scenario that the heaviest person in the criteria is feeling comfortable and cannot fully compress the springs. The final selection for the spring was rated 8.5 lbs/in (1.52 kg/cm) with 1.5” range of compression.

The orientation and the dimension of the VSLS was decided after the validations. Tested with multiple VSLS with various orientation, one larger module for lumbar region and two smaller modules to support midback were to be used to provide the optimal comfort level. It is agreed that the larger contacting surface provides more comfort to the user, so the size of the plate was decided to be 7.6 x 18 cm for the prototype. The plates of VSLS for mid back was decided to be 7.6 x 7.6 cm after experimenting with different sized blocks.

The torque required to compress the spring was calculated conservatively. With ½” UNC threaded rod and 20 % lead screw efficiency, the minimum torque obtained was 1.93 lbs-in. The motor was selected to fulfill the torque requirement.

3.1.1.2 VSLS-to-Frame Subassembly

The subassembly connecting VSLS to frame is consisted of three major components: Y mount, bar mount and bars to hold VSLS. VSLS is mounted on the two aluminum bars by fitting the cut-out at the edge of bottom plate in between the two aluminum bars. The bar mount is attached to Y mount with a friction material at the mating point and connected by a 3/8" bolts. Similar to the bar mount, Y mount is connected to the frame with a friction material in between. The position and tilt of VSLS can be locked in place by tightening the knobs.

In designing the subassembly, 30 % of body weight of 100 kg person was used in stress analysis as a pragmatic maximum loading scenario. In actual usage of the chair, it is unusual that people 'forces' to lean against the back support of the chair. Therefore, it is believed to be safe to use 30 % instead of the ratio at forced leaning (40 %) to reduce the printing time of each parts. In addition, large safety factor was applied to each part to avoid potential failure from this decision.

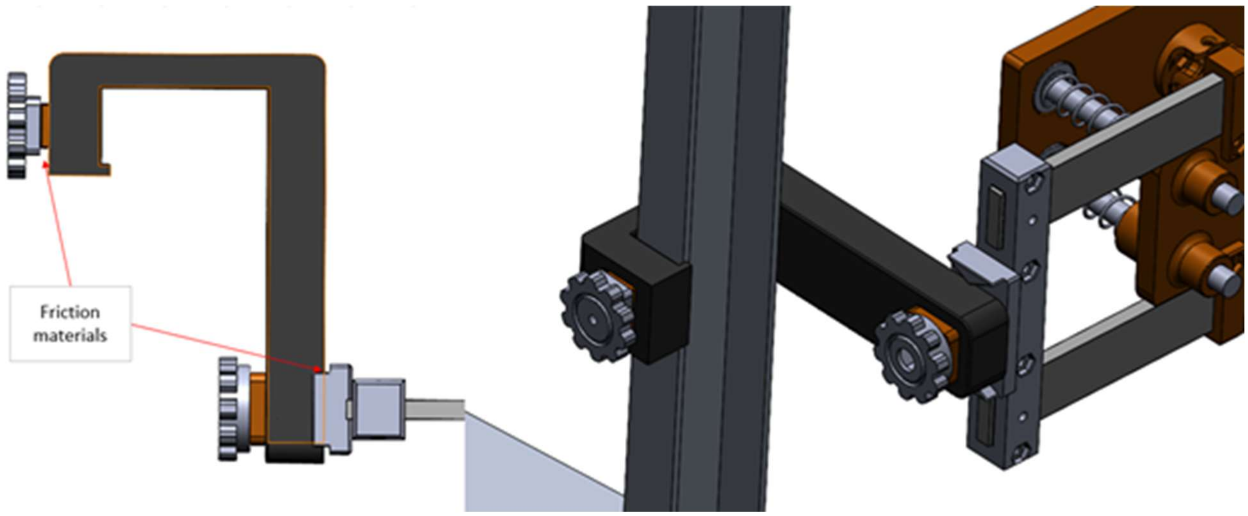

Figure F: VSLS-to-Frame subassembly (left) and how it is mounted to frame (right)

Y mount was designed to hold the frame without interfering the joint support that prevents frame from bending significantly. To allow the wide range to cover lumbar region, C-shaped hook with a tight fit to the frame was selected. The stress calculation was performed under simplified failure scenario that pragmatic maximum loading is applied vertically toward the opening and endures the tear-out failure. The thickness of the Y mount was iterated to have higher safety factor than 4 to compensate the simplicity of the loading scenario and to prevent unexpected failure of 3d printed parts.

Bar mount was designed to hold the bars and allow the tilt of VSLS. The stress calculation for bar mount was also performed to avoid tear-out failure in a loading scenario that the mount holds the shear force and bending moment from the pragmatic maximum loading applied to the center of the bar. The dimension for the bar mount was iterated to have higher safety factor than 2 to prevent any unexpected failure of the 3d printed parts.

The bars were intended to hold VSLS modules and keep the even spacing between the frames. The material selection and the sizing of the bars were focused to have minimum fabrication and endures the stress caused by maximum loading scenario. ¼” x 1” x 12” aluminum 6061 bar was selected because it does not yield in the pragmatic maximum loading and was available in the engineering machine shop as raw material without the need of further fabrication.

3.2.2 Electrical

The electrical hardware needed to actuate the motion of the VSLS was determined to have 4 major components which can been seen in figure 7. The electrical components used are the controller, power supply, motor driver and motor.

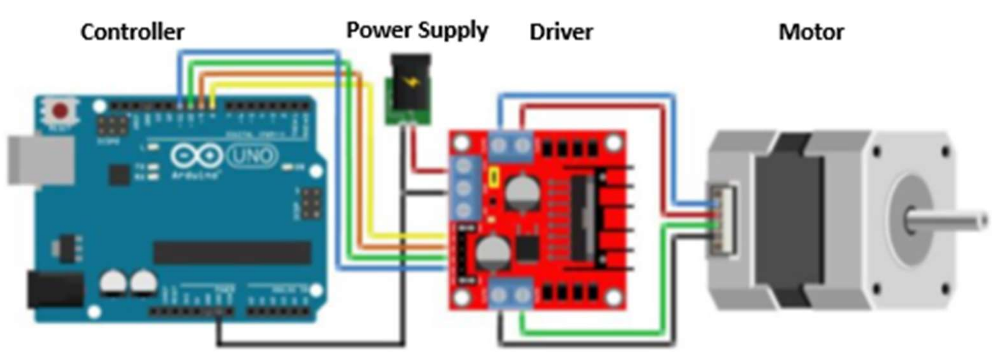

Figure G: Schematic of L298N Driver and Stepper Motor [2]

The controller we used is Arduino Mega2560 microcontroller It is inexpensive and is open sourced. The Arduino is used to control the motor, done VIA USB. It runs on 5V input and used to communicate to other hardware through electrical signals [3].

For the power supply we used an adapter which converts AC to DC from 120V-3.5A to 12V-4A. This is used to supply the motor and other electrical components [3].

The motor driver we selected is the L298N driver which can hand up to 4 amps of current [4]. We selected this driver after running a series of test at max loading condition. The test was ran using a multimeter to test current drawn at max load and found that it draws below 3.4-3.8A.

The motor we selected is the NEMA17, which is a 12V-1.2 DC 4 phase stepper motor [5]. This motor was selected after calculating the torque required to fasten driven bolt at the maximum loading condition (see appendix). The torque required at maximum load is 0.2147 Nm, and the NEMA17 motor provided a Unipolar holding torque of 0.627 Nm [5].

3.2.3 Software

The software used in project Cathedra has 4 major components shown in figure 8. The software components were: COM connect, Arduino programming, development of a graphical user interface, and data storage.

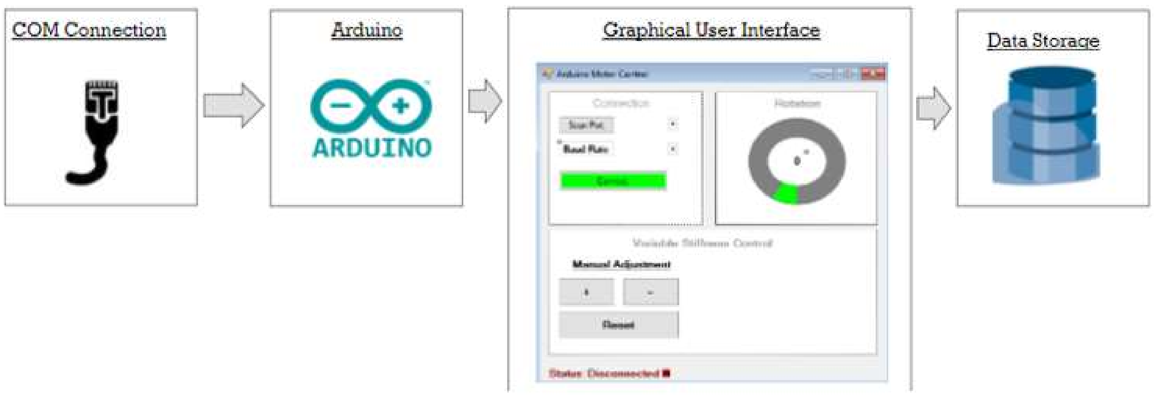

Figure H: Schematic of Software Development

Firstly, we have the COM connect. We communicated to the Arduino VIA USB wired port. This allows for Arduino to move according to user input directly. We investigated using Bluetooth and other wireless solutions, they were viable, but we decided to go with a wired connection for the scope of the project.

Next using the Arduino IDE (Integrate Development Environment), we built code that would expect user input in the serial monitor. The Arduino waits for user input, and once it receives an input it will go through a series of if statements or cases. Once an input is received the motor will rotate 180 degrees in either direction depending on the input. The user will not be inputting data directly into the Arduino IDE, but rather they do so through the DUI
The graphical user interface was designed using Visual Studio IDE and will communicate to the Arduino board directly.

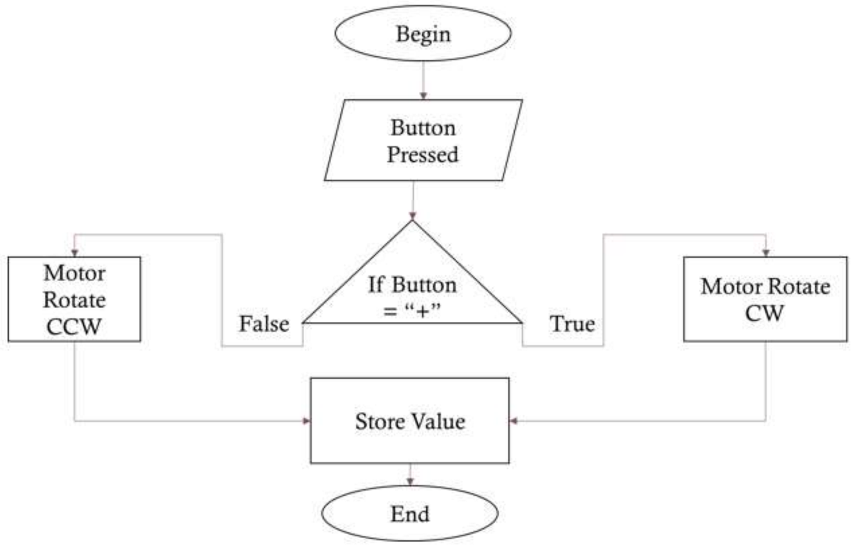

Figure I: Flowchart of the Simplified Pseudocode

The GUI was design to be a desktop application and is seen in figure 9. This GUI is design more for the group of Project Cathedra to be able to easily run tests. The top left depicts selection which will allow the user to establish a connection to Arduino. This connection is used along with the push buttons in the button section in figure 10 denoted by the "+" or "-" for adjustment of the VSLS. This is done by writing to the Serial monitor in the Arduino. The top right shows how far the motor has moved and keeps track of motor position or VSLS position.

