Rose-Hulman Institute of Technology

Liquid Chromatography Scale Development Report

Written for Dr. Eric Constans' Independent Study

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2-28-2020

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Introduction

This paper documents the development of the liquid chromatography (LC) scale during the fall and winter quarters of the 2019–2020 academic year. Included are complete instructions on how to construct the current version of the LC scale as of 2/28/2020.

The instruction section explains the disassembly of the donor scale, modification of the strain gauge, assembly of the LC scale scaffolding, assembly of the weighing linkage, and mating of the linkage to the scaffolding. Each section details the parts needed for a particular aspect of the assembly; a complete parts list can be found in the appendix.

The design portion of the document addresses development of version 1, lessons learned from version 1, development of version 2, and final thoughts about version 2.

Overview of Project to Date

As of the end of winter quarter of the 2019–2020 academic year, the LC project has gone from concept to multiple developed prototypes. Working prototypes of the filtering and amplification circuit as well as the weighing linkage have been developed thus far. The amplification has gone through multiple iterations, from using multiple chips for amplification to consolidating into a single-chip amplification model. The weighing linkage has also gone through multiple iterations from version 1 to version 2. The current version features bearings and a larger weighing plate for better sensor pickup. Version 2 also features a new connection for the strain gauge and weighing linkage connection. Some aesthetic changes have also been made to version 2.

Section 1: Instructional Section

Part 1: Disassembly of the Donor Scale

This section focuses on the disassembly of the off-the-shelf scale (referred to here as the "donor scale") to retrieve the strain gauge, which is the only part of the donor scale used in the LC scale.

Parts needed:

- 1x American Weigh Scale Gemini Series Precision Digital Milligram Scale (listing on Amazon)

Tools needed:

- Electronics screwdriver set
- Box cutter
- Wire cutter

Figure 1. The donor scale

Figure 1 shows the donor scale. The first step in disassembling this scale is the removal of the two screws on the underside of the donor scale, under the two rear felt pads (indicated by blue arrows in **Figure 2**). Remove the two batteries shown in **Figure 2** as well.

Figure 3 shows the donor scale with batteries and screws removed.

After the 2 rear screws have been removed, it is possible to slide the top cover of the scale out through the back gap created by the missing screws. When the cover has been removed, use the box cutter to score a line on the top of the scale at the position shown in **Figure 4**.

Figure 2. Screws and batteries to be removed

Figure 3. Screws and batteries removed

Figure 4. Revealing hidden screws

Using the box cutter, pry the top plate away from the adhesive to reveal the remaining 3 screws securing the top of the donor scale.

Remove these 3 screws and slide the box cutter along the seams on the sides of the donor scale to disengage the tabs on the sides of the donor scale. Carefully spread open the top and bottom of the donor scale. The result is shown in **Figure 5**.

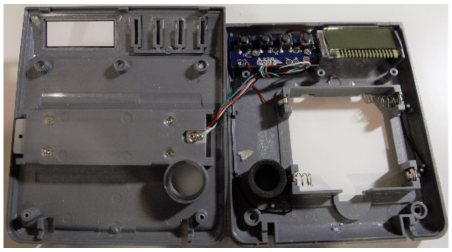


Figure 5. Donor scale opened up

Cut the wires shown in **Figure 6** to completely separate the top and the bottom parts of the donor scale.

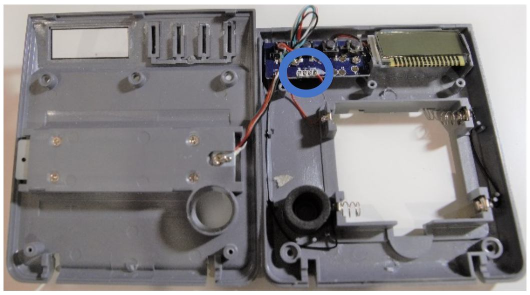


Figure 6. Wires to cut to separate top and bottom of donor scale

Figure 7. Removal of scored section of top plate

Remove the scored section of the top plate as shown in **Figure 7**. Next, cut out the small piece of top plate in between the area where the scored section has been removed and the circular access hole for the weigh plate. The cut marks are circled in blue in **Figure 8**. Pull and bend the top plate around the weigh plate, being careful not to damage the weigh plate or any wires below it. The result is shown in **Figure 8**. Remove the screw circled in red in **Figure 8**.

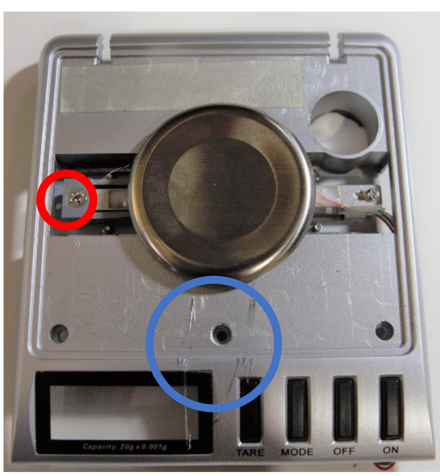


Figure 8. Removal of top plate of donor scale

Remove the weight plate and the result should look like **Figure 9**. Next, turn over the top of the scale and remove the 4 screws that hold in the strain gauge assembly. They are circled in blue in **Figure 10**.

Figure 9. Donor scale with weight plate removed

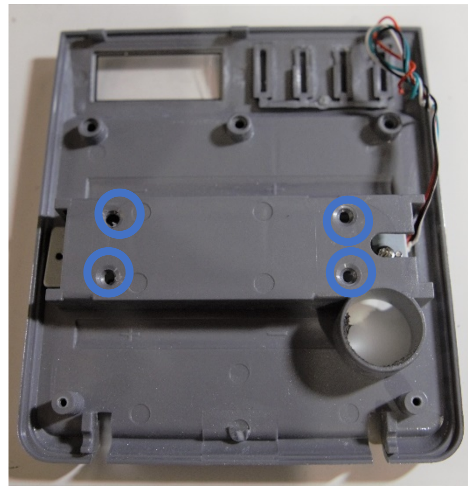


Figure 10. Removal of screws holding in the strain gauge assembly

The strain gauge assembly that has been removed is shown in **Figure 11**. Remove the 2 screws at the base of the strain gauge. (The top screw is circled in **Figure 11**.) Carefully remove the strain gauge, shown in **Figure 12**.

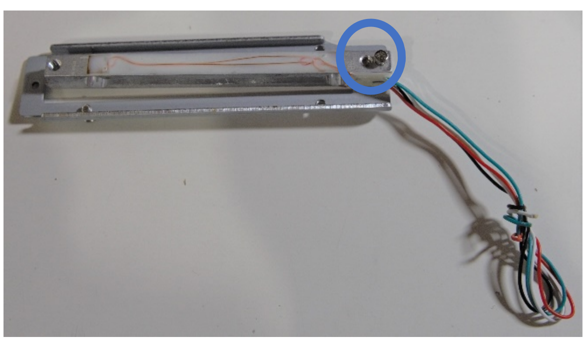


Figure 11. Removing screws from strain gauge assembly

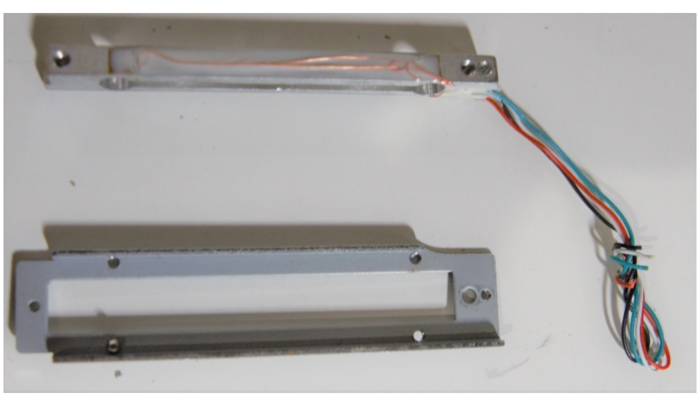


Figure 12. Separating the strain gauge from its assembly

Part 2: Modifications to the Strain Gauge

Parts needed:

- Strain gauge sidewall (must be printed)
- 4x different 16 AWG colored wire, about 1ft each in length
- 4x 16 AWG heat shrink
- 4x pin
- 1x 4-pin header
- 1x 4-pin plug

Tools needed:

- Soldering iron
- Solder, about 6in
- Heat gun
- Hot-melt glue gun
- Electronics screwdriver set
- Wire stripper
- Wire cutter
- Box cutter

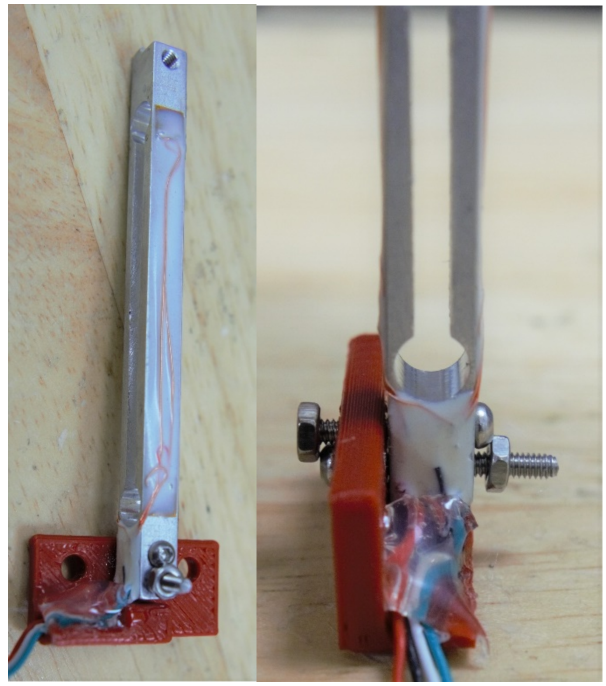


Figure 13. Strain gauge mounted on the strain gauge sidewall

Because the wire connections on the strain gauge are very weak, immediately after isolating the strain gauge from the donor scale, mount it on the strain gauge sidewall. Insert the wires into the semi-conduit and cover them with hot glue, being careful not to block the screw holes. The result is shown in **Figure 13**.

