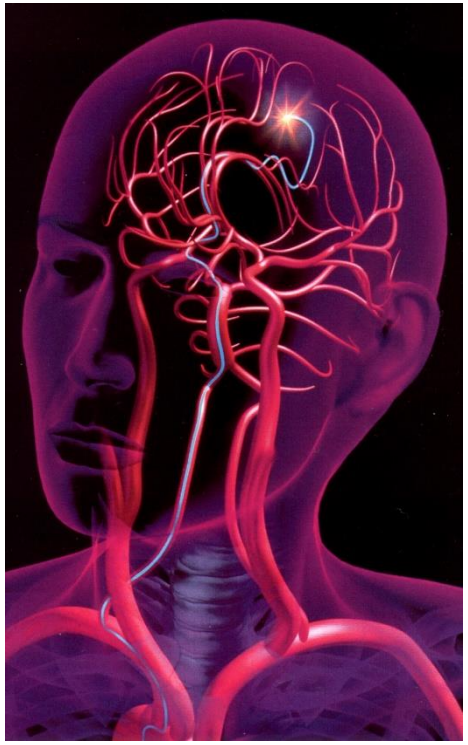
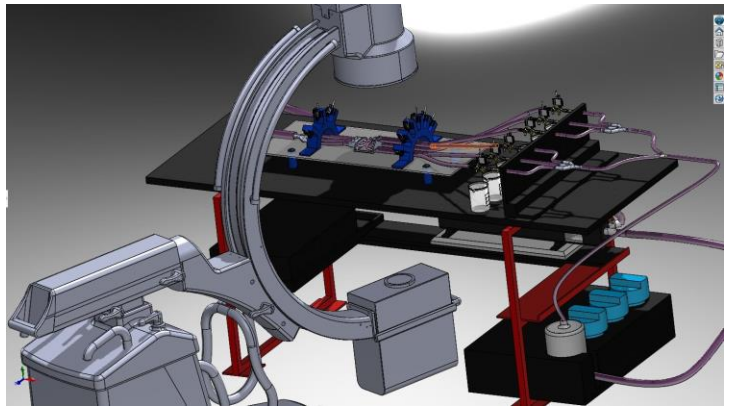
NORTHERN ARIZONA UNIVERSITY



ME 476C Spring 2026 – PIV team V2

Carley Barton
Blake Pottinger
Clinton Nelson
Ryan Abelman

Particle Image Velocimetry integration with the Bioengineering Devices Lab benchtop flow model



Project Description/Importance

Particle Image Velocimetry (PIV):

- Evaluate fluid flow with outputs of velocities that can be derived to find stresses.
- Uses lasers to illuminate particles in flow and a camera to capture a sequence of images to be analyzed.

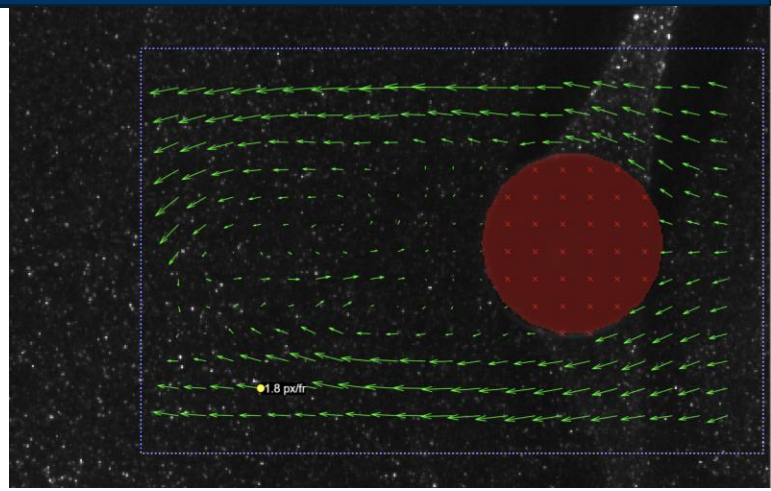


Figure 1: Flow analysis with vectors

What has been done:

- The previous capstone team created a set up of a PIV system but without the flow loop. Preliminary tests conducted were a proof of concept for setting up the laser and camera.

Goals for the future:

- Incorporating a PIV set up into the BDL benchtop flow model.
- Test medical products on different phantoms with a flow system to see how the flow is behaving around these products.

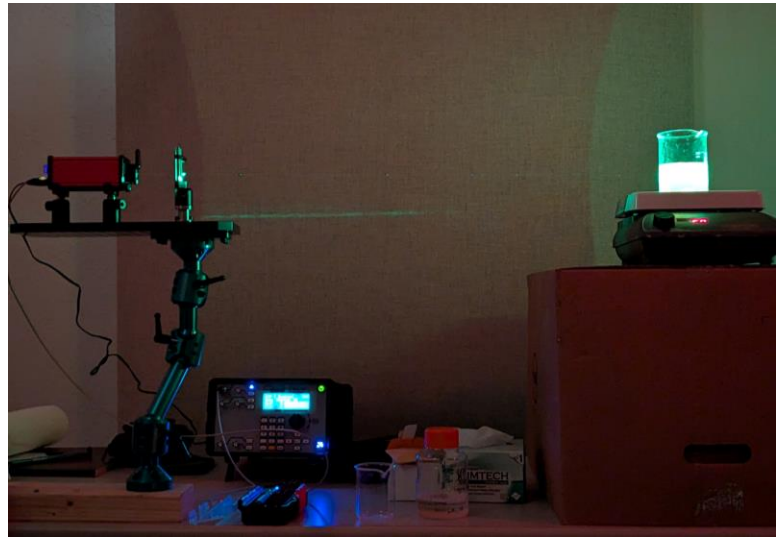


Figure 2: Previous PIV set up

Benchmarking

Benchmark #1:

Figure 3: Cerebral arteries phantom [2]

Intricate model that we will try to replicate something similar to in our molds. Eventually we will also benchmark our data during experiments to the data in this research article.