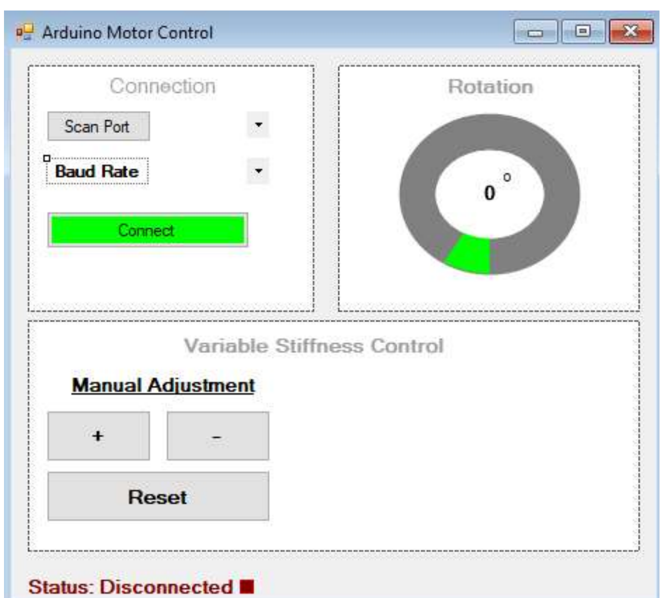

Figure J: Motor control GUI

The program is also set to keep a detailed log of the motion for each individual user. This data is initially stored in an array after 5 minutes of no changes in position, and after 8 hours it is stored in a .Text file. This text file is used for long term storage of user data.

This text file can be used to develop a database of user data. Once the database has been developed for individual user It will be sorted and user preferences will be found.

4.0 Prototype Fabrication and Assembly

The beginning of the ME 482 term until the midterm review was spent on fabrication, refinement, and validation of the VSLS module. Due to COVID-19 lockdown in January of 2021, the student machine shop on campus was inaccessible. The lockdown had also presented challenges in acquiring materials since many stores had to obey lockdown procedures. Thus, most of the VSLS components were 3D printed using our team's personal 3D printer while only a few were fabricated by machine shop personnel. Fabrication methods were determined by conducting a make or buy analysis to compare lead times, costs, and quality.

The final design phase was to prototype a chair with a frame that can house the VSLS with adjustability in the x-y direction, incorporate stepper motor actuated stiffness in the VSLS, and attachment of arm rests. Detailed design and fabrication process of the chair will be discussed in the following section.

4.1 Housing and Framing Design

A new frame fixture needed to be constructed to support and position the VSLS at the desired back rest location. Modification of an existing chair back did not permit the high variability of adjustment we wanted to demonstrate with our concept of the ergonomic chair. Constructing a new frame will also permit height adjustment in the arm rest as well. Key engineering specifications is to be light enough to be handled safely, dimensioned to fit most body sizes, and is structurally sound to support 100kg body mass. Dimensions of the chair are based off a chair making handbook [6].

Materials

- Aluminum 6061
    - 2x1x Channel
    - 1/8-inch sheet metal
- PLA Plastic
- Steel fasteners

Primary materials used for the frame design include aluminum 6061, PLA plastic, and steel bolts and fasteners. The aluminum channel extrusions allow the VSLS module to be adjusted up and down along the back. Epoxy is applied to secure unnecessary slack of the chair. An existing base support of the Herman Miller Setu chair salvaged from the street side is modified to save worktime and budget.

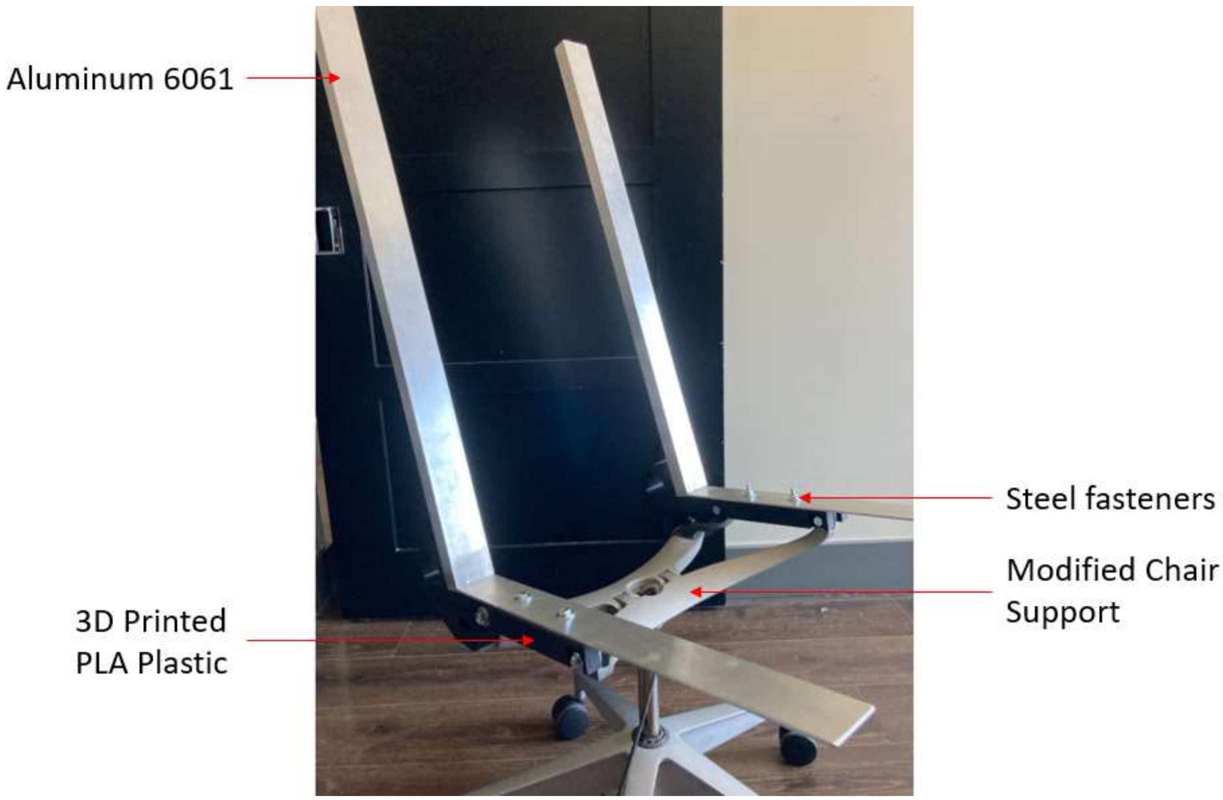

Figure K: Frame of the chair

4.1.1 Validation

Finite element analysis (FEA) was conducted using Abaqus for the aluminum frame to ensure that there was minimum deflection. A 2x1 channel was used to reduce deflection. The deflection is inversely proportional to the area moment of inertia. A 45lbf (200N) load representing the upper body mass that is 40% of a 100kg person shared between two supports was used as the loading scenario for the FEA. This resulted in a 0.2in deflection, which is desired to be under 3 inches.

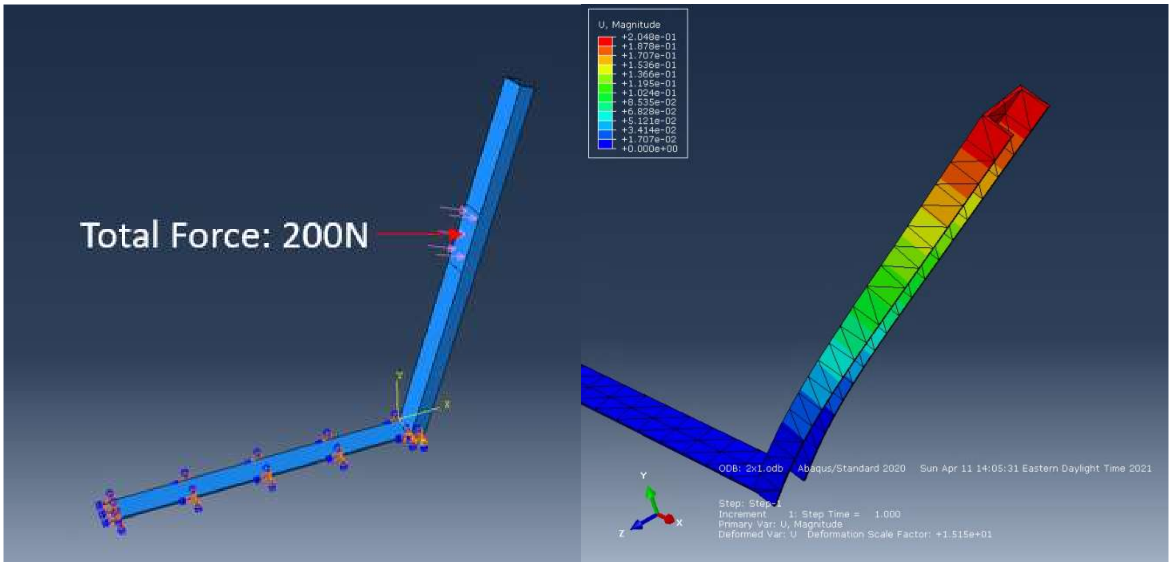

Figure L: Finite Element Model in Abaqus of the loading scenario (left) and deflection (right) in an Aluminum Channel Beam

The channel was welded to the sheet metal at 95 degrees. A critical yield location exists at the joint between the sheet metal and the channel. A joint support was 3D printed using PLA plastic and to supply support behind the channel.

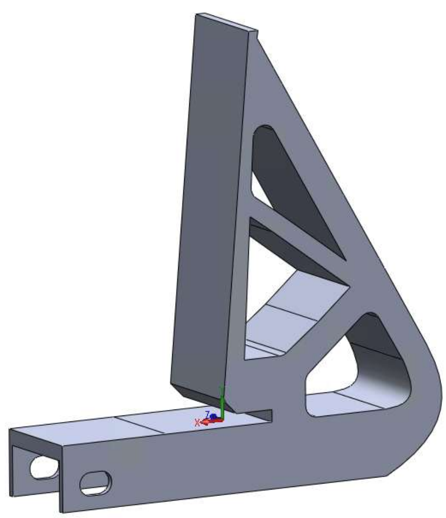
Figure M: Joint Support Model

The PLA joint support was designed using the Abaqus CAE optimization tool. A total force of 45 lbf was applied to the face that would be mated to the back of the channel. The objective function to optimize the model is to minimize strain energy, while the volume is constrained to be below 20%. The optimized Abaqus model was referenced to obtain the angles and dimensions for the joint support.