Using the box cutter, shave off the insulation on the end of the strain gauge wiring harness. The result is shown in **Figure 14**.

Using wire strippers, strip the ends of the four 16 AWG wires, as shown in **Figure 15**.

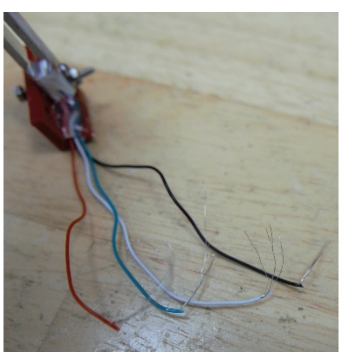


Figure 14. Wiring harness with insulation removed

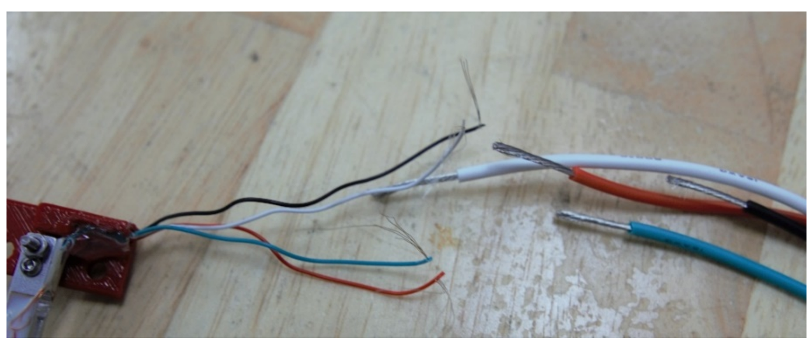


Figure 15. 16 AWG wires after stripping

Solder the strain gauge harness to the four 16 AWG wires. An example setup is shown in **Figure 16**. The final product is shown in **Figure 17**.

Using a heat gun, heat the shrink wrap over the solder joints. An example setup is shown in **Figure 18**. The final product is shown in **Figure 19**.

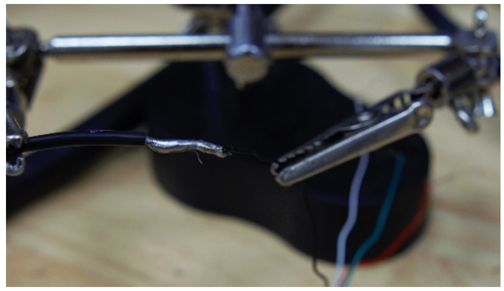


Figure 16. Setup for soldering strain gauge harness to 16 AWG wires

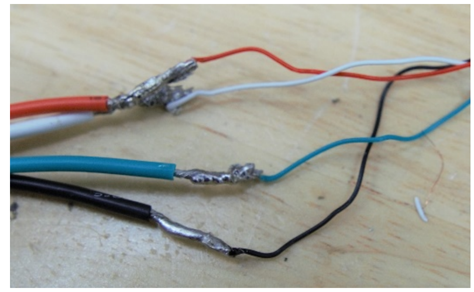


Figure 17. 16 AWG wires soldered to the strain gauge harness

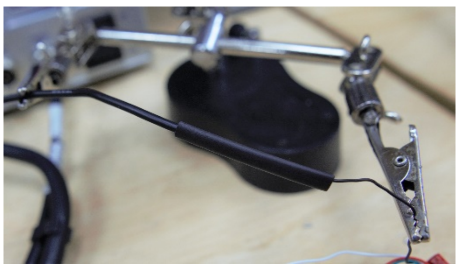


Figure 18. Setup for heating the shrink wrap over the solder joints

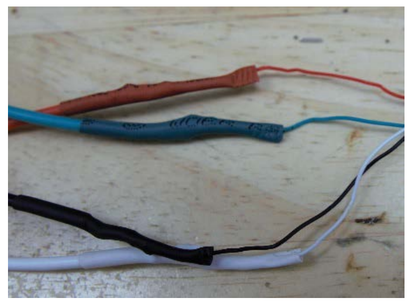


Figure 19. Soldered joints covered with heat shrink tubing

Next, crimp the crimp pins onto the 16 AWG wire. Insert the terminated ends into the 4-pin header. Finally, connect the 4-pin header to the 4-pin plug. The result is shown in **Figure 20**.

Figure 20. Assembled breadboard interface

Part 3: Construction of the LC Scale Scaffolding

This is the most part- and labor-intensive section of the build. This explanation covers the assembly of the scaffolding that the weighing linkage and the strain gauge sit on.

Parts needed:

- 8x 10mm x 10mm T-slot @ 6in long
- 4x 10mm x 10mm T-slot @ 2in long (must be cut from a 3- or 6-in piece)
- 4x 10mm x 10mm T-slot @ 3in long
- 8x corner braces
- 1x screw bag w/ washers
- 26x L brackets

Tools needed:

- Electronics screwdriver set
- Assorted small files
- Box cutter
- Metric Allen key set
- Patience and anger control because those screws are SMALL!

Building the bottom plate

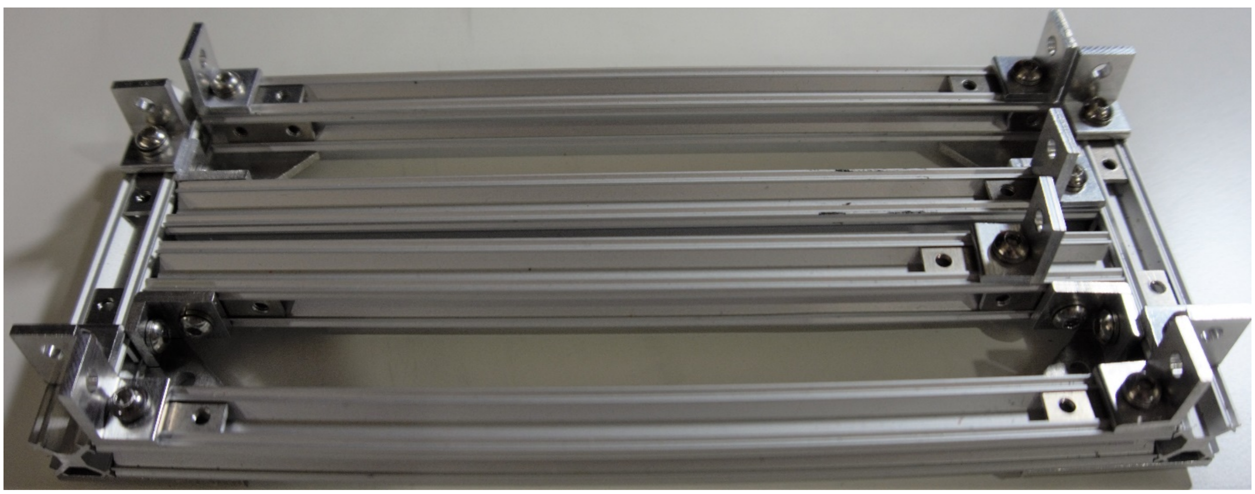


Figure 21. Bottom base plate, complete

Figure 21, above, shows the finished bottom base plate.

First, attach L brackets to the mid-running 6in pieces of T-slot, as shown in **Figure 22**. These are the T-slots that will hold the strain gauge in place.