Benchmark #2:

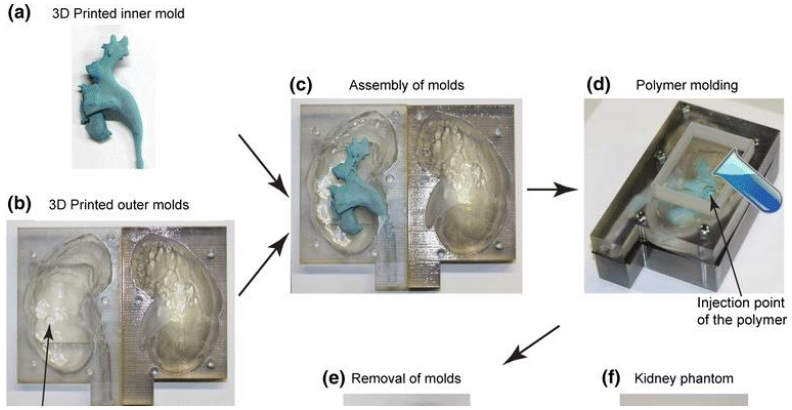


Figure 4: Kidney Phantom [1]

Casting step by step, how we will model our phantom and the process of silicone casting.

Benchmark #3:

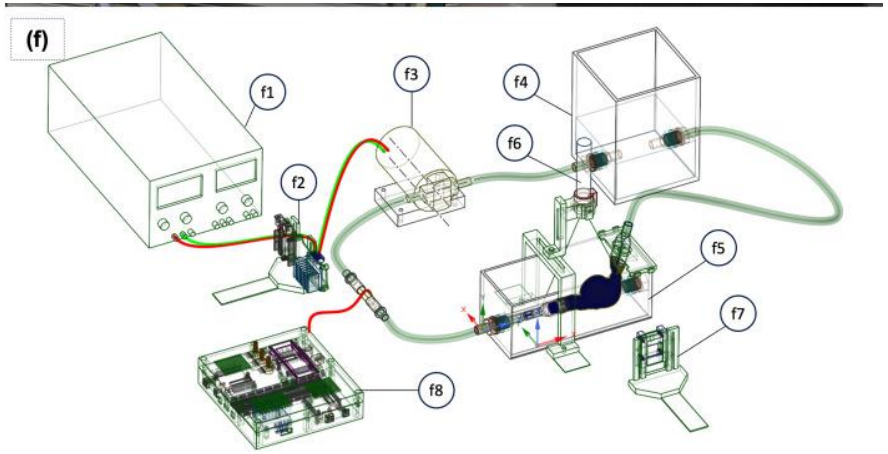


Figure 5: Abdominal aortic aneurysm phantom and PIV set up [3]

Flow loop model set up. Shows where the pump, phantom and reservoir is. This is helpful for our future when integrating PIV with the BDL benchtop model.

Sponsor

Sponsor: Tim Becker, PhD

Associate Professor

Mechanical Engineering Department

Principle Investigator

Bioengineering Devices Lab

Chief Technology Officer

Aneuvas Technologies, Inc. (ATI)

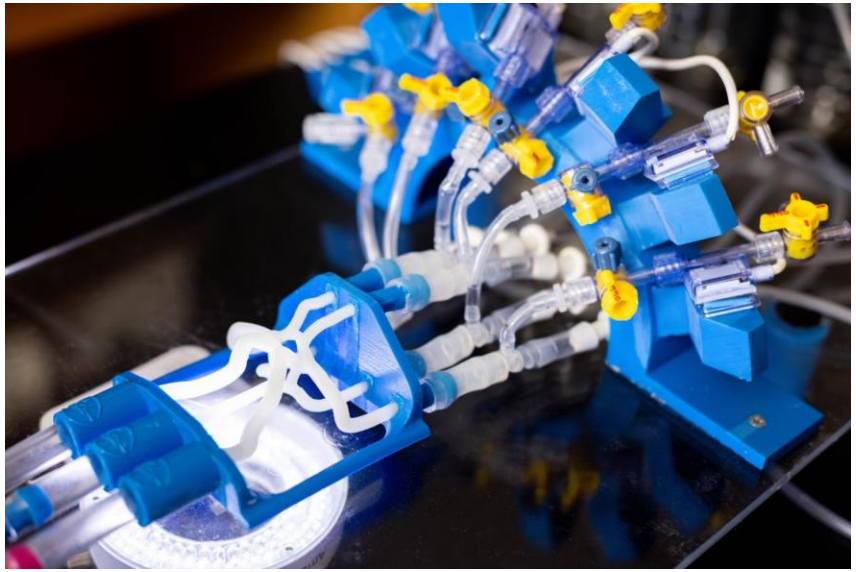
Client: Jesse Wells, B.S.