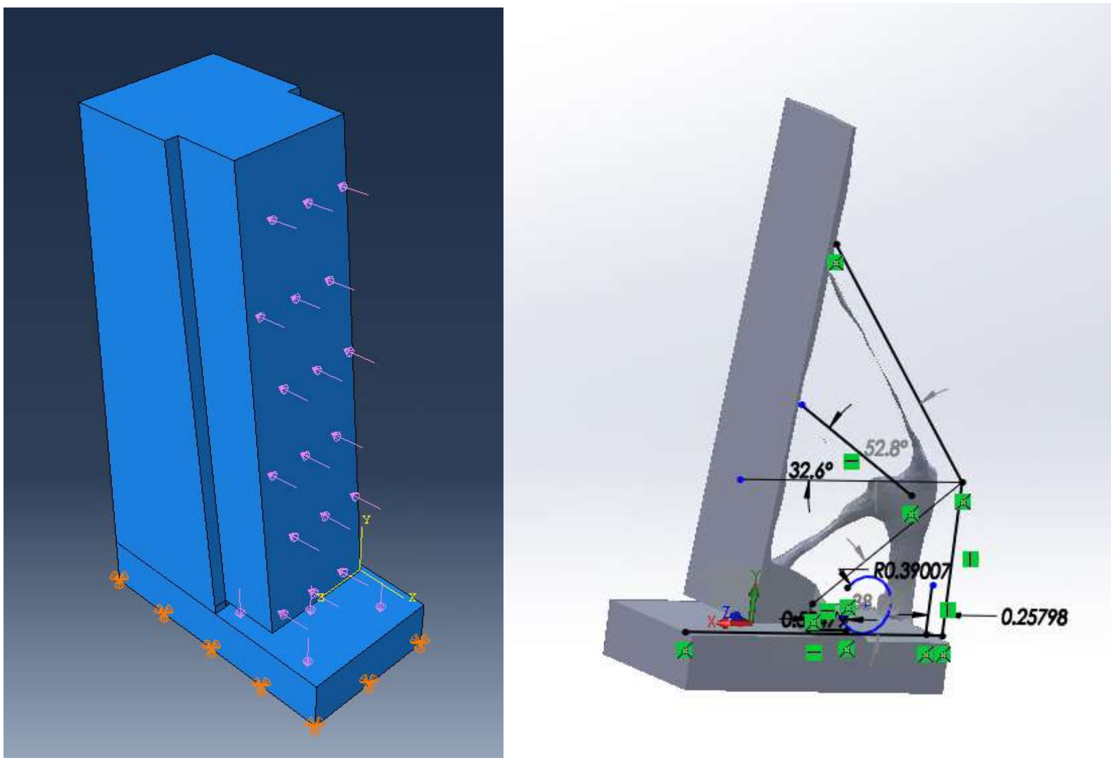

Figure N: Pre-optimized model with loading parameters (left) and optimized model (right)

Miscellaneous parts were 3D printed to be fitted to the base support in an iterative process. Initial iterations were printed with less than 15% in fill to conserve material. Figure 13 is the fastened to the base of the chair and holds the aluminum supports. Figure 14 is the rear piece attached to the base of the chair to support any vertical loading. Figure 15 is the design of the arm rest. The arm rest was designed to endure a 5kg distributive load. The mass of the arms were obtained using Dempster's anthropometric table of a 100 kg male [1].

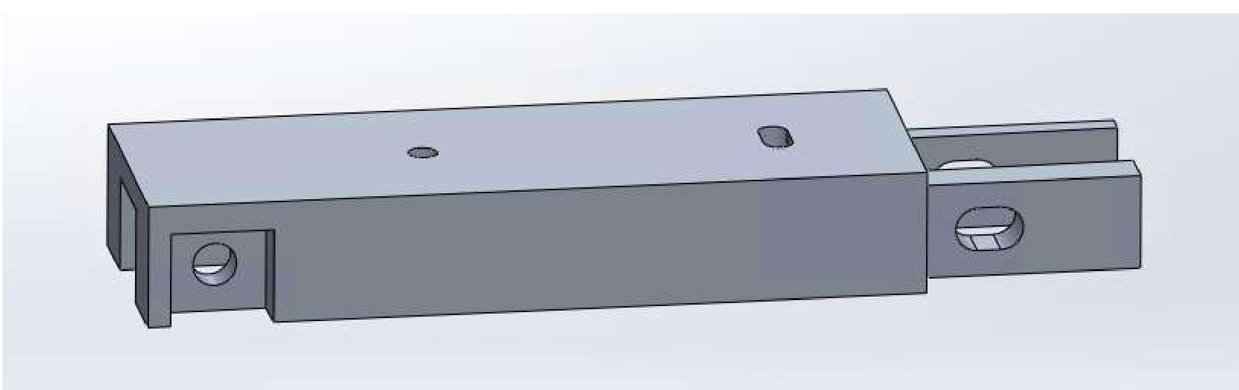

Figure O: CAD model of a chair base attachment

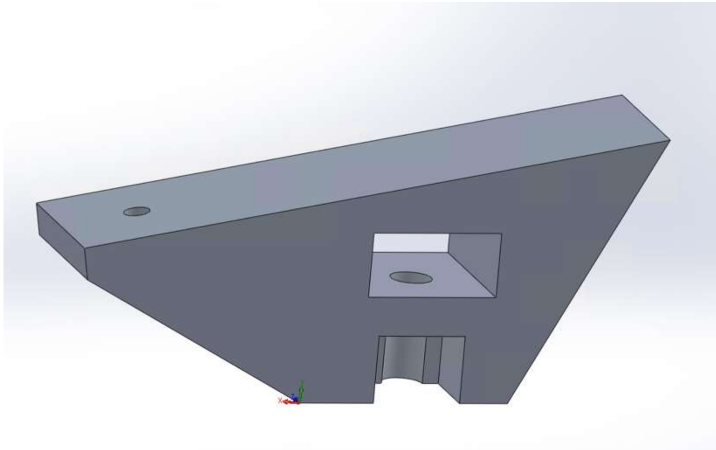

Figure P: CAD model of rear chair attachment mount

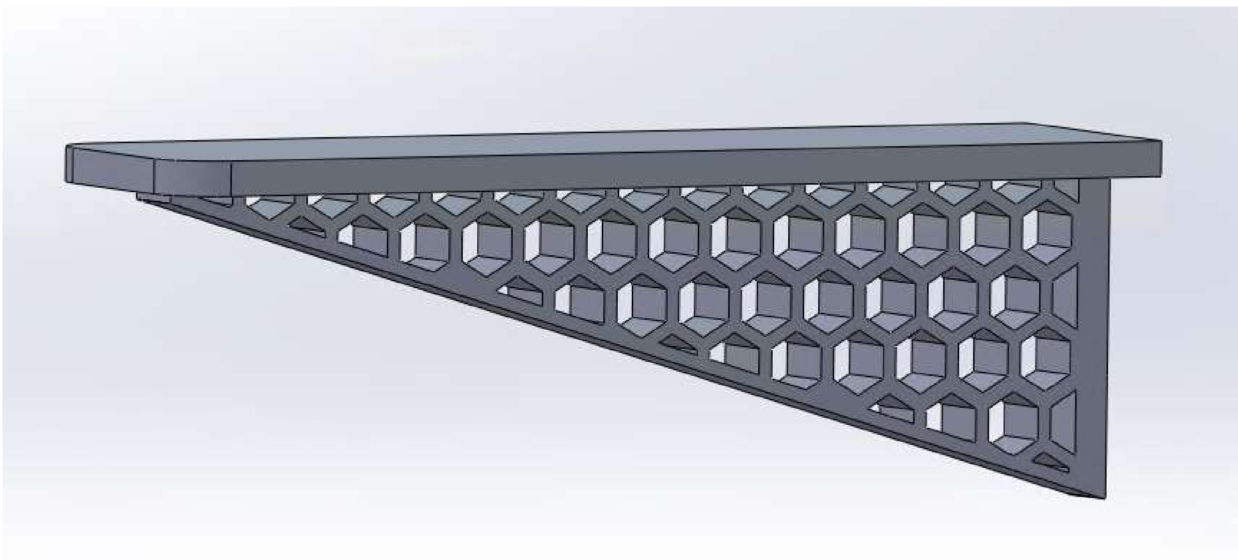

Figure Q: CAD model of the Arm rest design

4.2 VSLS Module

4.2.1 Top and bottom plates

The top plate provides the user the large contact surface with 1” thick sponge padding for user’s comfort. The bottom plates functions as a foundation of the module and is attached to the subassembly. Due to the plates are the primary contact point between the user and the chair, both plates were printed with 80 % infill density to behave like a solid object when they deflect. The holes in the bottom plates were drilled and lubricated to smooth the uneven surface inside the holes to allow the guide rods to slide freely.

4.2.2 Swivel joints and guide rods

The entire swivel joints are 3d printed as shown in the figure 18. The swivel was printed in-place with its shell and fully trapped inside after printing. The swivel joints are assembled inside the holes of the top plate by instant glue. Guide rods are sanded with fine sandpaper to smooth the surface then glued to the hole in the swivel. Since the guide rods slide freely through the hole in the bottom plate and do not take any axial load, using instant glue to fix the guide rods to the swivels was enough to hold two parts together.

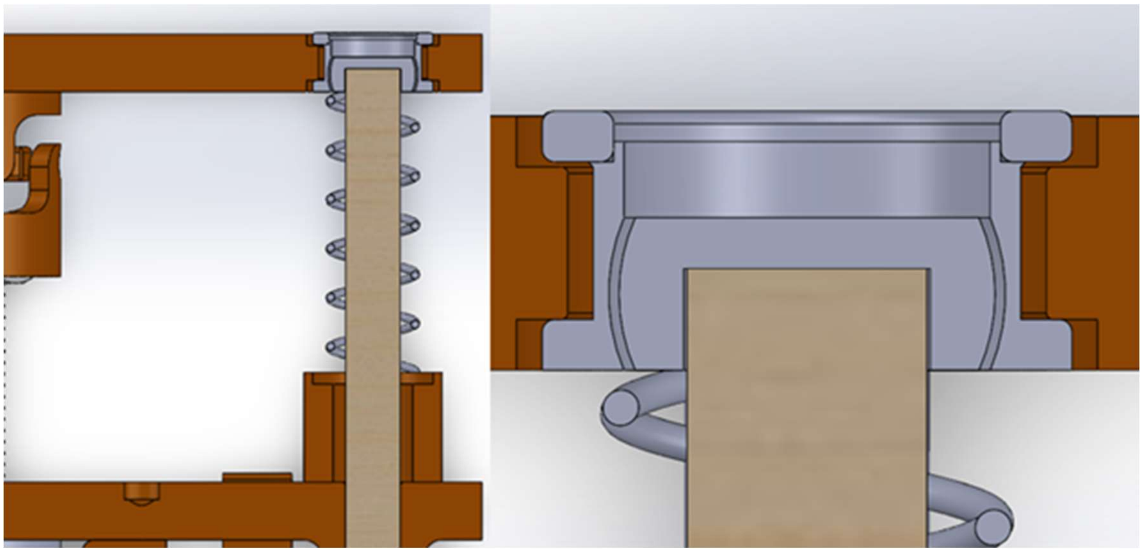

Figure R: Cross-sectional view of swivel joint, top plate and guide rods

4.2.3 Universal joint and threaded rod

Universal joint parts were printed with 20 % infill density but 100 % near the holes for the pins because the printed universal joint is prone to layer separation at the pin. Four 1/8” nuts were embedded at the center cross and the universal joints are assembled with 1/8” bolts as the pin. To fix a threaded rod, the nut was heated up and embedded into the yoke that faces bottom plate. Permanent Threadlocker was used to hold the threaded rod to the universal joint.