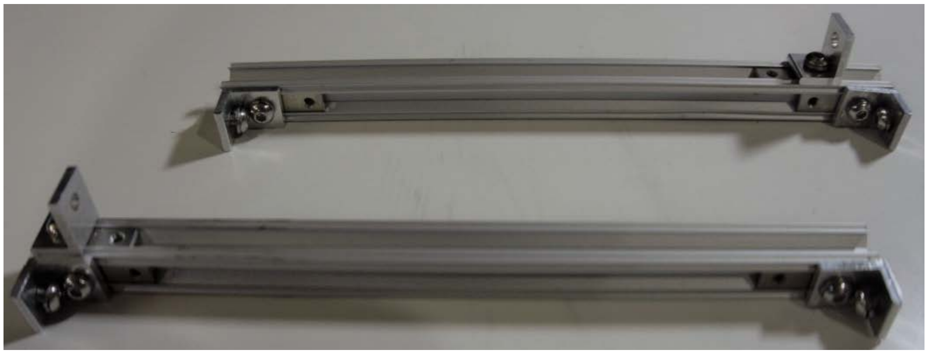


Figure 22. Assembled mid-running piece

Assemble the outer frame using two 6in pieces of T-slot, one 3in piece of T-slot, and 4 corner brackets. The result is shown in **Figure 23.** NOTE: Ensure that these sliders are in the positions shown in **Figure 24** before continuing the assembly.

Figure 23. The outer frame

Assemble the outer and mid-running frames together.

Figure 24. Correct positioning of sliders

The result should look like **Figure 25**. NOTE: Ensure that the sliders are in the positions shown.

Attach the final 3in T-slot piece to the bottom shell. The result is shown below in **Figure 26**. NOTE: Ensure all sliders are in the correct positions.

Figure 25. Assembly of outer and mid-runner frames

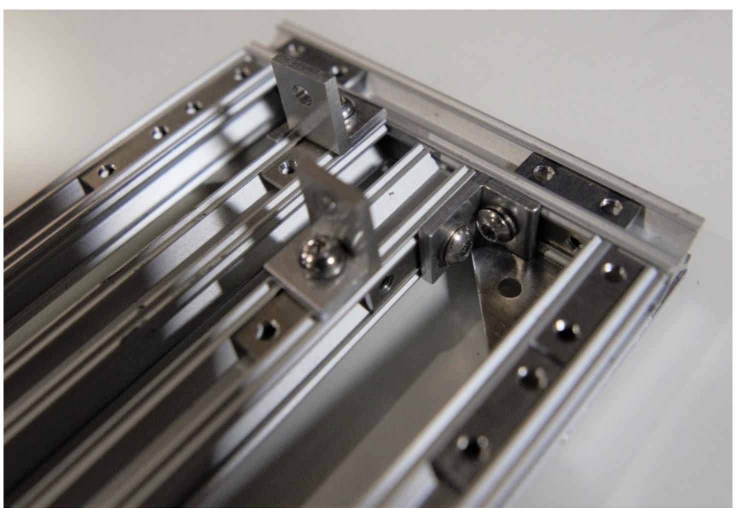


Figure 26. Bottom shell with the final T-slot installed

Building the top plate

The construction of the top plate is very similar to that of the bottom plate. Shown below in **Figure 27** is the finished top plate, seen from the bottom. **Figure 28** shows the finished top plate, seen from the top. NOTE: Again, ensure all sliders are in the correct positions.

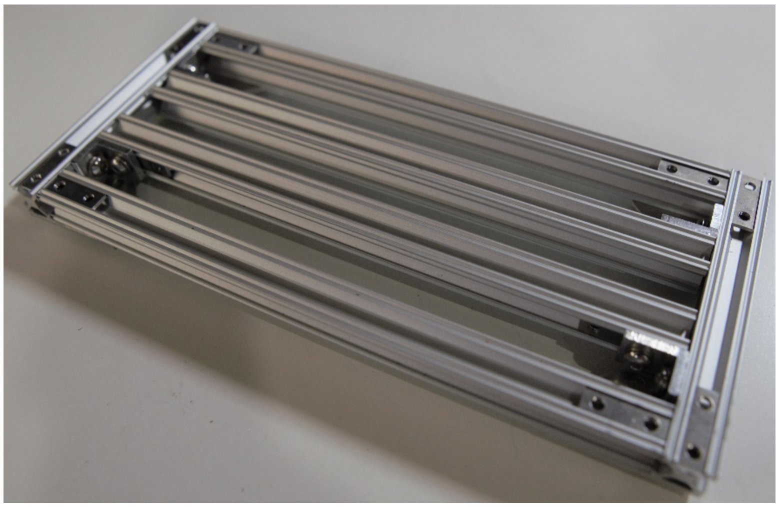


Figure 27. Fully assembled top plate, seen from the bottom

Figure 28. Fully assembled top plate, seen from the top

Start by assembling the mid-running 6in T-slot framing. Ensure all L brackets and sliders are in the correct positions. **Figure 29** shows the assembly.

Figure 29. Correct positioning of L brackets and sliders

Assemble the outer frame with two 6in T-slots, 4 corner brackets, and one 3in T-slot. The final assembly is shown in **Figure 30**. NOTE: Ensure all sliders have been installed as shown in **Figure 31**. **Figure 32** shows all sliders on the BOTTOM of the top plate that need to be installed.

Figure 30. Outer frame, final assembly

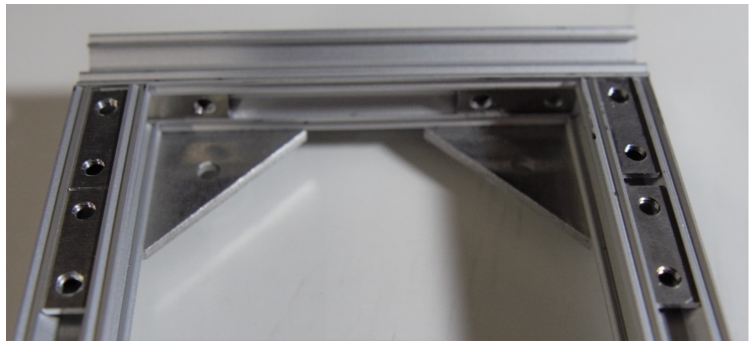


Figure 31. Correct installation of sliders on outer frame

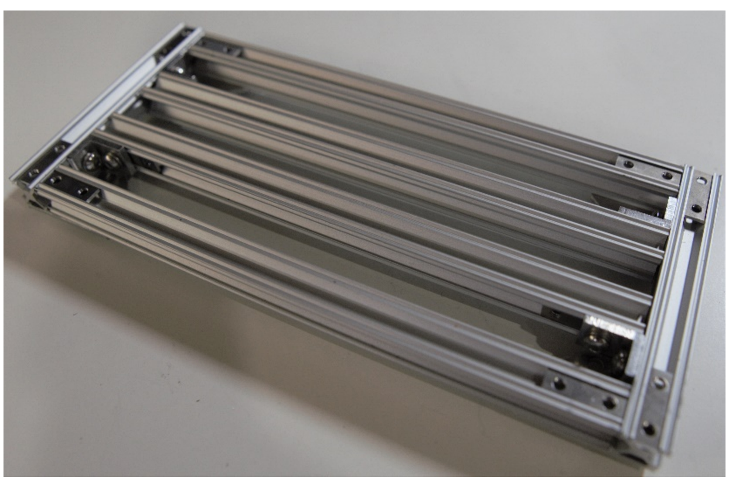


Figure 32. Top plate, seen from bottom

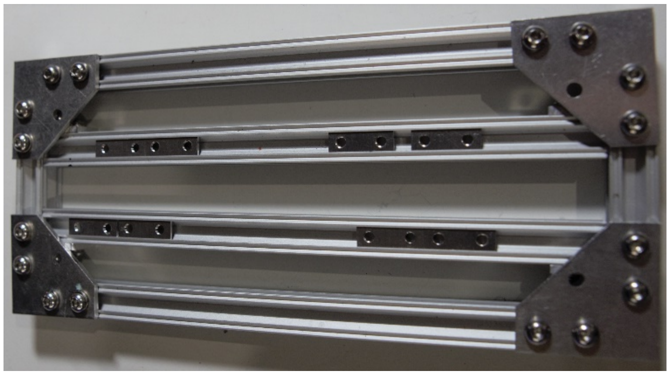


Figure 33. All sliders needed for top plate, shown from the top

Install the final 3in T-slot once all sliders are in the correct position. **Figure 33** shows the final TOP view of the plate with all parts installed.

Building the connecting posts:

The connecting post is a relatively simple part to make. **Figure 34** and **Figure 35** illustrate completed connecting posts and all required parts. NOTE: Four connecting rods are needed.