Lead Engineer

Bioengineering Devices Lab

Lead Engineer

Aneuvas Technologies, Inc. (ATI)



Black Box Model

Manufacturing Inputs

Materials
- Silicone
- PVA/PLA/Wax
- Solvent
- Container

Energy
- Mixing
- Pressure chamber
- Time

Signal
- On/off

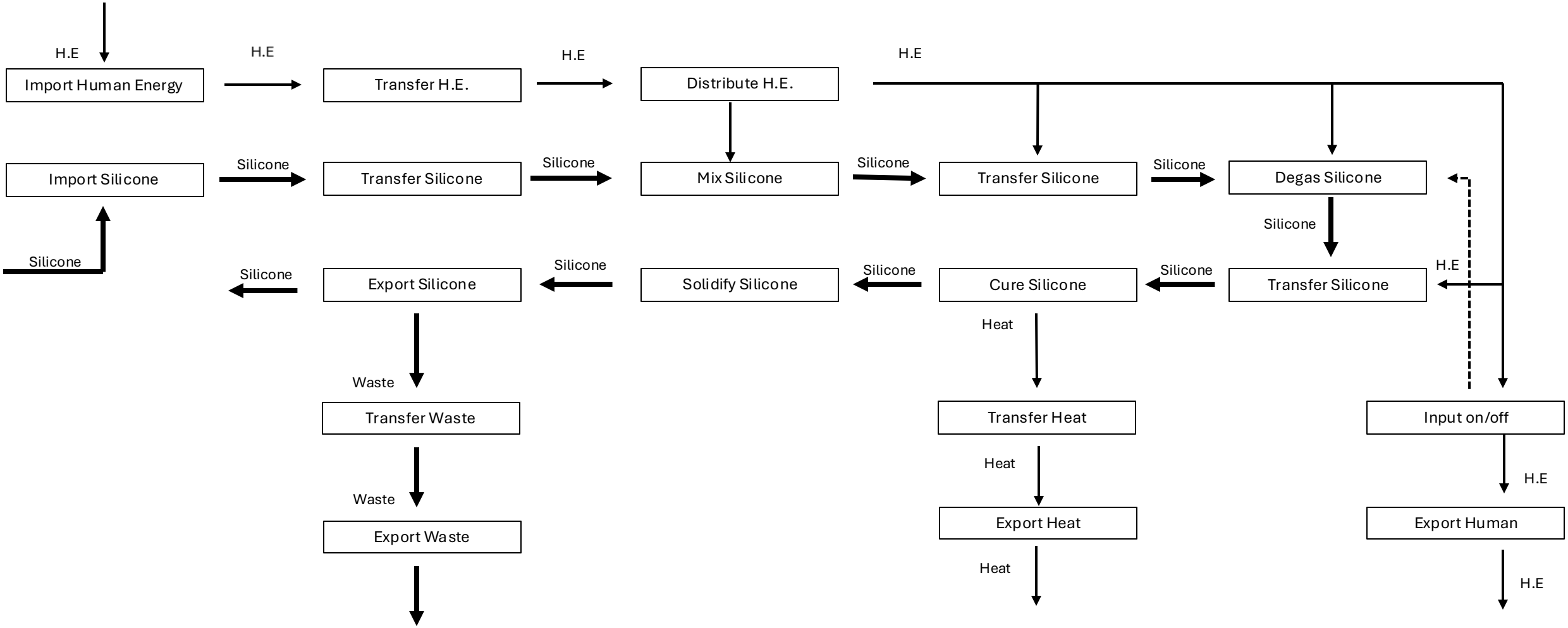
Manufacturing Output

Materials
- Silicone Model
- Waste Material

Energy
- Heat

Signal
- On/off
- Visual signal

Decomposition Model



Mathematical Modeling – Refractive Index

Lorentz-Lorenz equation [4]

$$N_i = \frac{{n^2}_i - 1}{{n^2}_i + 2}$$

$$N_{mix} = \emptyset_s N_s + \emptyset_w N_w$$

N_i= Lorentz-Lorenz parameter of component

$\emptyset_i$= Volume fraction

n_i= refractive index of component

Known:

RI Water = 1.333

RI Silicone= 1.41

Last presentation solved for RI of HPMC mixture which is about 1.334

- **For silicone**

$n_s = 1.41 \implies {n_s}^2 = 1.988$

$N_s = \frac{1.988-1}{1.988+2} = 0.248$

- **For water**

$n_w = 1.333 \implies {n_w}^2 = 1.777$

$N_s = \frac{1.777-1}{1.777+2} = 0.206$

- **Target silicone mixture**

n= $1.334 \implies n^2 = 1.7796$

N= $\frac{1.7796-1}{1.7796+2} = 0.2063$

$N_{mix} = \emptyset_s N_s + \emptyset_w N_w$ Since $\emptyset_s + \emptyset_w = 1$ we can plug in $\emptyset_w = 1 - \emptyset_s$ and solve

$0.2063 = \emptyset_s (0.248) + (1 - \emptyset_s)(0.206)$

Solve and $\emptyset_s = 0.00714$

Therefore, the volume fractions would be 0.71% silicone and 99.29% water which is not possible.

Mathematical Modeling – Refractive Index

Lorentz-Lorenz equation [4]

$$N_i = \frac{{n^2}_i - 1}{{n^2}_i + 2}$$

$$N_{mix} = \emptyset_G\, N_G + \emptyset_H N_H$$

N_i= Lorentz-Lorenz parameter of component

$\emptyset_i$= Volume fraction

n_i= refractive index of component

Known:

RI HPMC = 1.334

RI Silicone= 1.41

RI Glycerin = 1.473 [6]

- **For glycerin**

$n_G = 1.473 \Longrightarrow {n_G}^2 = 2.17$

$N_G = \frac{1.988-1}{1.988+2}$ = 0.281

- **For HPMC**

$n_w = 1.334 \Longrightarrow {n_w}^2 = 1.78$

$N_w = \frac{1.78-1}{1.78+2}$ = 0.206

- **Target silicone mixture**

n= $1.41 \Longrightarrow n^2 = 1.988$

N= $\frac{1.988-1}{1.988+2}$ = 0.248

$N_{mix} = \emptyset_G\, N_G + \emptyset_H N_H$ Since $\emptyset_G + \emptyset_H = 1$ we can plug in $\emptyset_H = 1 - \emptyset_G$ and solve

$0.248 = \emptyset_G$ (0.281)+(1- $\emptyset_G$)(0.206)