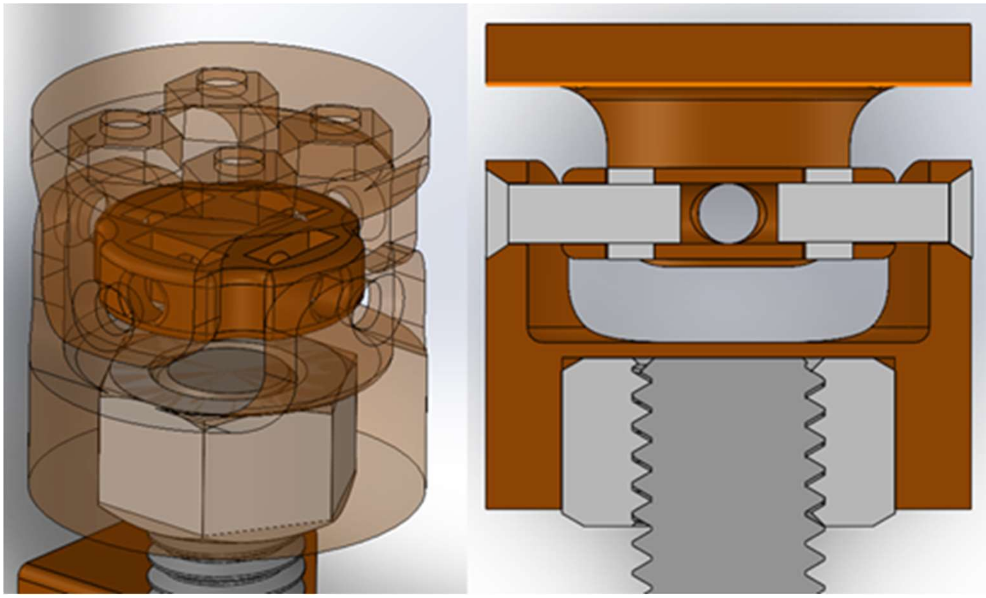

Figure S: Detailed view of universal joint assembly

4.2.4 Motor shaft coupling, donut and motor mount

The VSLS module relies on the revolution of the nut to adjust the lateral displacement of the spring leading to a firmer or softer lumbar support. In order to control this revolution, the generic nut was replaced by a machined flange nut and a shaft coupling was purchased to provide an interface for connecting the flange nut to the motor. A drawing of the flange nut is shown in figure A1 of appendix A while the motor coupling can be seen in figure 20.

Figure T: Motor coupling

However, it turned out that the diameter of the flange nut was too large to allow a bolted connection from the motor shaft coupling to the flange nut. The design options available were either a redesign of the motor coupling or the design of an attachment to align the motor coupling to the flange nut. This resulted in the donut attachment design intended to extend the diameter of the motor coupling and allow a straight connection from the donut to the flange nut. This was decided as the best approach because redesigning the motor shaft coupling could create tolerance errors and affect the performance of the motor. The donut to flange nut connection can be seen in the figure 21.

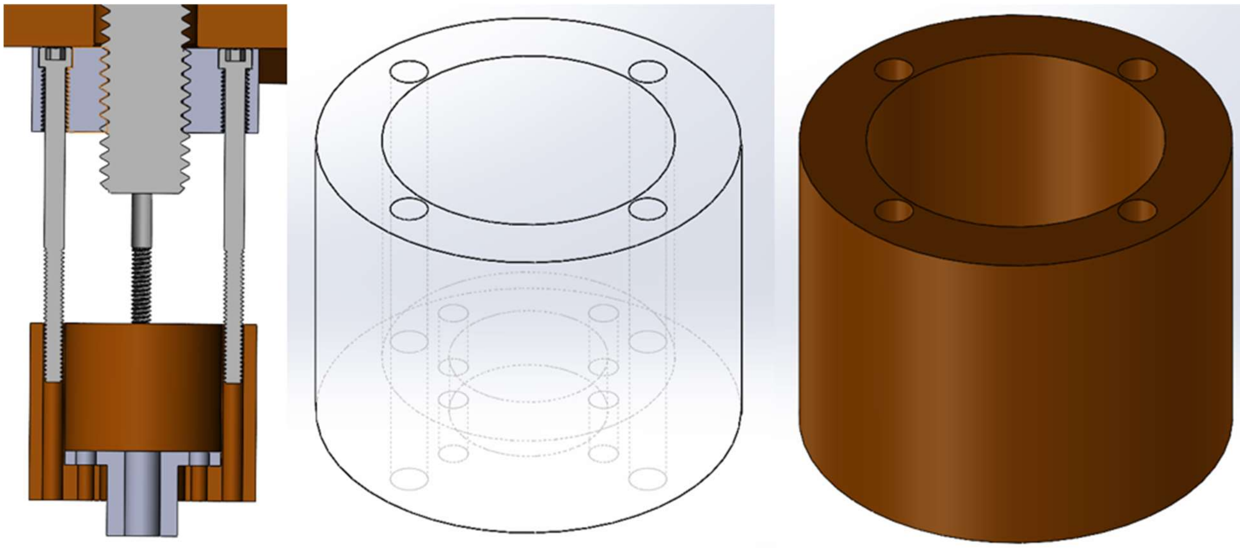

Figure U: Motor connection assembly (left) and coupling donut (right)

The four M4 bolts fixed to the flange nut are inserted into through holes of the donut. The freedom to move along the treaded rod allows the movement caused by user leaning on the VSLS. The through holes were drilled to smooth the path of the M4 bolts. Motor mounts shown in the figure 22 are fixed to the motor and bottom plate and keeps the distance between them. The distance is decided to cover full range of compression of the springs.

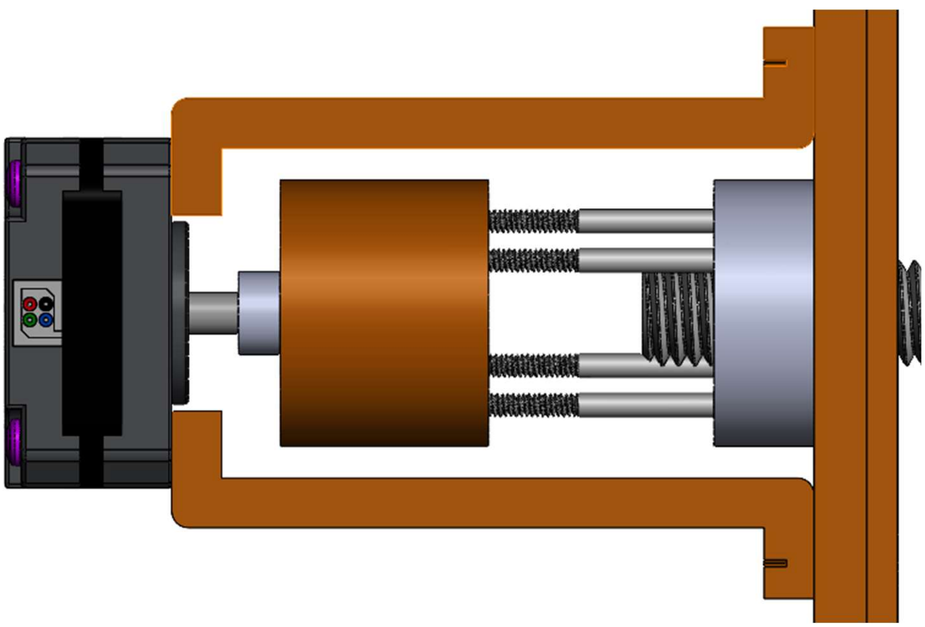

Figure V: Motor mount assembly attached to bottom plate

4.3 VSLS-to-Frame Subassembly

4.3.1 Y mount

Y mounts were printed with 30 % infill density for fast printing because the safety factor for tear out failure in the design process was set high to compensate the low infill. Each Y mount has two locking mechanisms using neoprene sheet (blue) as a friction material shown in the figure 23. Neoprene sheet was selected due to its high friction coefficient, which allows smaller surface for friction. The head of the bolt is fixed to the friction block but free to rotate by applying Threadlocker to the specified location. The second nut from the left is fully constrained the Y mount, so the neoprene sheet is compressed against the frame by tightening the knob. By loosening the knob, the Y mount is unlocked and the height of VSLS becomes adjustable.

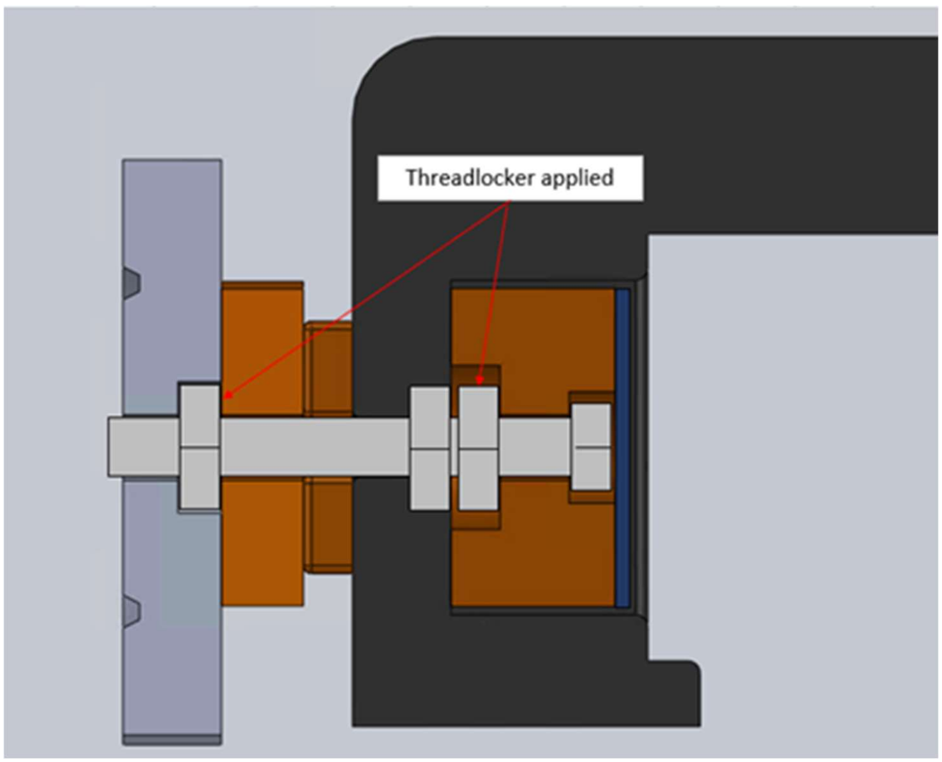

Figure W: Cross-sectional view of locking mechanism to hold Y mount to the frame

4.3.2 Bar Mount Assembly

Bar mounts shown in figure 24 were also printed with 30 % infill density for fast printing. Bar mounts is consisted of two main parts: the bar mount that holds the aluminum bars and the block to set the limit for tilt angle and to provide surface that the friction material is compressed against. The parts were printed separately to reduce the support material required and to achieve accurate dimensions because the dimensions perpendicular to layers tends to be inaccurate due to large layer height. 3/8" hex bolt fixed to the bar mount goes through the bar mount block, friction block, Y mount and the knob in the order. By tightening the knob, the neoprene sheet is compressed and locks the tilt angle.