Figure 34. Quarter view of completed connecting post

Figure 35. Alternate view of completed connecting post

Putting it all together

For this last section of the strain gauge scaffolding, the bottom plate, the top plate, and the connecting posts are mated. The 4 connecting posts are installed onto the bottom plate. The result is shown in **Figure 36.**

Figure 36. Installation of the 4 connecting posts on the bottom plate

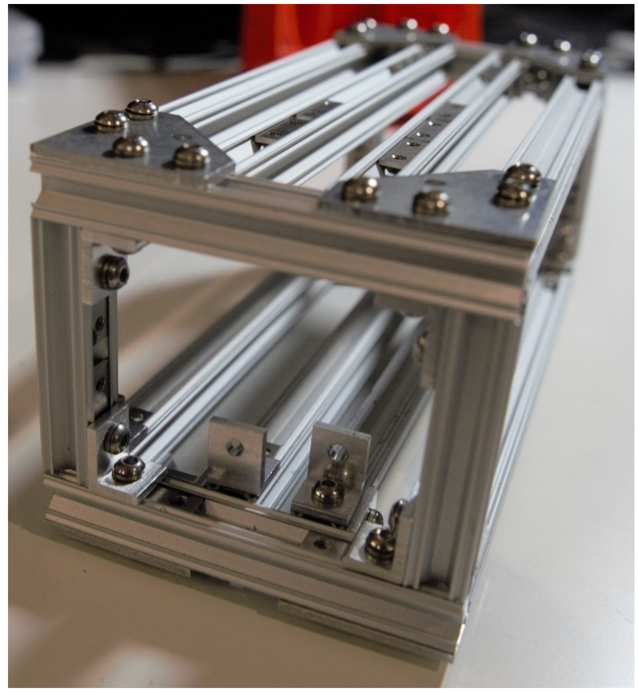


Figure 37. Addition of the top plate, view 1

Next, Attach the top plate to the top of the connecting posts. The result is shown in **Figure 37** and **Figure 38**.

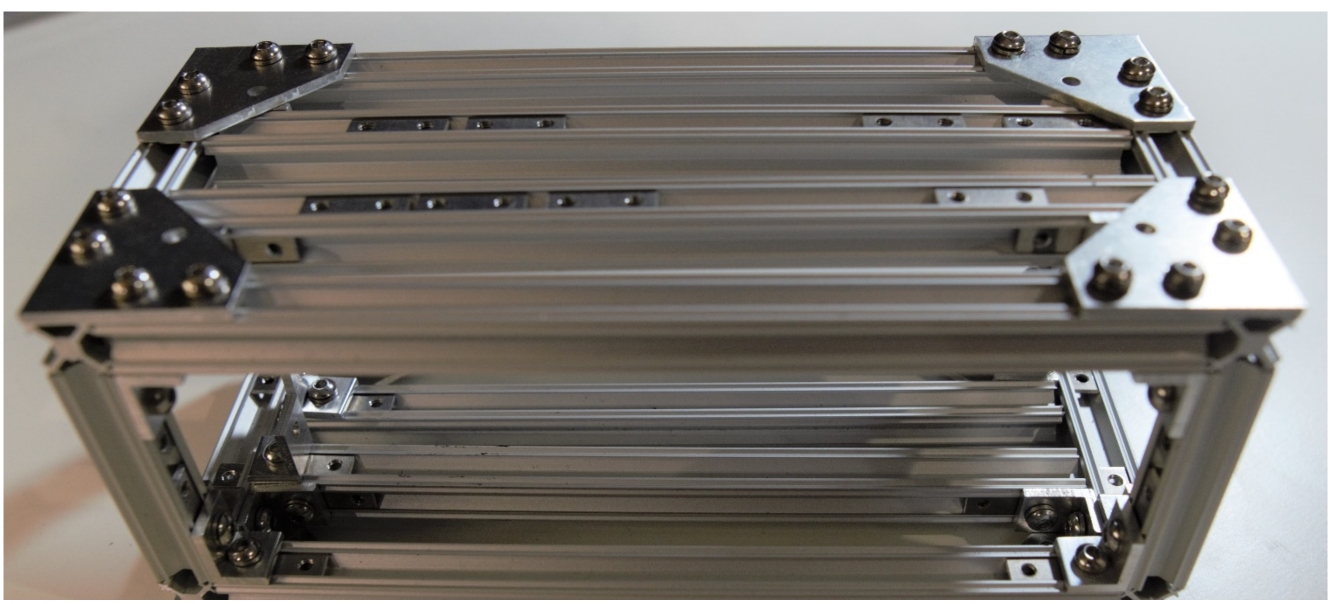


Figure 38. Addition of the top plate, view 2

Part 4: Assembly of the Weighing Linkage (Under Development)

Parts needed:

- Long link
- Short link
- Slider
- Base plate
- Push block
- 10x ball bearings, 6mm OD, 3mm ID
- 5x 50mm long, 3mm diameter shafts

Tools needed:

- 3D printer
- Super Glue
- Drill press (drill will suffice)
- Assorted files
- Benchtop grinder (sandpaper will suffice)

This section is relatively straightforward to build because the 3D printer does the heavy lifting. Print all the parts listed above.

The holes for the 3mm shafts were underprinted to ensure a uniform circular hole. These holes must be drilled out using a 3mm or 1/8-in drill bit. An example is shown in **Figure 39**.

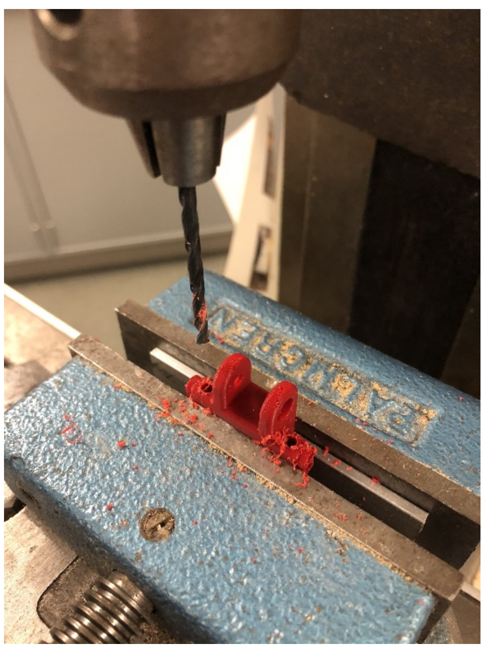


Figure 39. Drilling holes for the 3mm shafts

The bearing holes are press fit, so no drilling is needed; simply clean any 3D printing detritus off the scaffolding. Next, test fit the bearings into their respective holes.

Once all bearings have been dry fitted, slide the 3mm rods into the joints to verify that the joints are smooth and in line, as shown in **Figure 40**. If there is friction, the holes may not be in line. If the rod does not slide into the bearing at all, use a benchtop grinder to sand down the rod. Check often to ensure no more material than necessary is removed. The links should hang freely as shown in **Figure 41**.

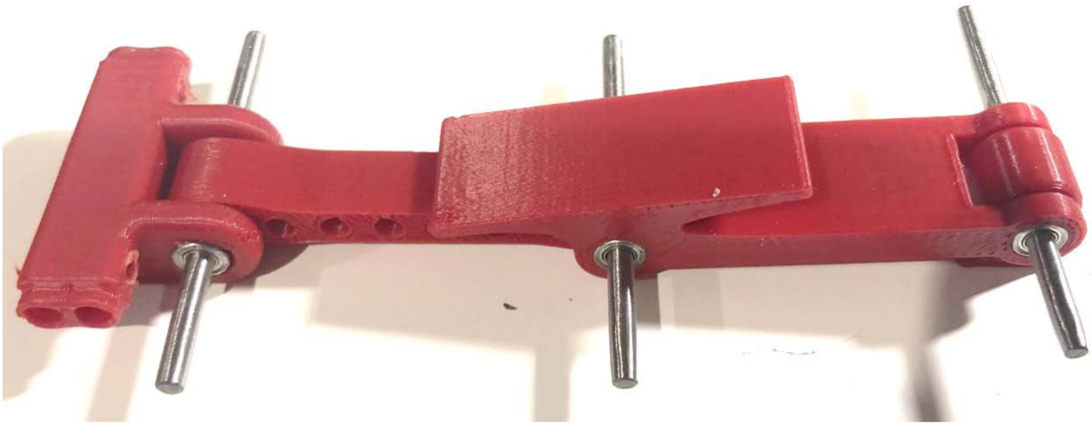


Figure 40. Rods installed and correctly aligned

Figure 41. Verifying that the links hang freely

Once the press fitting is complete, and only then, the bearings should be glued into place.

NOTE: Because I have not yet finalized the method for locking the slider onto the base plate using the threaded inserts, I have not included detailed instructions for that step. In the current version, the slider tends to come unscrewed under load.

Part 5: Mating the Scaffold and the Linkage (Under Development)

This section is an explanation of a straightforward method for attaching the strain gauge and linkage to the scaffolding.

Parts needed:

- Assembled linkage
- Modified strain gauge
- Scaffold
- 4x M3 bolt 10mm long
- 2x M3 bolt 10mm long w/nuts
- 1x M2 bolt 10mm long w/nut

Tools needed:

- Electronics screwdriver set

Attaching the strain gauge

To attach the strain gauge, slide it in between the two L brackets and bolt the M3 bolts through the pre-aligned holes. If the mid-running rails are too far apart, loosen the rail's L brackets and slide them until the fit is snug but not damaging. **Figure 42** shows the assembly.