Solve and $\emptyset_G = 0.56$

Our fluid mixture in order to have a refractive index of 1.41 it needs to be comprised of 56% glycerin and 44% HPMC

Mathematical Modeling – Minimum Wall Thickness

$$[5]\ Hoop\ Stress:\ \sigma = \frac{Pr}{t}$$

$$t = \frac{Pr}{\sigma_{allowable}}$$

$$t = 0.0262mm$$

$P = Internal\ Press = 0.015995\left(\frac{n}{mm^2}\right) = 120mmHg$

$r = Radius = 2.5mm$ (average vessel radius)

$\sigma_{allowable} = 1.5MPA$ (given from silicone properties[7])

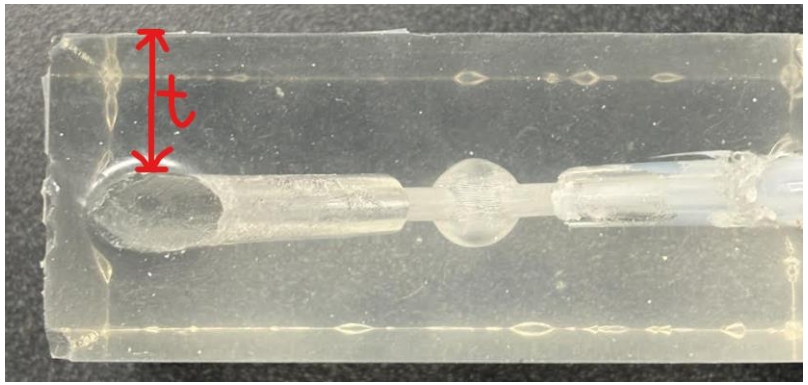


Figure 6: Side view of Example Model

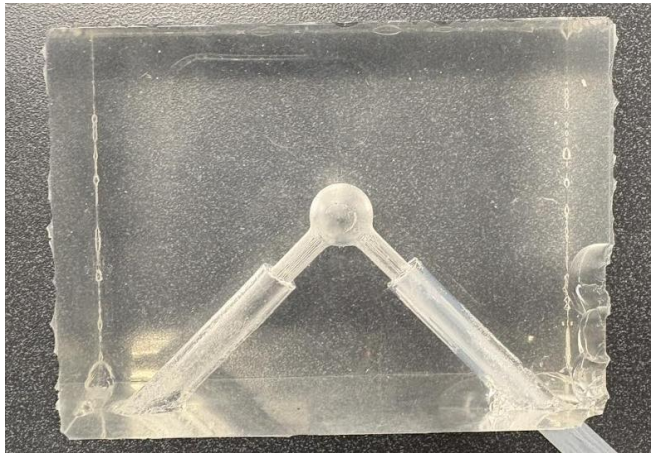


Figure 7: Front view of Example Model

Mathematical Modeling – Phantom Cost Analysis

$$price\ per\ unit\ (PPU) = \left(\frac{C_f}{n}\right) + C_v$$

$$C_v = Variable\ Cost \approx \$17.06$$

$$C_f = Fixed\ Cost \approx \$5 \text{ (non-heated) and } \$7 \text{ (heated)}$$

$$n = quantity$$

$$volume\ of\ phantom\ unit \approx 392\ cm^3\ or\ mL$$

$$one\ order\ of\ silicone\ (5500mL) \approx \$196.25$$

$$number\ of\ units\ produce\ per\ order \approx 14.03$$

$$price\ per\ unit\ volume \approx \$14.02$$

Cost Analysis Table

Quantity (n)	Normal Cure Time (7-8hrs)	Faster Cure Time (1-2hrs @ 120°C)
1	$22.02	$24.02
2	$19.52	$20.52
3	$18.69	$19.35
5	$18.02	$18.42
10	$17.52	$17.72

Table 1: Phantom Cost analysis

Mathematical Modeling – Summary

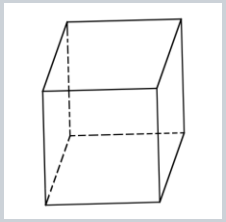
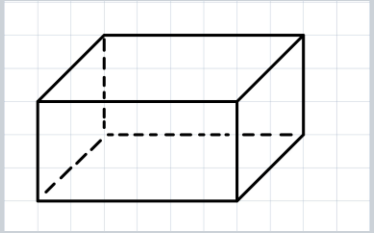
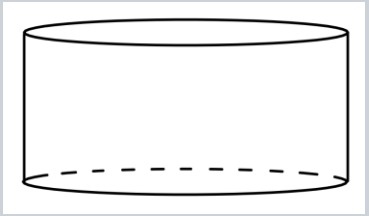
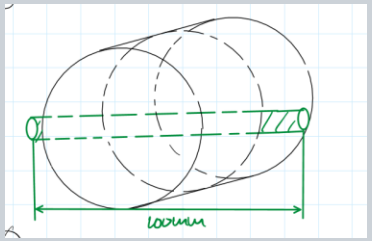
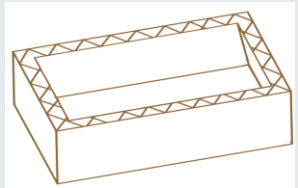
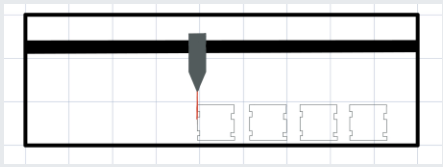
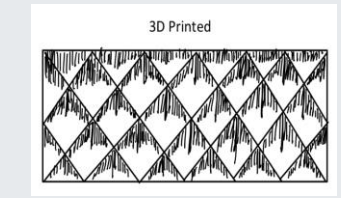
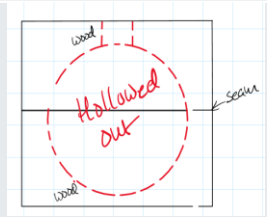
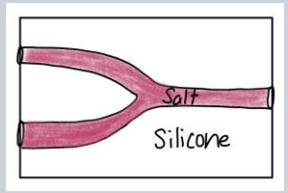
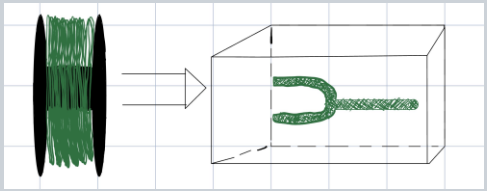
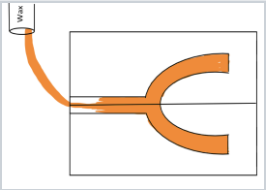
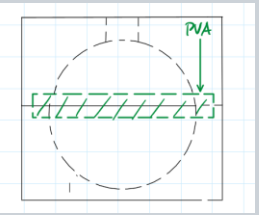
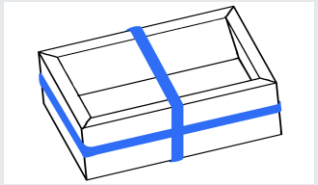
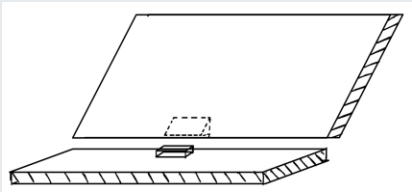
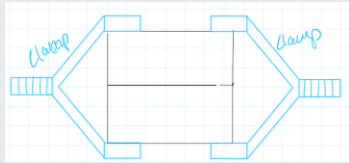
Refractive index silicone – this informed our future decisions by disproving our plan to add water to our silicone mixture to lower the refractive index and match the solid silicone to the liquid flow.