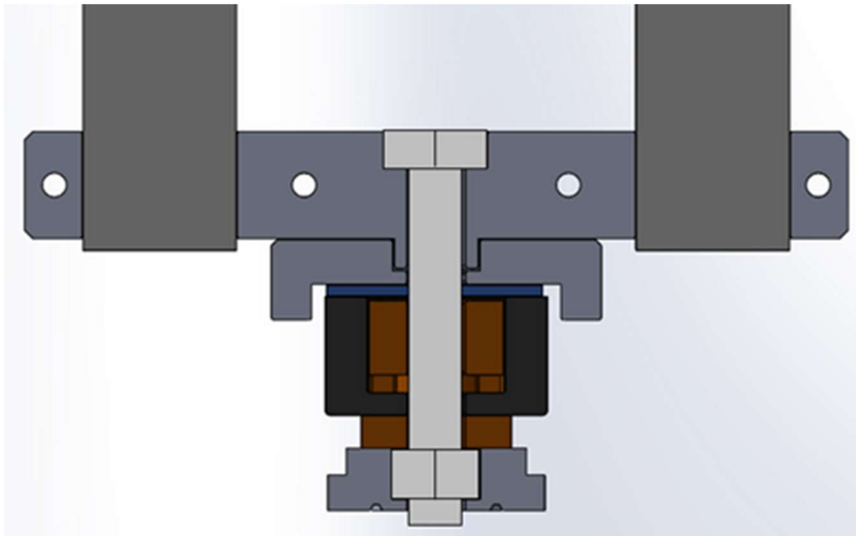

Figure X: Cross-sectional view of locking mechanism for tilt angle of VSLS

4.4 Final Prototype Assembly

The final prototype assembly started with joining welded aluminum frame and joint support by applying epoxy at the mating surface. The epoxy was applied to prevent the joint support to not slide out from the channel of the frame because joint support slid out when installed without any adhesive and the frame started to be bent. With the aluminum frames assembled to the base of chair, the pre-assembled VSLS-to-frame subassembly is inserted from the top of the channel. The structural bare bone chair is as shown in the figure 25.

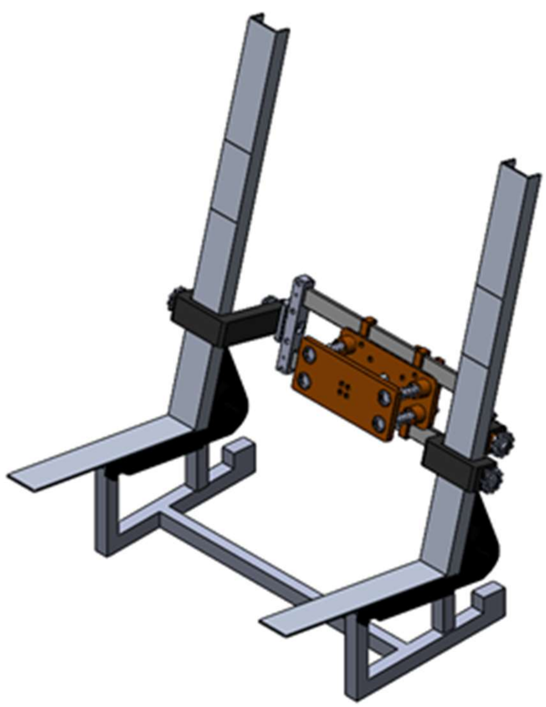

Figure Y: CAD model for bare bone prototype chair assembly

The initial approach for the seat was to put layers of mesh fabrics with some tension, similar to Herman Miller chairs. However, it was not possible to find any vendor who sells the highly stretchable mesh fabric for small quantity, and the fabric obtained from local fabric store was pragmatically impossible to install on the chair without any damage. It was expected to tear out with few repetitive trials, so the alternative option to use sponge cushion for the seat was decided. Three 1"x1/4" aluminum bars were placed on top of the aluminum frame and 3" thick cushion was placed on it. The cushion was covered and stitched by a grey fabric for aesthetics. 1" thick cushion was used for VSLS contacting surface. The prototype of the chair design with cushions are shown in figure 26.

Figure Z: Fully built prototype of the chair

5.0 Project Management

5.1 Major Milestones

5.1.1 Research and Development

This stage of the design focused on in-depth analysis of existing ergonomic chairs. This analysis involved identifying key features in typical ergonomic chairs, difference in these features across top brands and gaining a good understanding of what makes a chair "ergonomic". Findings from this research exposed which ergonomic features to prioritize and were used to develop our design criteria and specifications.

Further research required to develop design concepts was also conducted. This led to subsequent revisions of our project scope causing delays in project progress. Conducted research identified the lower back region as a focus area for the project. The resulting scope revision now prioritizes lumbar support design as it has been identified as the most important ergonomic feature. Conducting interviews with ergonomic specialists as well as people affected by lower back pain uncovered limitations in current ergonomic chair designs. Overall, this research resulted in the development of a viable, less expensive alternative design that meets our revised scope. Resources available to us at this stage include the internet, the biotechnology lab, a kinesiology professor with extensive knowledge of ergonomic chairs and a faculty advisor who has experience with lower back injuries.

5.1.2 Design Drafting and Testing

This stage of the project was focused on designing the mechanism that will configure the back rest particularly in the lower back region to suit the user's ergonomic needs. The goal of this stage was to determine how the mechanism should be designed to maximize user comfort. This was approached by observing user comfort with varying adjustable mechanism features. Important factors that were considered include range of motion required to meet specified ergonomic needs, force/pressure distribution and calculation and selection of material to maintain a reasonably portable chair weight while supporting user's weight. Integration of mechanical subsystem designs was an important consideration in this stage. Thus, upon completion of research and design development, an initial scaled down prototype was built as proof of concept and further testing was carried out to determine important design parameters such as spring stiffness, VSLS module positioning and dimensions. This aided in evaluating design feasibility, mechanical properties, bill of materials and assembly options.

5.1.3 Final Prototype Fabrication

At this stage, the electrical and mechanical subsystems of the design were combined to build a prototype that meets the project needs. The testing of the validation model in the design stage determined mechanical specifications and required tasks and components for completion of the final prototype. For ease of prototyping task assignments, the project was broken into 3 subsystems: VSLS module, Housing and Chair body subsystems. Each subsystem was assigned a team member responsible for prototyping tasks and a prototyping lead was assigned to coordinate prototyping efforts for successful integration of subsystems. This breakdown into subsystems allowed team members to contribute equally to the completion of the final prototype. Critical tasks involved here include motor coupling design for VSLS manipulation, design of mounts and fixtures for chair support and Arduino programming to record and respond to users' preferences. Finally, the project scope was validated by verifying the project requirements, specifications and deliverables. Simulations were conducted to ensure the sensors and mechanism worked in harmony to achieve project objective. The work breakdown structure can be found in figureB1 of appendix B.

5.2 Compliance

5.2.1 Safety

Safety compliance during execution of this project was dictated by organizational process assets such as Policy 34 of the University's policies and procedures as well as external enterprise factors particularly government regulations surrounding COVID-19 restrictions. Policy 34 states that "students will take responsibility for their own safety and actions while taking into consideration the impact on others around themselves. Students were expected to be proactive about reporting situations that impact health and safety on university property." [7] This policy was particularly important in light of local regulations due to the pandemic. Team members took extra precautions to stay healthy in accordance with the safety rules. In person team meetings were regulated and only held when necessary. Additional safety measures implemented in our design include the removal of potential pinch points and fail-safe mechanisms to protect the user in the case of an electrical failure.

5.2.2 Sustainability

Sustainability consideration was an important factor for the success of this project. Environmental impact was reduced by using recycled or disposed material for construction of the prototype thereby bypassing energy wasted during primary production. The design was also further optimized to reduce quantity of material required. Energy usage was controlled by selecting lighter materials where possible thus reducing the load on the motors.

5.2.3 Professional Ethics

The team stayed committed to the goal of developing the best ergonomic product to meet its intended clients' needs. Additionally, the team's actions towards achieving this goal were guided by the Professional Engineers Ontario's acts, regulations and by-laws [8]. The team also read and understood Policy 71 of the University of Waterloo, which highlights that students are responsible for demonstrating honest and ethical behavior in their academic work [9].

Each member is held to the highest standards of honesty and integrity. All errors in judgement were acknowledged and only designs that conform to all applicable engineering standards were signed off on.

5.3 Budget

5.3.1 Cost Management

The University of Waterloo provided a total of $600 based on the individual allocation of $150 per student for two terms. This $600 was the budget at completion for this project and represents our cost baseline. Additionally, team members agreed to contribute a total of $200 from personal funds as a contingency reserve. Cost control was important here due to the agile nature of the project and nature of risks encountered. By estimating future budget allocations, reserve analysis was conducted to monitor the status of the contingency reserves to determine if these reserves were still needed. The available budget can be seen in table B3 of the appendix. A breakdown of project expenses can be seen in table B4. Since the final prototype is completed, the incurred expenses have been documented as fixed costs. The team practiced cost control during the term by using recycled materials from the machine shop, returning any unused purchases, and renting supplies instead of purchasing where possible. Furthermore, a make or buy analysis was conducted for components to support cost savings. The team's financial goal was to minimize cost variance at completion, as $600 should be sufficient to assemble a working prototype of the design. The resulting total project expenses fell below the cost baseline.

5.3.2 Schedule Management

The timeline for this project focused mainly on the research and design implementation phases in the fall term and prototype fabrication and validation phases in the winter term. The new findings and design iterations present in initial phases led to the agile nature of the schedule model for this project. The rolling wave planning technique was used in the development of the schedule model to accommodate for varying team member class schedules and resource availability. This required constant monitoring and update of the Gantt chart to reflect changes to the project timeline. However, upon commencement of the prototyping phase, most tasks were completed in parallel allowing for better duration estimates to be made for tasks. Task precedence was considered during prototype build and more team resources were allocated to preceding tasks to avoid delays in the timeline. This scheduling technique made sure team members had the support they needed to complete tasks ahead of deadline.

The team has also decided to allocate time during the non-academic term to work on the design project to meet the client's needs. As seen in figure B3 of the appendix, a scheduled Gantt chart has been organized to ensure that deliverables are monitored daily and weekly. Based on the course loading per each student, it was decided that each team member would contribute approximately 10 hours per week toward the design project. Over the 8-month academic term, this allocates to an estimated 182 hours of individual work hours aside from reviews, examinations, and weekly meetings. As expected, there were variances in the work time budgeted versus work time expended for each team member. This could be attributed to the skill and knowledge level of individual members in completing scheduled tasks. Resource allocation was adjusted to accommodate this.

5.4 Risk Assessment and Mitigation Plan

Some known potential risks that hindered the progress of this project were identified and shown in table B2 of appendix B. It was essential to have mitigation plans for each of these risks so that the project could move forward regardless of circumstances.

One of the risks identified was shortage of required supplies and resources. Due to COVID-19 effects and regulations, a lot of companies had reduced operating hours or had gone out of business completely. Resources at risk include but were not limited to public meeting space, electrical supplies and tool and equipment rentals from the University. This could severely impede the manufacturing and prototyping stage of this project. Thus, to minimize this risk, multiple vendors and resources were confirmed for majority of design components. Also, prototyping space was moved from design machine shop to a team member's residence.

Another major risk in this project was scope creep. The complex nature of our identified problem allowed room for the continuous improvement as no perfect solution currently exists. This made the team liable to time wastage in search of better solution which would likely go beyond the defined scope of our project. This was also due to the personal and professional ties team members have with this project. This risk was mitigated by adhering strictly to outlined engineering specifications and monitoring task progress closely. Additionally, a design freeze was implemented after which no alternative design ideas were to be considered. Deliverables were also verified against the scope statement to ensure alignment.

During the prototyping stage of this project, there was a potential risk of not meeting design specifications due to poor quality of assembled prototype or scarcity of validation tools required. This was typically either linked to limited electrical design knowledge for motor programming or lack of clear understanding of design requirements. To address this, subject matter experts were consulted regularly through the course of the project and a working prototype was built and continuously validated ahead of schedule to accommodate any delays in obtaining validation tools for final prototype.