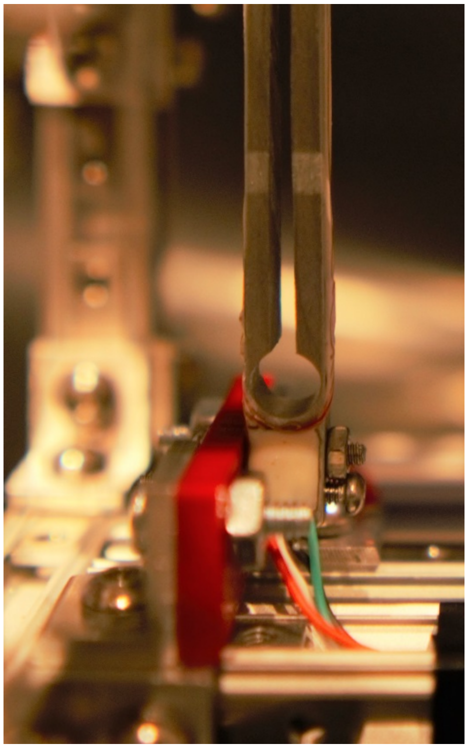


Figure 42. Mating of scaffold and strain gauge

Attaching the weighing linkage

Only 5 screws are needed to attach the weighing linkage. Bolt the base plate to the top of the scaffold using the M3 bolts; the bolts should go into the sliders mounted directly below them in the scaffold. **Figure 43** shows the attached weighing linkage.

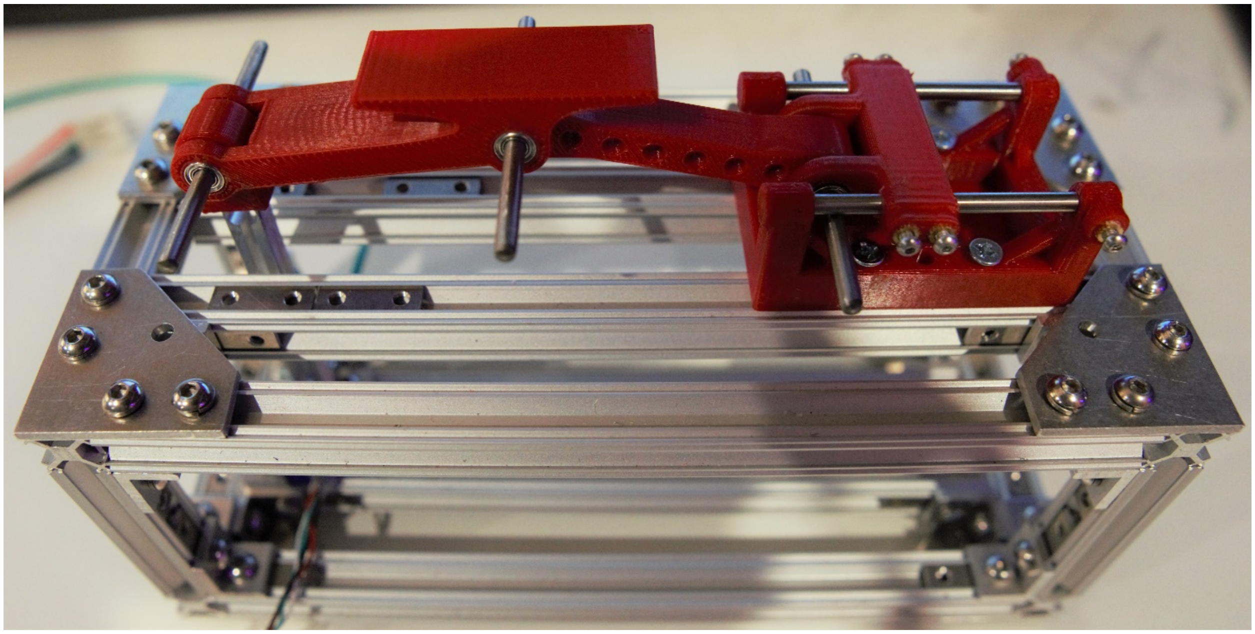


Figure 43. Mating of weighing linkage to scaffold

To attach the strain gauge to the weighing linkage, slide the push block over the strain gauge and bolt it in with an M2 screw and nut. **Figure 44** shows a closeup of the mate between the strain gauge and the weighing linkage.

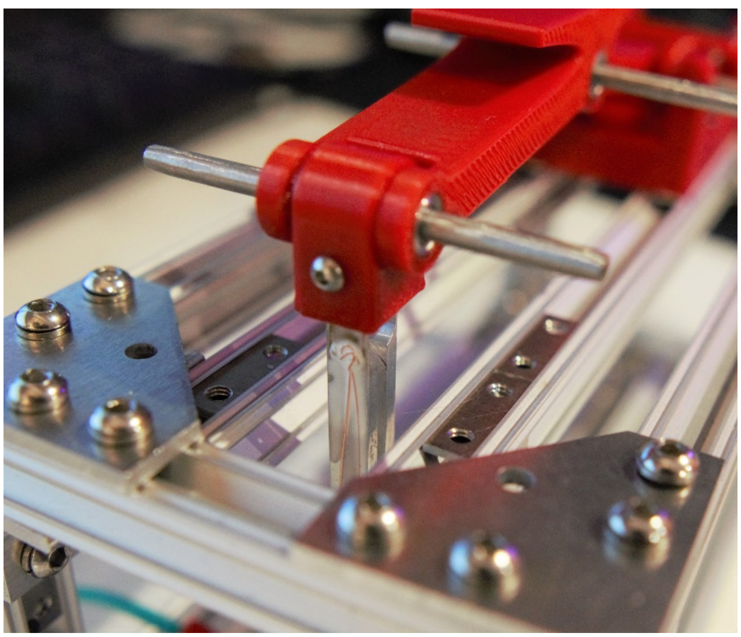


Figure 44. Closeup of mate of strain gauge and linkage

Section 2: Design

Part 1: Development of Version 1

Development of version 1 began midway through the fall quarter of the 2019–2020 academic year after the strain gauge removal process and rudimentary amplifier circuit had been finalized. The first step was to decide on a weighing linkage. Two designs were created. The original sketches used to calculate the amplification of each linkage are shown below. **Figure 45** shows the scissor-inspired linkage; this design was rejected because it distributes too much of the load in the Y-direction, whereas the goal was to have most of the force distributed in the X-direction. **Figure 46** shows the 2-bar linkage chosen for the version 1 and 2 prototypes. The 2-bar linkage had a much better distribution of the forces in the X-direction than the scissor-inspired design.

After the type of linkage had been determined, rough sketches were made to get an idea of how the linkage would look and how it would interface with the scaffold and the strain gauge. An early sketch of the weighing linkage is shown below in **Figure 47**.

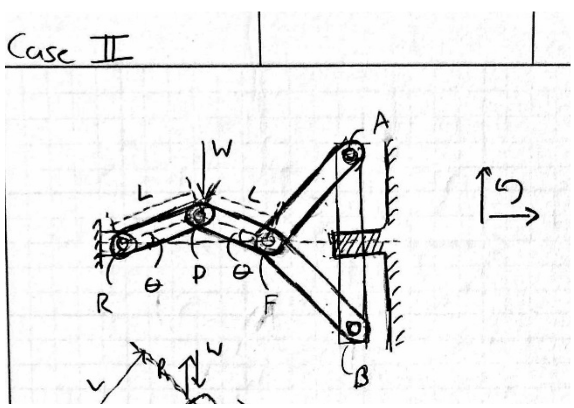


Figure 45. Scissor-inspired linkage

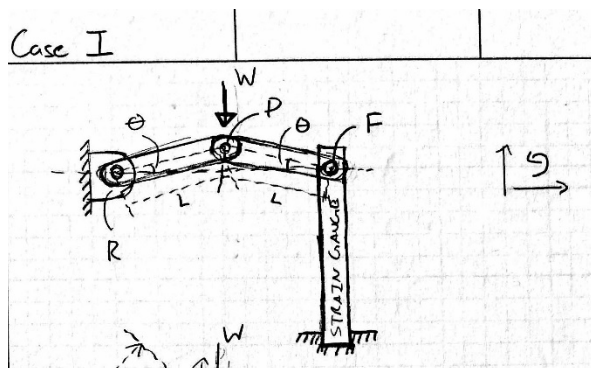


Figure 46. 2-bar linkage

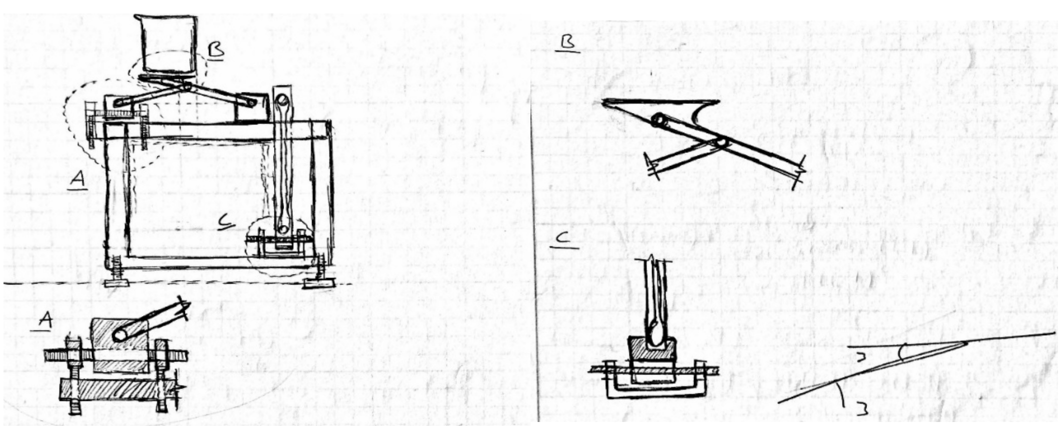


Figure 47. Early sketch of weighing linkage

The hardest part of designing version 1 was the base plate and slider assembly. The goal of this assembly was to ensure that the weighing plate was always level at the outset even if there was a beaker on the weighing plate. This meant that one end of the linkage had to be adjustable and lockable at any interval. This design imperative led to the birth of the current slider and base plate assembly. The slider slides on two parallel rods affixed to the base plate. Set screws allow the slider to be locked onto the rods at any point. The slider has 50mm of travel, which is more than ample for this application. **Figure 48** shows early progressive sketches of potential slider and base plate designs.