Refractive index adding glycerin to HPMC – To pivot from our original plan as stated above we are now planning on adding glycerin to our HPMC flow mixture to raise the refractive index to 1.41 and match it to the silicone. Solving for the weight fractions will allow us to test it later when making the mixture ourselves, and this will be validated then.

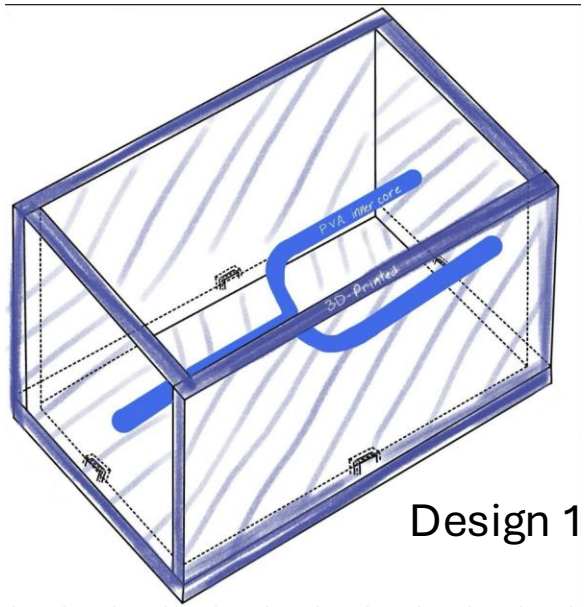
Minimum wall thickness – By solving for this thickness we found that the minimum is very small therefore we can make the thickness however small or large and we will continue to research a good value for this thickness. This was validated by comparing examples in textbooks and sources.

Phantom cost – This is a new cost analysis based on an average silicone volume of a phantom; the volume we will start out with will be around a 140x70x40[mm^3] block. This cost shows us how much silicone we will need for multiple phantoms and a rough budget if more needs to be purchased.

Concept Generation

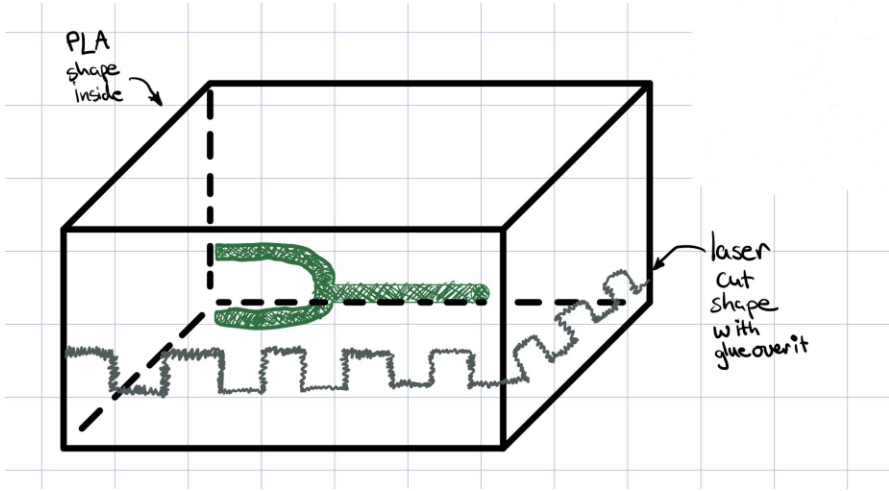
	1	2	3	4
A Shape of silicone block	 Square	 Rectangle	 Oval	 Circle
B Material of outside silicone mold	 Cardboard	 Laser cut acrylic	 3D printed	 Wood
C Male mold material	 Salt	 PLA	 Wax	 PVA
D Outside box mold assembly	 Rubber band	 Glue	 Pins	 Clamps