Finally, a common risk with most projects is the inability to meet projected deadlines particularly given the unfortunate conditions under which this project was managed. Team members were required to work on tight schedules to ensure all important milestone deadlines were met. The team's involvement in biotech competitions stretched our resources even further. Keeping this in mind, this risk was mitigated by prioritizing the most important deliverables and using schedule compression techniques to allocate available resources accordingly.

6.0 Reflection

Need Identification, research, Solutions and Iterations, Pivots

The need identification was an important and essential first step towards engineering design. The generation and refinement of the need identification can take a lot of time and must not be rushed. In the beginning, the team brainstormed many need statements and through many iterations of reduction, the final need statement was established.

Research was a tedious process, but crucial to guide the solution ideation straight. We began looking at what currently existed on the market that aided with back pain during prolonged sitting. We found that the ergonomic chair market was heavily saturated. However, the feedback of people who suffer from back pain complains about the ineffectiveness of the products. Sufferers had tried multiple products and are always searching for something better. Technical research about back health and IVD helped better understand the mechanism for pain and injury. This way our product will not harm the user. The best considerations came from suggestions of people who experience low back pain. Multiple people who experience low back pain expressed similar design considerations.

A foundational need statement backed with technical research was essential to boil down the brainstorming of ideas. The best ideas encapsulated the essence of the need statement, also with consideration to effectiveness, market need, and feasibility. It is easy to brainstorm ideas that were theoretically ideal. In the initial and midterm design review of ME 481, the hypothetical solution seemed effective. The hands-on experience of building the first validation model really given us a pragmatic perspective on our solution. We realized that our initial solution was a cool showcase of engineering with many moving parts, but it was not an effective solution. With the results of the first validation model, we decided to go back to the drawing board and pivot our solution. The findings of validation model refined our area of focus to the lumbar region. We were thrilled about what we had learned from initial validation model but was frustrated we had to reapproach our design.

7.0 Recommendations

The structural stability of the chair can be improved by reducing the number of parts and limiting the range of motion. Due to the limited capacity of the 3D printer, the maximum size of a printed part is constrained to be printed in a 20cm-by-20cm space. Parts larger than the 3D printing space had to be split into smaller parts and fastened together. Minor tolerance inaccuracies and limited fastening locations resulted in gaps. The chair felt unstable when accepting the load and during postural shifts. After the load takes out the slack, the chair felt more structurally sound. A recommendation for chair design is to minimize joints and fasteners. The commercial office chairs on the market are usually made using injection moulding, such that the frame is one single piece without unnecessary fasteners.

The strength and accuracy of most 3d printed parts was sacrificed to meet the schedule by lowering their infill density and increasing layer height. Even though large safety factor was applied to compensate the strength loss from the infill density, there were unexpected failures of the parts because the stress calculations were performed with the assumption that the parts are isotropic solids. In addition, the parts were prone to layer separation at the unexpected three-dimensional loading cases because of the large layer height for fast printing. With more time allowed, the structural integrity of the full assembly can be improved by increasing the infill density and lowering the layer height.

8.0 Conclusion

Increasing number of studies supports that low back pain is associated with prolonged sitting. Especially with the COVID-19 lockdown, people are indoors and sitting more than ever. Poorly designed office chairs can be detrimental to the musculoskeletal structure of your back. High end ergonomic chairs and its lumbar support is designed for the 50-percentile person, with limited adjustability of the lumbar support location. The fixed lumbar support location can be detrimental to people who suffer from low back pain. Project Cathedra is inspired by people who suffer from low back pain who cannot find an existing product that works. The location of back pain varies person to person, case by case. There lacks a device on the market that lacks adjustability of the stiffness and the location of support. This led to the design of the VSLS module that is automated to adjust the stiffness of the lumbar support with a frame design that allows the user to position it anywhere along the back rest. Subcomponents of this project include the frame, adjustable mounts, the VSLS, and the stiffness actuator. Due to the COVID-19 lockdown, the validation of low back pain reduction and comfort could not be conducted. Ergonomic design is in its infancy and this project explored a new proactive concept of ergonomics.

9.0 References

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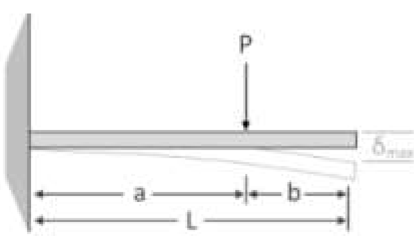
[9] "Professional Engineers Act," Professional Engineers Ontario, [Online]. Available: www.peo.on.ca/about-peo.

Appendix A: Engineering Data

Housing and Framing

Table A1: Frame Design Specification

Mass	< 22.5 kg
Seat Width	16 in
Seat Length	14 – 20 in
Back Support Height	30 in
Back Support Width (comment: constraint to existing base leg of the chair)	16 in
Angle of the Back Support to the Seat Surface	100 to 120 degrees
Back Support Loading	40 kg
Seat Loading	100 kg
Back Deflection	< 3 in



$$\delta_{max} = \frac{Pa^2(3L - a)}{6EI}$$

Equation A1: Deflection of a cantilever beam

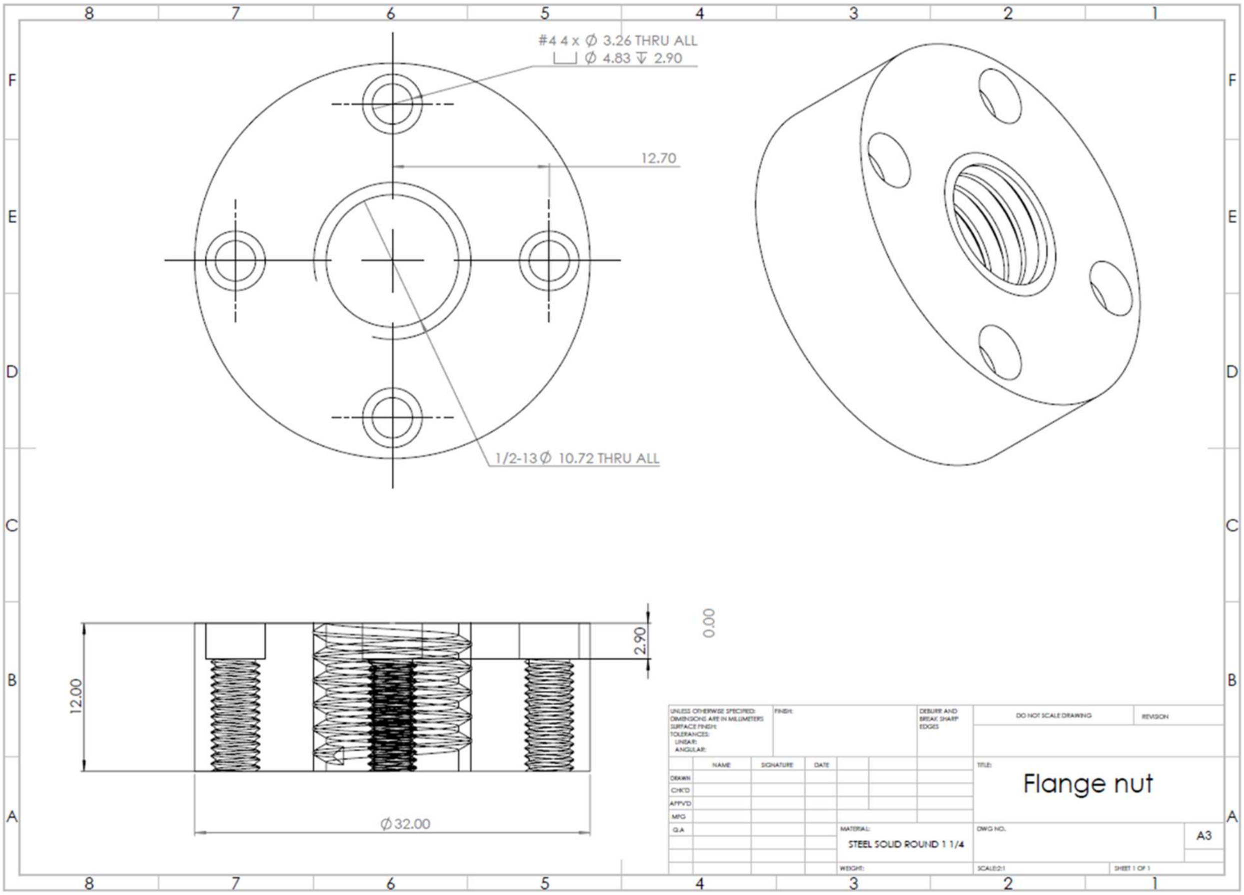


Figure A 1: Flange nut drawing

Appendix B: Project Management Data

Table B2: Team Organizational Chart

Position	**Project Manager**	**Research & Development Engineer (R&D)**	**Design Engineer**	**Software Engineer**
Main-Lead	**Gabriel**	**Hansen**	**Daejun**	**Burim**
Sub-Lead	**Hansen**	**Burim**	**Gabriel**	**Daejun**
Responsibilities	Ensure project deadlines are met	Gather fundamental research for the scope of design	Lead mech design stage	Responsible for programming of design
	Outline projects tasks and deliverables	Define engineering specifications	Responsible for 3D modelling	Troubleshoot all software bugs and issues
	Lead team meetings and create meeting agenda	Explore new principles and techniques to tackle design problems	Finite element material selection	Selecting electrical components for design
	Cost and Schedule management	Lead testing and validation of design	Responsible for manufacturing of prototype	Conduct data analysis and optimization

Table B3: Risk Register

Number	Risk Title	Risk Description	Probability of Occurrence	Severity of Impact	Mitigation Plan
1	Material Delivery	Unable to attain materials required for prototyping due to cost or availability	M	H	Confirm multiple material sources and order well ahead of time
2	Scope Creep	Risk of time wastage in search of perfect solution beyond scope	H	H	Adhere to engineering specification and implement design freeze
3	Prototype Validation	Risk of not having required personnel and equipment resources to verify design	M	M	Build a small-scale validation model early and consult faculty advisor
4	Deadlines	Risk of not meeting time constraint of project due to competition involvement	M	H	Prioritize project deadlines and allocate resources accordingly

Table B4: Team Budget

Funding Sources	Amounts
University of Waterloo	$600
Student Self-Funding (Contingency reserves)	$200
Total Available Budget	**$800**

Table B5: Cost Breakdown

Item	Expected Unit Cost (CAD)
Chair (Modifications)	$40
Motor	$25
Raw materials [wood, fabric, rubber]	$140
Springs	$60
Fasteners	$60
Arduino and electrical equipment [Breadboard, Wires, Battery, Driver]	$110
PLA plastic for 3d printing (5kg)	$140
Total	$575