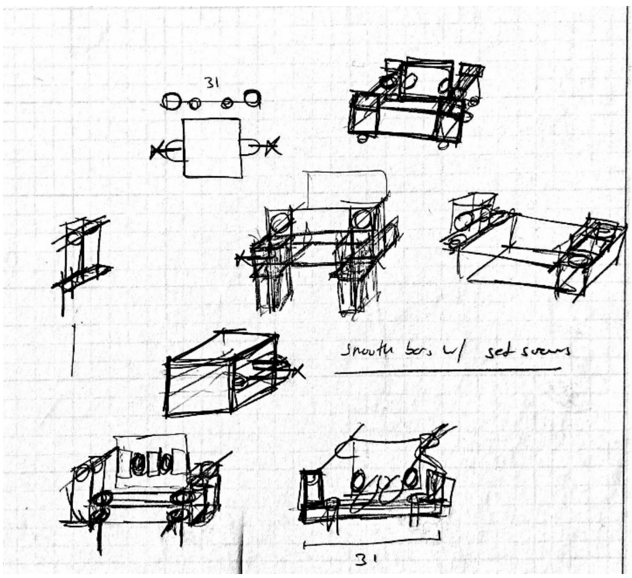


Figure 48. Progressive sketches of slider base design

Version 1 was designed to have an angle of 3 degrees between the horizonal axis and the linkage in the unloaded position. This specification was chosen to ensure the greatest practical amount of force amplification possible. Shown below in **Figure 49** is a picture of the assembled version 1.


Figure 49. Assembled version 1

Part 2: Changes to Version 1

Version 1 was a sound initial prototype; however, there were significant issues that prevented it from gathering accurate measurements.

The first issue was the amount of friction in the weighing linkage. The linkage would not spring back to its original position because the bending force exerted by the strain gauge was not sufficient to overcome the friction caused by the linkage joints.

The second issue is the size of the linkage angle. That is, the proximity of the 3-degree linkage angle to 0 degrees caused the linkage to bind so frequently that the bonus amplification from a small initial angle was invalidated by the lack of practicality of that design. **Figure 50** shows the 3-degree angle and how close it is to the 0-degree mark.

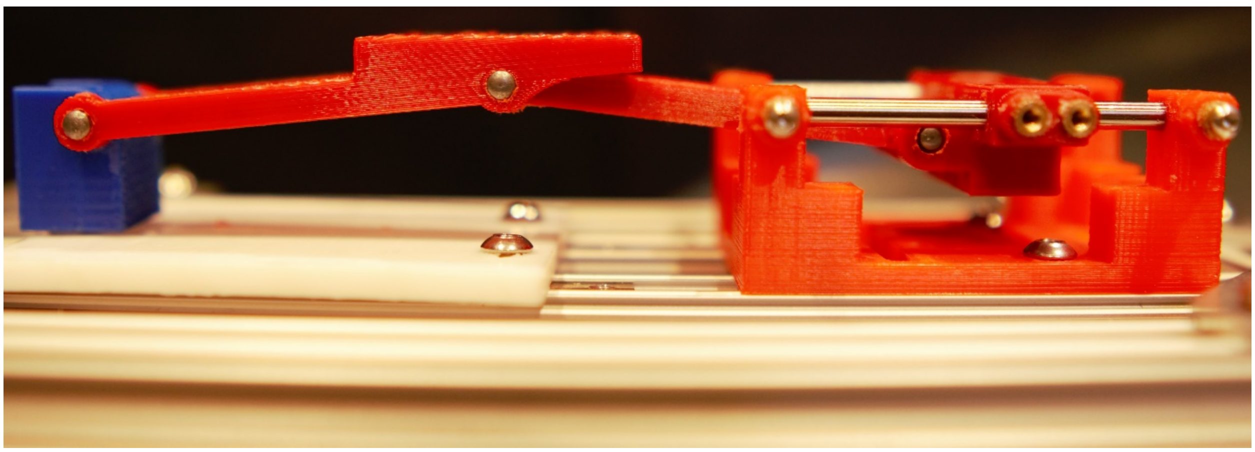


Figure 50. 3-degree angle on version 1

The third issue was that the frame was not grounded and acted as a sort of resonant antenna, which interfered with the oscilloscope readings from the amplification circuit.

Finally, the slider block that attached the weighing linkage to the strain gauge was prone to detaching, had a lot of friction associated with it, and was constantly sliding into an acrylic plate.

Part 3: Designing Version 2

All the problems noted above needed to be addressed in version 2. The friction in the linkage was combatted by adding bearings at all attachment points in the linkage. This modification vastly reduced the friction but made the overall linkage bigger because the addition of bearings required the redesign of most of the components in the weighing linkage.

The small initial angle of 3 degrees was changed to 6 degrees, greatly reducing the chance for the link to bind during normal usage.

The ungrounded frame was easily fixed by adding a wire to the strain gauge sidewall, which eliminated all antennae-like amplification signals.

The redesign of the slider block was the most prominent design change in this version. All contact with the ground was eliminated in this version; in version 2, the slider block simply fits over the top of the strain gauge. The slider block is held in position by a screw and attaches to the weighing linkage by a bearing-rod connection.

Shown below in **Figure 51** is the final construction of version 2.

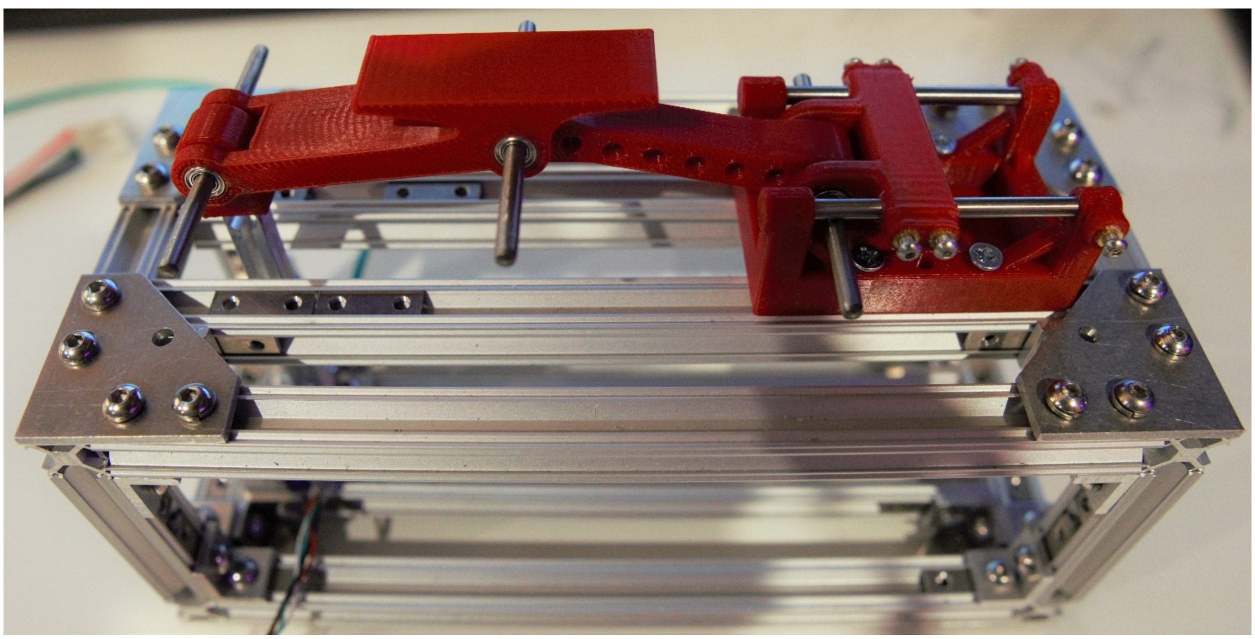


Figure 51. Final construction of version 2

Part 4: Changes to Version 2

Version 2 is a great improvement over all aspects of version 1. However, version 2 does require one modification. The glaring issue is still the connection between the strain gauge and the weighing linkage. There is still too much play in the vertical connection; therefore, a modified connection must be implemented. Shown below in **Figure 52** is a potential design to solve this problem. The engineering drawings can be found in the appendix.