Decision Matrix Designs



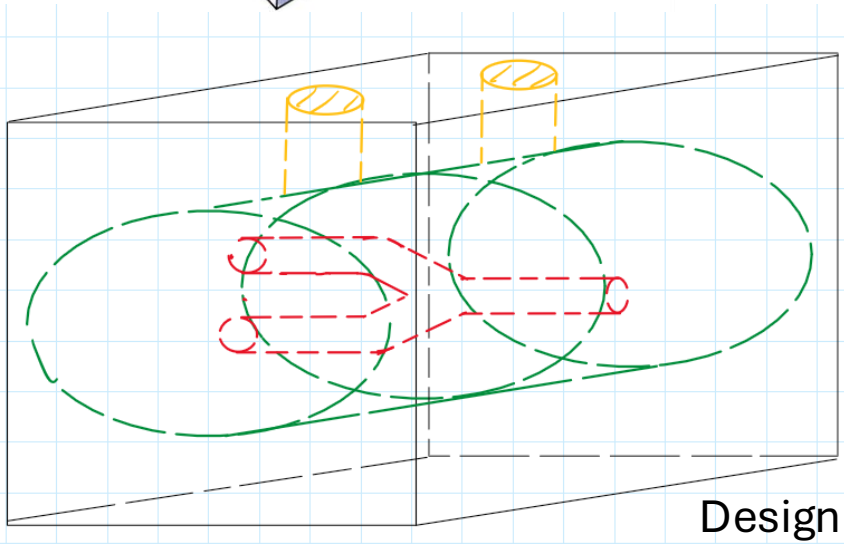
A2
B3
C4
D3

Design 1



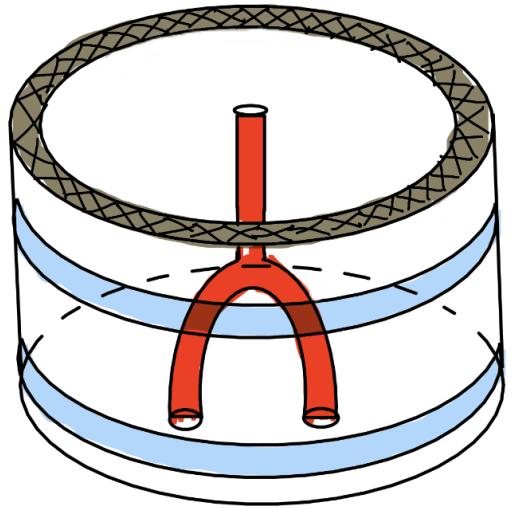
A1
B2
C2
D2

Design 2



A4
B4
C3
D4

Design 3



A3
B1
C1
D1

Design 4

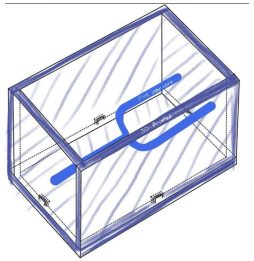
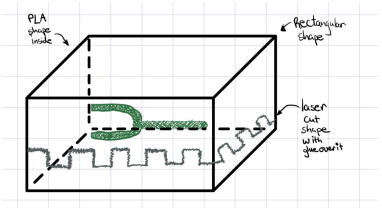
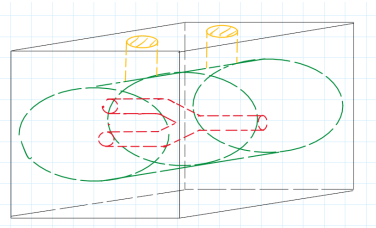
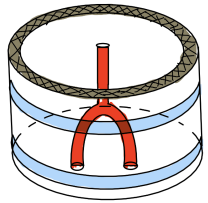
Pugh Chart

- Pugh Chart
- Used to Narrow down our final Design.
- Our third Design was used to compare our other designs.

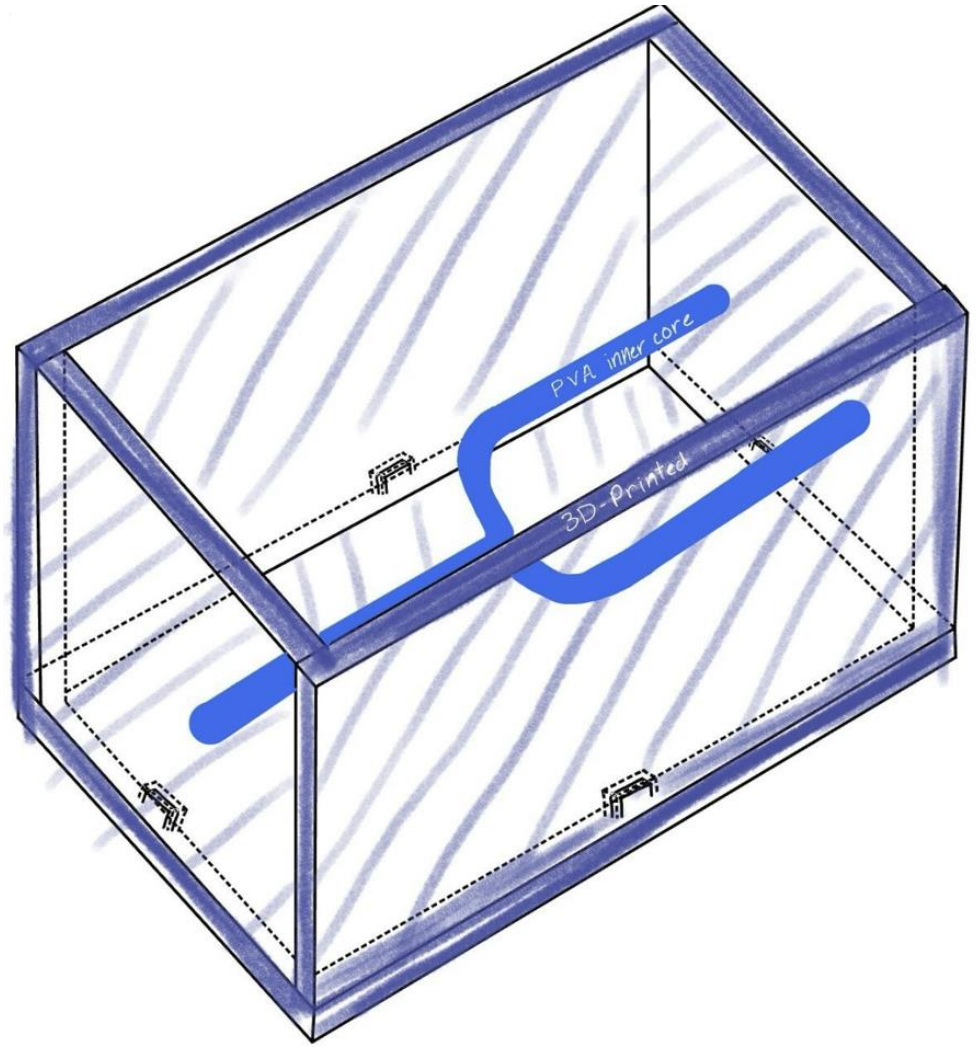
Concept/ Criteria	Design 1	Design 2	Design 3	Design 4
Clarity Of Silicon	S	S	Datum	S
Validation	+	+		+
Ease of Core Removal	+	-		-
Material Usage	S	+		-
Sum +	2	2	Datum	1
Sum -	0	1	Datum	2
Sum S	2	1	Datum	1