Task name	Assignee	Due date
VSLS subsystem		
CAD and submit work request for chair fixture replacement	Hansen Lu	Jan 11 – 18
CAD and 3D print VSLS module components	DJ Lee	Jan 18 – 29
Purchase required parts of model assembly	burim	Feb 1 – 7
Assemble validation model and test VSLS features	Gabriel Ok...	Feb 8 – 12
Conduct engineering analysis and make final design decisions		Feb 15 – 24
CAD flange nut for attachment to motor shaft	Gabriel Ok...	Feb 25 – Mar 11
Purchase motor couplings and fasteners	Gabriel Ok...	Feb 25 – Mar 11
CAD donut and spring mechanism for motor coupling	Gabriel Ok...	Mar 11 – 25
Purchase springs with lower stiffness	DJ Lee	Feb 25 – Mar 11
Arduino programming, motor selection and electrical	burim	Feb 25 – Mar 11
Integrate automated program for easy configuration	burim	Mar 11 – 25
Add task...		
Enclosure and Mounts		
Design motor mounts and CAD assembly	Gabriel Ok...	Mar 11 – 25
Determine optimal fastening methods mounting locations	Hansen Lu	Mar 11 – 25
Design and 3D print attachments for chair frame	DJ Lee	Mar 11 – 25
Add task...		
Chair body		
Select material for back support/seat/legs 1	Hansen Lu	Feb 25 – Mar 11
Determine shape/dimensions for back support and seat 1	Hansen Lu	Feb 25 – Mar 11
Refine designs for 3D printer and purchase fasteners	DJ Lee	Mar 11 – 25
Design chair modifications	Hansen Lu	Feb 25 – Mar 11

Figure 27: work Breakdown Structure

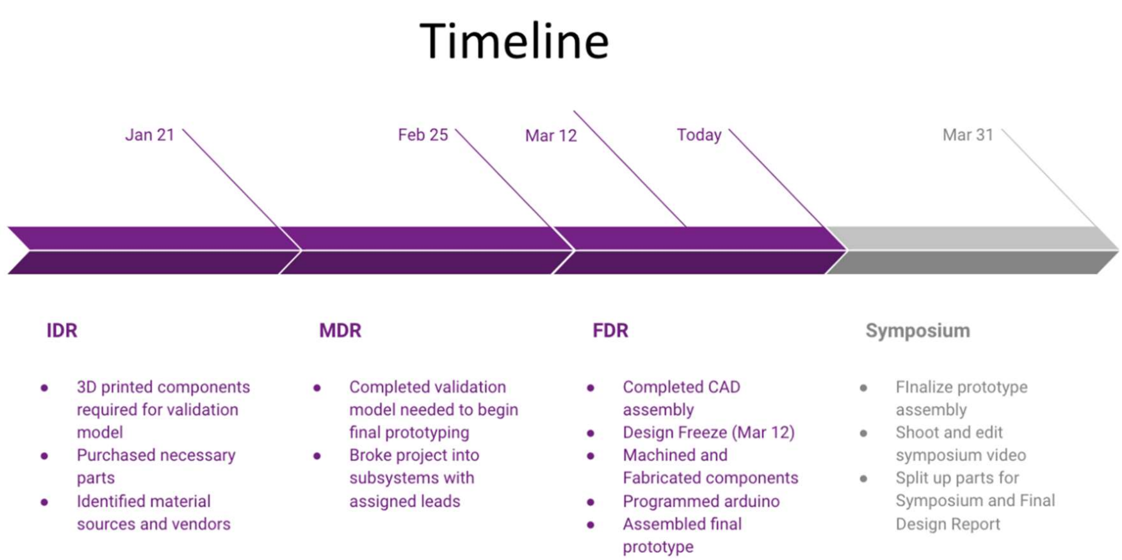


Figure 28: Major Milestones and Timeline

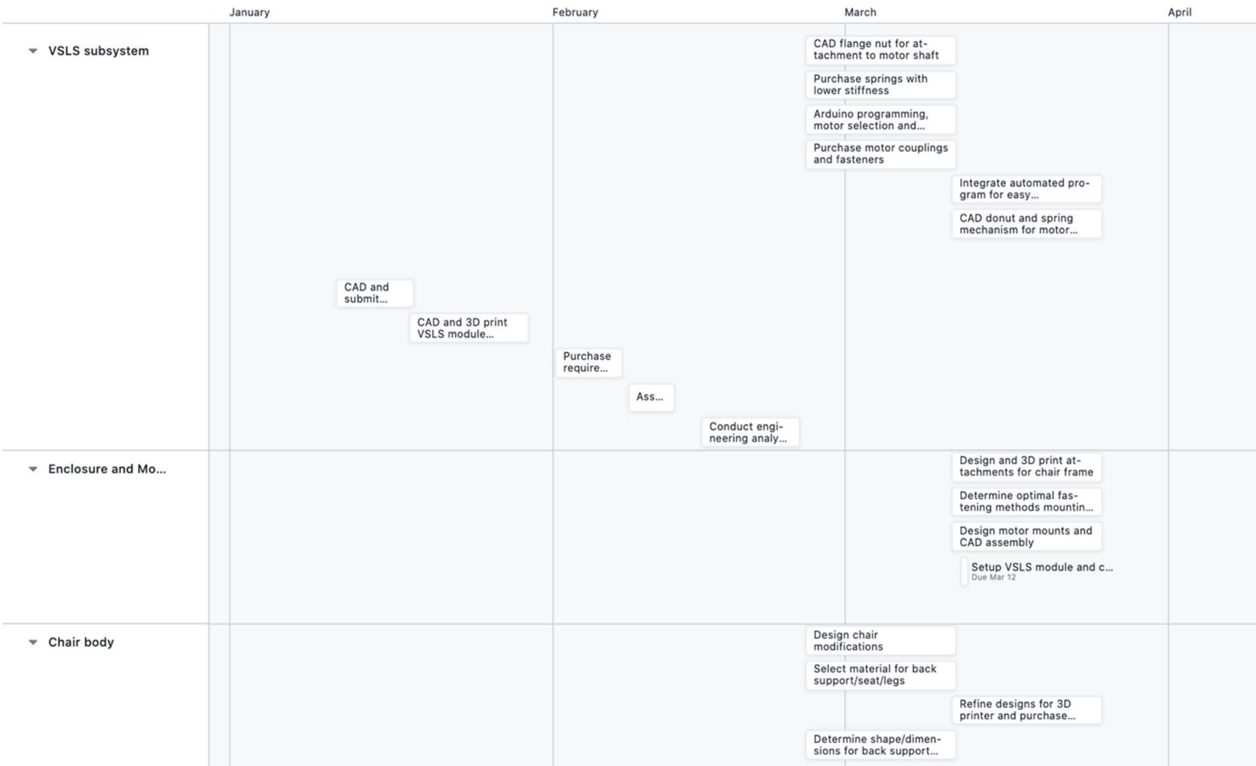


Figure 29: Project Gantt Chart

Appendix C: Other Project Info

C1 Lessons Learned

WATERLOO | ENGINEERING

Department of Mechanical and Mechatronics Engineering
University of Waterloo

ME482 Mechanical Engineering Design Project

Lessons Learned

Student Name: Hansen Lu **Team No.:** 28

Design

- Identify, represent and communicate a mechanical engineering problem or opportunity
- Design a mechanical engineering system, product and/or process
- Implement, verify and refine a design
- Identify and address safety, regulatory, sustainability and professional ethics

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments, engineering specification, CAD Model, Analyses etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications	Biomechanical research for low back and inspired by previous clients who suffer from LBP	Boiling down a solid need statement that required many iterations and kept asking why. A lot of effort in research to narrow down a viable solution.	The need statement is the most important first step to not get lost in middle of the design process when faced with challenges.
Identify a solution that satisfies the needs analysis	Fabricated validation models and design analysis for VSLS, deducted from sitting research	A lot of ideas seems good in theory, but are ineffective practically	Keep it simple, stupid. It is rare to get anything right on the first try. And knowing when to pivot.
Consider safety, society and sustainability issues in selecting a solution	Provided safety specifications in report, used FEA to design a safe frame of the chair, iterated design	Want to help people with low back pain, but can't guarantee effectiveness until studies after	Don't sell false promises
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	Chair frame design 3D printed parts made in Solidworks, submitted the design job for second validation model	A lot of iterations for parts to fit properly or as intended. CAD doesn't always translate to real life.	The first CAD to life design will likely be imperfect. Expect the first go to be a lesson for further iterations
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	Built first validation model, interviewed kinesiology profs, acquired feedback from past clients, surveyed individuals, consulted with chiropractors	Some are hypercritical of any design they didn't think of themselves.	How to separate constructive criticism vs skepticism. Many people are skeptical due to the complexity of the problem. But complex problems are worth tackling.

Project Management

- Apply project management skills and techniques

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Decompose a project into a manageable set of objectives and/or tasks	Broken down tasks based on the capability for each member. Specified the scope that can be achieve realistically.	COVID 19 lockdown slowed down the design process	Why job qualifications need minimum 2 year experience
Develop and track a schedule with milestones	Ensured everyone met deadlines for design presentations and deliverable dates	Pressuring teammates to meet deadlines	Boundaries need to be set for friend relationship and work expectations early
Manage financial, human and/or physical resources	Sourced physical materials for both mechanical and electrical components.	Unique parts are hard to obtain	Design parts using standard sizes so fasteners and other components are available
Identify and manage risks	Figure out ways around the lockdown	Not having work space and tools	Adaptability to find a solution on fabricating a part
Apply change management	Persuade others to pivot	Hard to effectively communicate and translate your understanding to others	Try to break things down to simple terms and common analogies

Communication

- Communicate accurately and effectively

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Write effective reports and design documentation	Responsible to explain the importance of the problem to such a trivial task of sitting, drafted drawings with clear specifications for the machinists	Writing and presenting technical content to the general audience	In person communication with machinists is absolutely necessary
Make effective presentations	Lead presentations and rehearsals.	Spending time to help others improve their presentation skills	Transitions to different topics of the presentation building on previously mentioned information.

Other Lessons-Learned

Researching
I learned how to browse academic research and interpret the findings to incorporate into design.
Understanding basic technical background with engineering knowledge made comprehending research articles very useful. Interpreting research can be challenging, especially in ergonomics. Research in biomechanics can have different results due to difference in experimental methods. It is important to understand what their experimental methods are to understand the result.

Computer Aided Engineering
I did not have experience in CAE prior to this term. Making parts, especially 3D printing, is best to have the minimum volume that can sustain the loading scenario. Abaqus CAE optimization tool was extremely useful to reduce volume without the tedious process of laying out mech design equations and iterating on MATLAB. Unlike practice problems we had done in our courses, a lot of parameters of design are not initially given. The optimization tool is a good initial tool to lean out important parameters.

Student Name: ____Gabriel Okoye____________

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments, engineering specification, CAD Model, Analyses etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications			
Identify a solution that satisfies the needs analysis	• Identified design solution for converting rotational motor motion to translation of VSLS module	• Design changes to related components led to reiterations of proposed solution	• Instant communication of design changes is crucial when doing a design project
Consider safety, society and sustainability issues in selecting a solution	• Outlined safety and sustainability measures adopted during in report	• Some sustainability initiatives that could have been easily adopted were missed	• Learned to always center design ideas around sustainability goal.
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	• Designed and generated drawings for flange nut and motor mount	• 3D printer had different tolerance requirements requiring redesign of part	• I learned a valuable lesson of always considering differences in fabrication methods when designing a part.
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	• Verified that flange nut and motor attachments performed intended function without failing through user testing	• Verification of design could not occur till all other parts were fabricated, this led to some delays as certain parts had to be modified.	• Always have multiple tools and resources for validation as final design may not be ready to test when required

Project Management

- Apply project management skills and techniques

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?