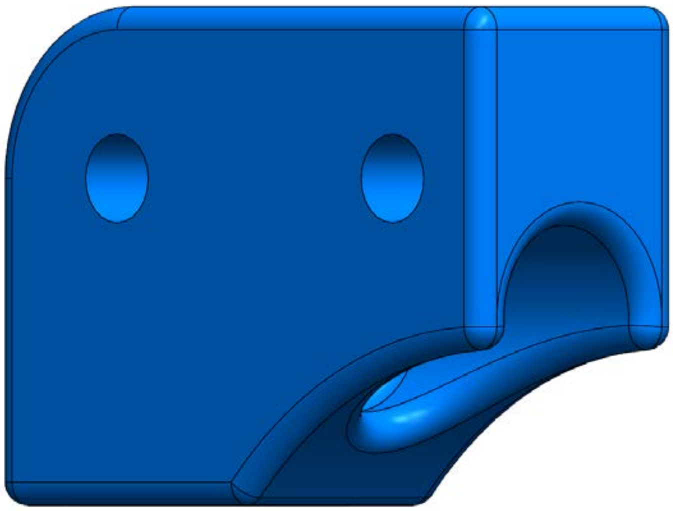


Figure 52. Proposed slider block change

So far, at this point in our testing, this connection is the only problem with version 2.

Appendix

Parts list

Parts to buy

- 1x American Weigh Scale Gemini Series Precision Digital Milligram Scale (listing on Amazon)
- Strain gauge sidewall (must be printed)
- 4x different 16 AWG colored wire, about 1ft each in length
- 4x 16 AWG heat shrink
- 4x pin
- 1x 4-pin header
- 1x 4-pin plug
- 8x 10mm x 10mm T-slot @ 6in long (McMaster Carr part number: 1959N1)
- 4x 10mm x 10mm T-slot @ 2in long (must be cut from a 3- or 6-in piece)
- 4x 10mm x 10mm T-slot @ 3in long (McMaster Carr part number: 1959N1)
- 8x corner braces (McMaster Carr part number: 1959N45)
- 1x screw bag w/ washers (McMaster Carr part number: 1959N39)
- 26x L brackets (McMaster Carr part number: 1959N41)
- 10x ball bearings, 6mm OD, 3mm ID (McMaster Carr part number: 7804K124)
- 5x 50mm long, 3mm diameter shafts (McMaster Carr part number: 1265K34)
- 4x M3 bolt 10mm long
- 2x M3 bolt 10mm long w/nuts
- 1x M2 bolt 10mm long w/nut

Parts to 3D print

- Long link
- Short link
- Slider
- Base plate
- Push block

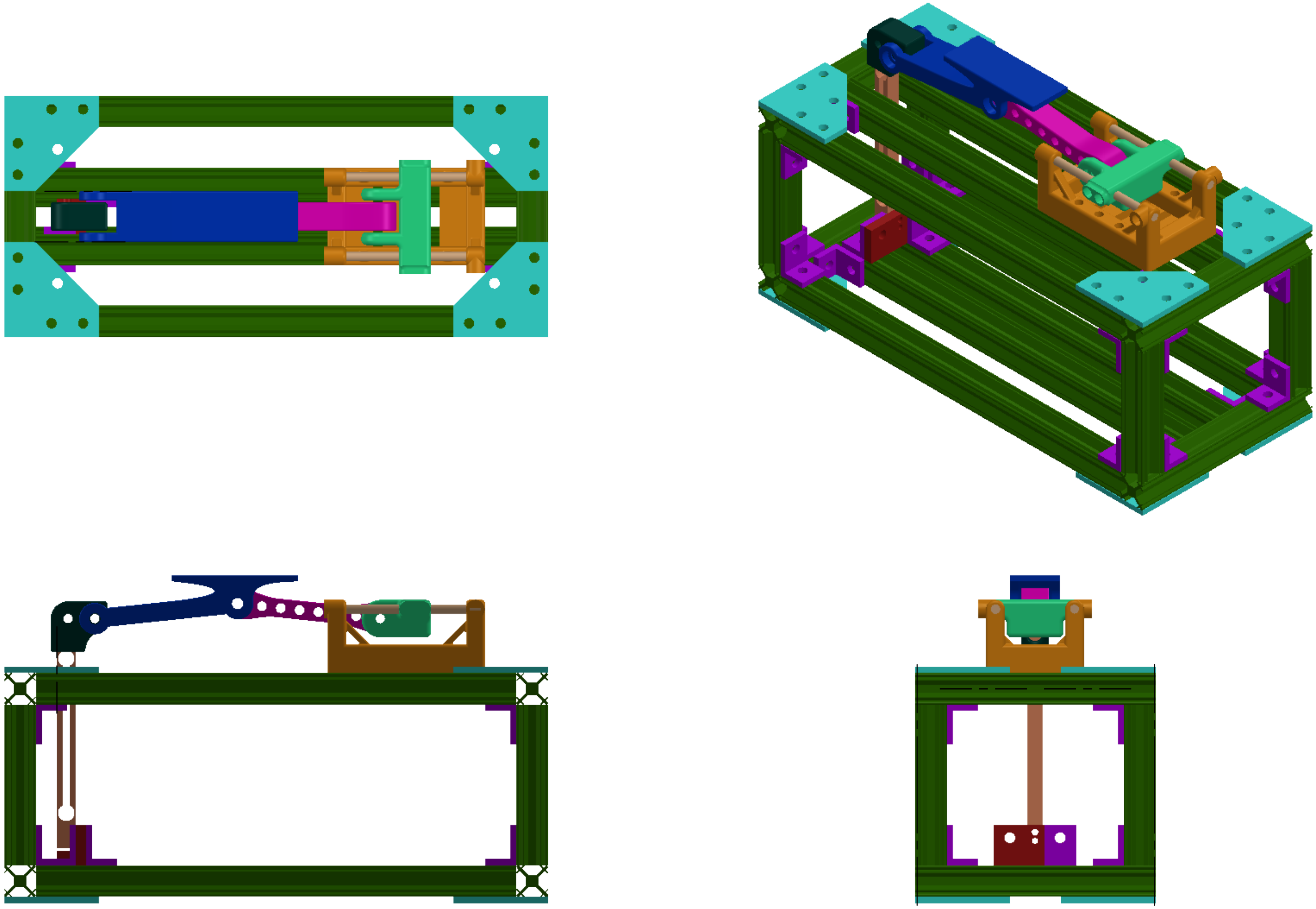
Parts to make

- Assembled linkage
- Modified strain gauge
- Scaffold

Tool list

- Electronics screwdriver set
- Box cutter
- Wire cutter
- Soldering iron
- Solder, about 6in
- Heat gun
- Hot-melt glue gun
- Electronics screwdriver set
- Wire stripper
- Assorted small files
- Metric Allen key set
- 3D printer
- Super Glue
- Drill press (drill will suffice)
- Assorted files
- Benchtop grinder (sandpaper will suffice)

Reference drawings



RHIT A LANDSCAPE

Dimensions are mm and degrees	Research_Assembly_V4
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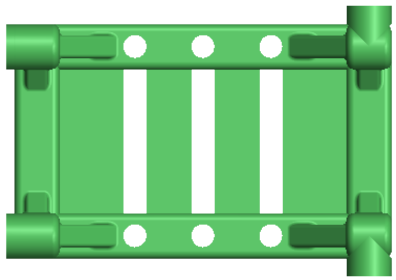