Decision Matrix

- Clarity of Silicon
  - The Overall Quality of the Silicon
- Validation
  - Future testing
- Ease of Core Removal
  - How easy it to remove core.
- Material Usage
  - How much material will be used throughout the process.

Criteria	Weight	Design 1 		Design 2 		Design 3 		Design 4 	
		Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted
Clarity Of Silicon	0.3	90	27	70	21	60	18	90	27
Validation	0.2	90	18	70	14	90	18	60	12
Ease of Core Removal	0.4	90	36	80	32	70	28	50	20
Material Usage	0.1	90	9.0	40	4.0	90	9.0	40	4.0
Total:	1.0	Sum:	90	Sum:	71	Sum:	73	Sum:	63

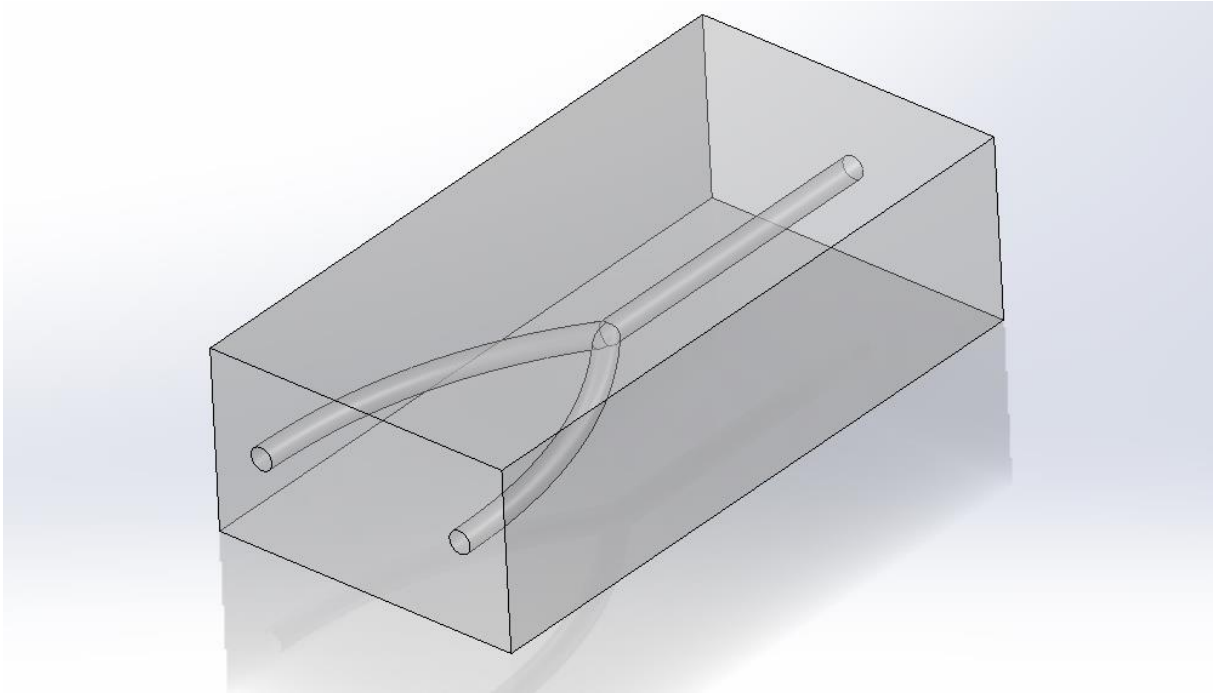
Final Design and Rough CAD Model



Design 1

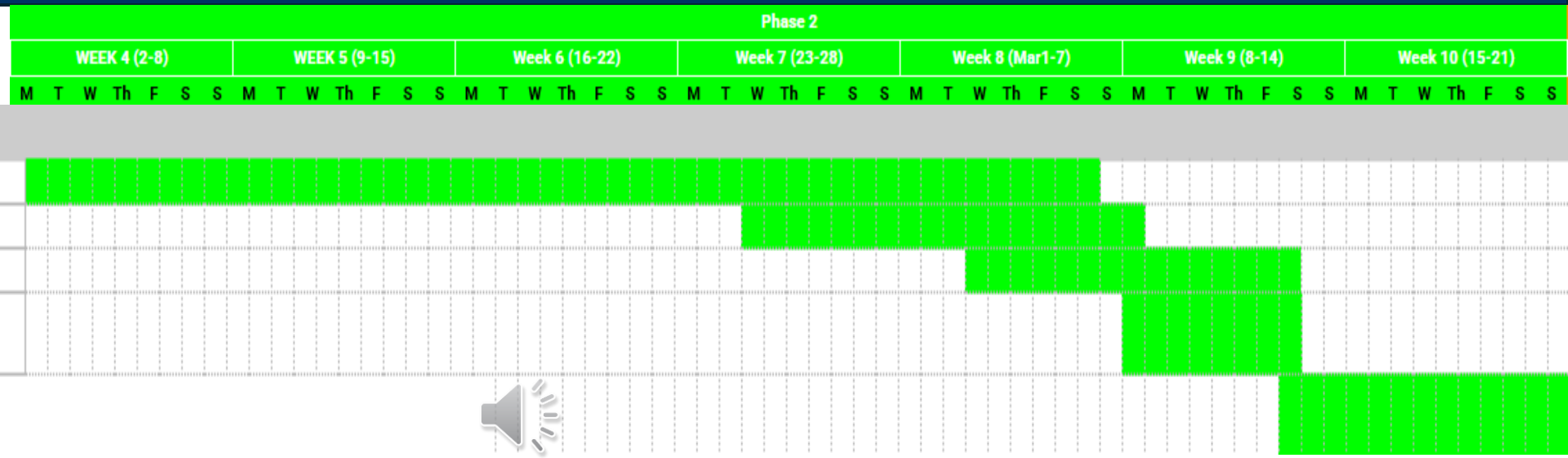
Final design:
Rectangular shape
3D printed outer mold with pins that hold it in place.
PVA water soluble inner core mold.

Rough CAD of final product



Schedule (Gantt Chart)

Current Schedule:



Phase 2				
HW3	Everyone	100%	1/12/26	2/27/26
Presentation 2	Everyone	100%	2/13/26	3/2/26
Report 1	Carley	15%	2/23/26	3/8/26
Website Check 1	Ryan and Carley	25%	3/1/26	3/8/26
Analysis Memo	Blake and Clint	0%	3/8/26	3/20/26

Future Schedule:

Phase 3				
1st Prototype Demo	Blake and Clint	5%	3/22/26	3/30/26
Presentation 3	Everyone	0%	3/22/26	3/30/26
Report 2	Carley	0%	4/5/26	4/17/26
Final CAD/BOM	Blake and Ryan	0%	4/5/26	4/25/26
HW4	Everyone	0%	4/5/26	4/26/26
Phase 4				
2nd Prototype Demo	Blake and Clint	0%	4/21/26	4/27/26
Project Management	Everyone	0%	4/21/26	5/1/26
Website Check 2	Ryan and Carley	0%	4/28/26	5/3/26

Projects Budget

- Income
  - Materials from previous PIV team
  - Fundraising
- Fundraising update
  - We are planning on reaching out to DOW for samples and donations of silicone
  - Contacting various 3-D printing companies such as Formlabs for filament samples
  - Receiving donations from family and friends