Decompose a project into a manageable set of objectives and/or tasks	• Broke down project into subsystems with defined tasks	• Intended parallel completion of subsystem tasks was not achieved as some tasks relied on others	• Adjust resource allocation to shorten lead times of priority tasks.
Develop and track a schedule with milestones	• Implemented rolling wave planning and schedule compression techniques to ensure deadlines were met	• Frequent design iterations resulted in significant changes to schedule model	• Have a change management protocol in place ahead of time in case this situation arises
Manage financial, human and/or physical resources	• Conducted make or buy analysis for components and implemented cost control measures • Assigned design tasks related to subsystems		
Identify and manage risks	• Implemented design freeze to mitigate risk of scope creep	• Some parts were still being designed past design freeze	• Outsource for parts when shorter lead time is required
Apply change management	• Adjusted project schedule and tasks to accommodate design reiterations	• Changes to project design were occurring more frequently than necessary	• Define protocol for approving changes to design ahead of time

Communication

- Communicate accurately and effectively

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Write effective reports and design documentation	• Handled formatting of final design reports	• Last minute additions to report made it a time crunch to get report formatted	• Learned to assign formatting responsibility to last person to finish after the deadline
Make effective presentations	• Prepared script for design reviews • Shot and edited symposium video	• Had to learn to use video editing tools to better communicate project	• Now familiar with video editing software that I would be able to use for future projects

Student Name: ____Daejun Lee______

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments, engineering specification, CAD Model, Analyses etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications			
Identify a solution that satisfies the needs analysis	Brought up the initial design concept of VSLS Deigned the locking mechanism for adjustability of VSLS	Unexpected tolerance issues from 3d printed parts Unexpected failures from 3d printed parts	Achieved deep understanding of how to prototype mechanical components to 3d printed parts
Consider safety, society and sustainability issues in selecting a solution	Addressed the potential safety concerns from processed parts and assembly	There always exist unexpected or overlooked failure cases when designing mechanical components and assemblies	Iteration of the design is critical to identify and analyze the potential safety risks
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	Generated the detailed VSLS components and its subassemblies including Y mounts and bar mounts	The specifications were changed frequently because the new data from investigation and validation proposed the detailed criteria for the design	Iteration reflecting new information is a key for the success in designing components or assemblies
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	Printed mechanical components with different setups of their expected loading scenario Post processed and assembled the components with hand tools	Sometimes actual components made did not match with our intention due to incorrect measurement, incorrect tolerance of parts, inaccuracy from making with hand tools, etc.	Accounted the possible inaccuracy when iterating a design Updated designs to avoid the causes of the inaccuracy

Project Management

- Apply project management skills and techniques

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Decompose a project into a manageable set of objectives and/or tasks	Broke down the VSLS related components into subsystems	Updates were often required to not interfere with components that were designed concurrently	Frequent communication is beneficial to avoid redundant design iterations

Develop and track a schedule with milestones			
Manage financial, human and/or physical resources	Focused on getting raw materials locally to avoid in delay in schedule from shipping	Restrictions and delays to get the parts from local vendor or retail store due to lockdown Required some travel to get the raw materials	Planning out the preparation of raw material with some rooms are essential for preventing any delays on the schedule
Identify and manage risks	Presented the 3d printing schedule and updated group members	Unexpected failures from 3d printer	Trouble shot the cause of failures and did consistent maintenance to prevent it
Apply change management	Prioritize the 3d printing schedule based on the iteration expectation of the parts	Frequent design updates due to the difficulty to get an accurate measurement caused some delays in printing less prioritized parts	Efficient scheduling for 3d printing was essential to meet the original schedule without delays

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Write effective reports and design documentation	Handled the formatting for the final reports	Writing my sections to match the information (terminology, logic, etc.) takes time	Taking the responsibility to compile and format the report
Make effective presentations	Prepared script for the design reviews and practiced for fluent speech	Required a lot of time to prepare script since I feel anxiety when presenting to people	Online presentation gave me opportunity to get over some anxieties

Student Name: Burim Lecaj

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments, engineering specification, CAD Model, Analyses etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Identify needs, function, criteria and constraints for a given design, considering engineering economic, health and safety, environmental and ethical specifications			
Identify a solution that satisfies the needs analysis	• Created GUI • Helped with mechanical calculations • Electrical connection	• Design changes to related components led to reiterations of proposed solution	• Better communication
Consider safety, society and sustainability issues in selecting a solution	• Outlined safety and sustainability measures for the electrical components	• Clear understanding of electrical components.	• Learned to always learn about safety concerns for each component
Generate detailed implementation specifications, including drawings, tolerances, components, etc. as required	• Designed and build electrical circuit • Designed and build all the software	• Limitations with Arduino IDE data storage.	• I learned to check the limitations of software, and design around these limitations.
Verify the design by implementation, prototype production, bench test validation of key elements, and/or acceptance opinion by recognized expert	• Verified the current drawn by the motor at maximum loading conditions.	• Understanding how to increase current and designing electrical circuit.	• Understand the limitations of design, and each component to easily identify where issues will arise.

Project Management

- Apply project management skills and techniques

Performance Indicator	List the specific deliverables you produced that demonstrated your performance (i.e. Reports, assignments etc.)	What challenges were presented to you in achieving this learning outcome?	What is the value of this learning outcome for a future design project task?
Decompose a project into a manageable set of objectives and/or tasks	Broke down the projects electrical and software sections into subsystems	Intended parallel completion of subsystem tasks.	Adjust resource allocation to shorten lead times of priority tasks.

Develop and track a schedule with milestones	Implemented use of different software to ensure deadlines were met.	Frequent design iterations resulted in significant changes to schedule model	Have a change management protocol in place ahead of time in case this situation arises
Manage financial, human and/or physical resources			
Identify and manage risks	Implemented design freeze to mitigate risk of scope creep	Some parts were still being designed after the freeze.	Better planning for sorter lead times.
Apply change management	Adjusted project tasks as to prioritize some of critical tasks first.	Changes to project design were occurring more frequently than necessary.	Define protocol for approving changes to design ahead of time.

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Performance Indicator	**List the specific deliverables you produced that demonstrated your performance** (i.e. Reports, assignments etc.)	**What challenges were presented to you in achieving this learning outcome?**	**What is the value of this learning outcome for a future design project task?**
Write effective reports and design documentation	Helped with formatting of final design report.	Last minute additions to report made it a time crunch to get report formatted.	Learned to assign formatting responsibility to last person to finish after the deadline.
Make effective presentations	Prepared script for design reviews.	Had to learn to use video editing tools to better communicate project.	Now familiar with video editing software.

ME482 W21 Hazard Disclosure Form

Team Number[1]:	28
Project Title:	Project Cathedra
Brief Project Description: (2-3 sentences)	Customize a surface of the chair to suit the ergonomic needs of the user using an automated variable dampener system for the lumbar support.

Answer all the following questions. If unsure, answer yes. **If you answer yes to any question you need to attach your own page which provides a concise and quantitative description of the items, use, and safety measures for each item**.

Hazard Classification	Fabrication / Manufacturing	Symposium Demonstration	Usage - post Symposium
1. Is electricity used for anything other than stand-alone unmodified computers?	yes ☒	yes ☒	yes ☒
2. Are any lasers used? See UW Laser Program.	yes ☐	yes ☐	yes ☐
3. Are any flashing or strobe lights used?	yes ☐	yes ☐	yes ☐
4. Are any lights brighter than a 60W bulb or 800 lumens?	yes ☐	yes ☐	yes ☐
5. Are there any radiation sources? See UW Radiation Safety.	yes ☐	yes ☐	yes ☐
6. Will there be any X-Rays emitted? See UW X-Ray Program.	yes ☐	yes ☐	yes ☐
7. Is there any combustion occurring?	yes ☐	yes ☐	yes ☐
8. Are any temperatures created above 45°C or below 10°C[2]	yes ☐	yes ☐	yes ☐
9. Are any compressed gasses used? See UW Compressed Gases.	yes ☐	yes ☐	yes ☐
10. Is there any significant stored energy (electrical, chemical, mechanical) in any component?	yes ☒	yes ☒	yes ☒
11. Are any chemicals used other than compressed gases described above? This includes gases, liquids, powders, and solids. See UW WHMIS. Attach MSDS sheets.	yes ☐	yes ☐	yes ☐

[1] Form based on MME Hazard Disclosure v2014-04-28
[2] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100020960.pdf, accessed 190106

12. Are any nano-sized objects used or made? This would include materials that have external dimension less than 100nm.	yes ☐	yes ☐	yes ☐
13. Are there any biological components? This includes (both dead and alive): blood, tissue, fluids, parts, from any organism from bacteria to live humans, or live test subjects. See [UW Bio-Safety.]()	yes ☐	yes ☐	yes ☐
14. Is any food for human or animal consumption used?	yes ☐	yes ☐	yes ☐
15. Are any gases, particles, or fluids being ejected into the environment?	yes ☐	yes ☐	yes ☐
16. Are there any moving parts?	yes ☒	yes ☒	yes ☒
17. Is any component or the entire project heavier than 10kg ?	yes ☐	yes ☐	yes ☐
18. Can any part fly?	yes ☐	yes ☐	yes ☐
19. Can there be any projectiles?	yes ☐	yes ☐	yes ☐
20. Is any noise generated above normal speaking voice levels?	yes ☐	yes ☐	yes ☐
21. Do you know of or suspect there might be any other hazards?	yes ☐	yes ☐	yes ☐

Please write a concise and quantitative statement to describe each potential hazard and identify your proposed mitigation procedure for each item. Note that you should consider the following hierarchy of Hazard Control:

- Eliminate the hazard
- Substitute a less hazardous component or process
- Implement engineering controls to minimize the hazard
- Implement administrative controls to minimize the hazard
- Use appropriate Personal Protective Equipment (PPE)

"*The most effective way to deal with a hazard is to remove it*"

Item 1[1]: Arduino will be used, and can have a current of 5A. This hazard can cause an electrical shock to users. The Arduino will be covered and no wires are to be exposed. If hazard occurs than we will notify professor, TA's, and call for medical help.

Item 2[10]: Capacitor (10µF) will be used to ensure constant supply of current to motors. This hazard can cause an electrical shock to users. The Capacitor will be covered and no wires are to be exposed. If hazard occurs than we will notify professor, TA's, and call for medical help.

Item 3[16]: Mechanical motion from variable dampener actuation. This hazard can cause physical injury to users. Prevent direct contact with user. If hazard occurs than we will notify professor, TA's, and call for medical help.

Hazard Classification No.	Hazard Classification	Description of Hazard	Consequences of Hazard	Probability of Harzard Occurring	Impact if the Harzard Occurs	Calculated Harzard Severity	Midigation Owner	Hazard Control	Mitigating Action (To Reduce Probability)	Contingent Action (If Harzard Occurs)
Item 1[1]	Is electricity used for anything other than stand-alone unmodified computers?	Arduino will be used, can have a current of 5A.	Electrical shock to users.	Low	High	Medium	Burim Lecaj	Implement engineering controls to minimize the hazard.	Make sure no wires are exposed and that the Arduino is covered.	Notify professor, TA's, and call for medical help.
Item 2[10]	Is there any significant stored energy (electrical, chemical, mechanical) in any component?	Capacitor (10µF) will be used to ensure constant supply of current to motors.	Electrical shock to users.	Low	High	Medium	Burim Lecaj	Implement engineering controls to minimize the hazard.	Make sure no wires are exposed and capacitor is covered.	Notify professor, TA's, and call for medical help.
Item 3[16]	Are there any moving parts?	Mechanical motion from variable dampener actuation.	physical injury to users.	Medium	Medium	Medium	Burim Lecaj	Implement engineering controls to minimize the hazard	Prevent direct contact with user.	Notify professor, TA's, and call for medical help.

Faculty Advisor: Naveen Chandrashekar

Date disclosure completed: 1/27/2021

Completed by: 1/27/2021