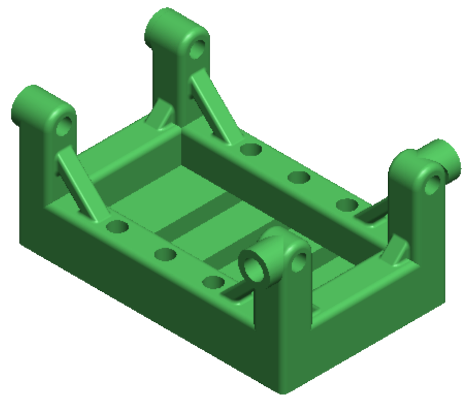

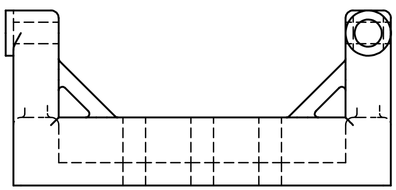

RHIT A LANDSCAPE	
Dimensions are mm and degrees	Jig_MKII
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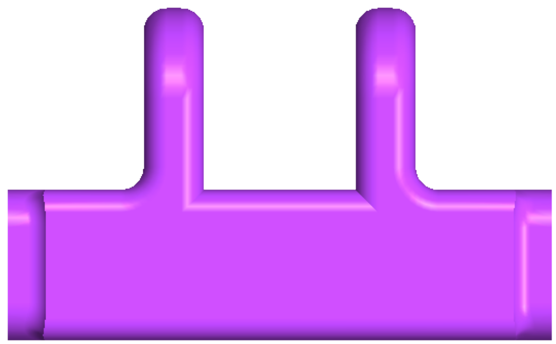
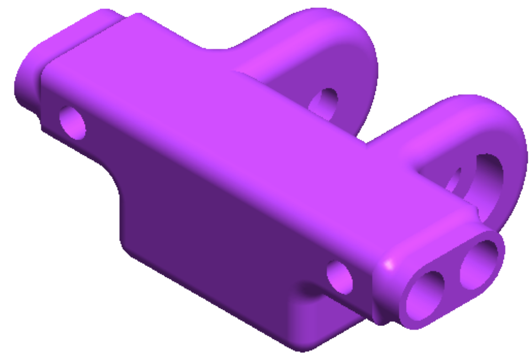
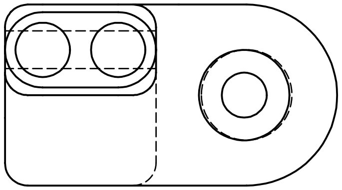
	Scale: 1:1 Date: 2/27/2020







RHIT A LANDSCAPE			
Dimensions are mm and degrees	Slider_MKII		
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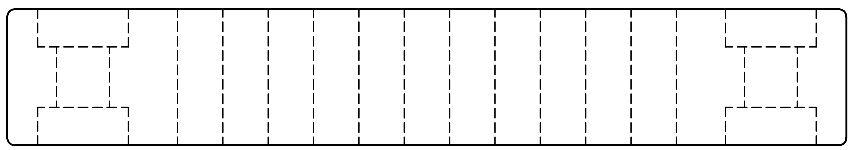
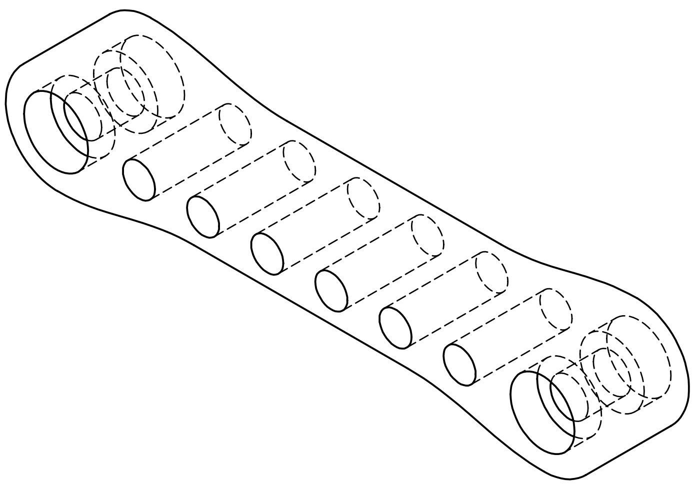
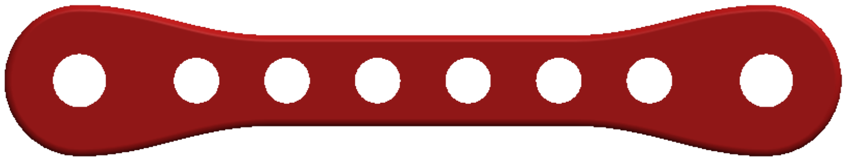
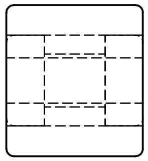








RHIT A LANDSCAPE

Dimensions are mm and degrees

Default Tolerances

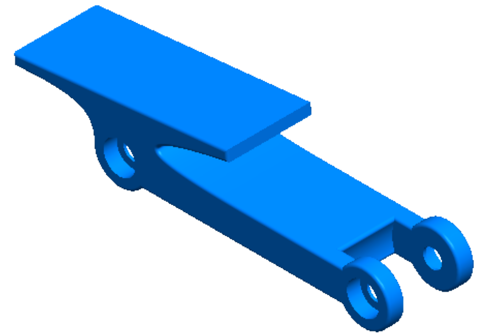
.X	±0.1
.XX	±0.03
.XXX	±0.005
Angles	±2

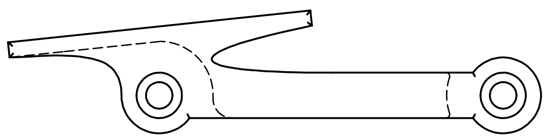
Short_linkMKII

Drawn by: salakbw

Scale: 2:1

Date: 2/27/2020





RHIT A LANDSCAPE

Dimensions are mm and degrees	Long_linkMKII
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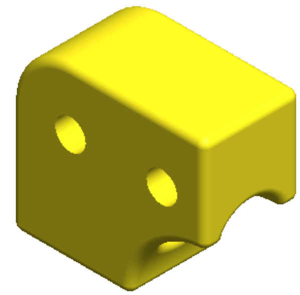

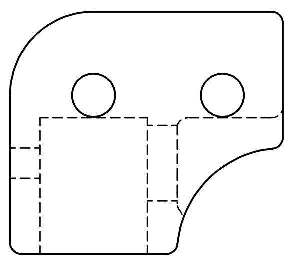

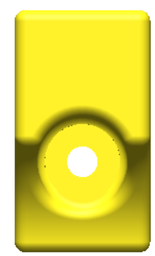

RHIT A LANDSCAPE		
Dimensions are mm and degrees	Connecter_MKIII	
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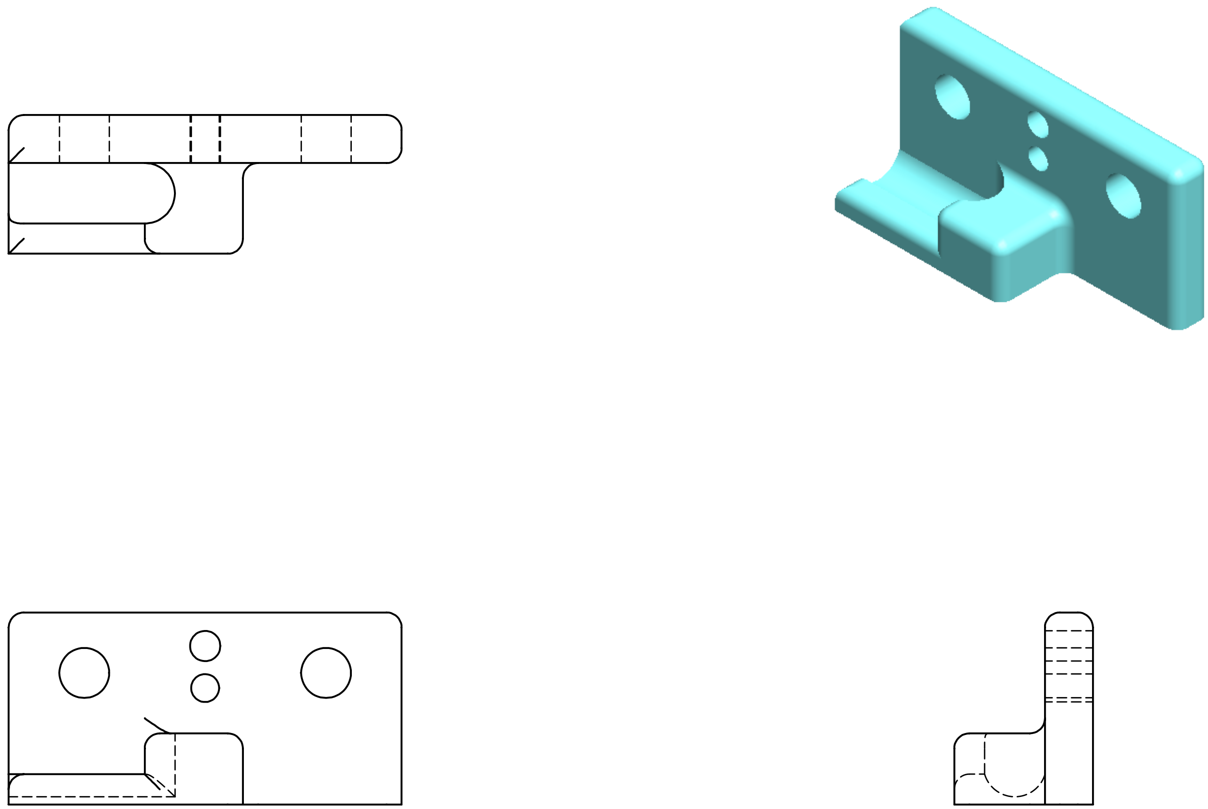

RHIT A LANDSCAPE		
Dimensions are mm and degrees	Strain_sidewallMKII	
Default Tolerances .X ±0.1 .XX ±0.03 .XXX ±0.005 Angles ±2	Drawn by: salakbw	
	Scale: 2:1	Date: 2/27/2020