- Predicted Expenses
  - $665.77 in testing materials
- Expenses to date
  - None
- Resulting Balance
  - $2,334.23

Projected budget		
Item	Cost	Quantity
PVA material	35.99	1 roll
PLA material	22.99	1 roll
1/8"IDx3/16"OD Tubing	7.26	25 ft
1/4"IDx3/8"OD Tubing	3.28	10 ft
Vial of particles color #1	200	1 vial
Vial of particles Color #2	200	1 vial
Liquasil clear silicone	196.25	5.5 kg
Total:	665.77	
Remaining Budget:	2334.23	

Table 2: Project expenses estimation

Bill of Materials

Part	Part Number	Quantity	Vendor	Manufacturer	Manufactured or Purchased	Lead Time	Part Material	Manufacturer Location	Part Status	Price
PVA 3D printing matieral	N/A	1	Amazon	TRONXY	Purchased	N/A	PVA	N/A	To be Purchased	35.99
PLA 3D printing material	N/A	1	Bambu	Bambu	Purchased	N/A	PLA	N/A	To be Purchased	22.99
1/8"IDx3/16"OD Tubing	N/A	25 ft	Home Depot	Home depot	Purchased	N/A	PVC	N/A	To be Purchased	7.26
1/4"IDx3/8"OD Tubing	N/A	10 ft	Home Depot	Home depot	Purchased	N/A	PVC	N/A	To be Purchased	3.28
Vial of particles color #1	N/A	1	Cospheric	Cospheric	Purchased	N/A	N/A	N/A	To be Purchased	200
Vial of particls color #2	N/A	1	Cospheric	Cospheric	Purchased	N/A	N/A	N/A	To be Purchased	200
Liqualsil clear silicone	N/A	5.5 kg	Castaldo	Castaldo	Purchased	N/A	Silicone	N/A	Donated	196.25
Mount for Lens	N/A	1	N/A	N/A	Purchased	N/A	N/A	N/A	Purchased	######
Breadboard	M45B612	1	ThorLabs	ThorLabs	Purchased	N/A	N/A	N/A	Donated	$0.00
Laser	NPL52C	1	ThorLabs	ThorLabs	Purchased	N/A	N/A	N/A	Purchased	######
Function Generator	9520	1	Quantum Composers	Quantum Composers	Purchased	N/A	N/A	N/A	Purchased	######
Camera	CR21-1.0-32M-FNL	1	TBD	TBD	Purchased	Up to 4 weeks	N/A	N/A	Purchased	######
Cylindrical Lens	LG1629L1-A	1	ThorLabs	ThorLabs	Purchased	N/A	N/A	N/A	Purchased	######
Articulating Arm Base	1530N11	2	McMaster Carr	McMaster Carr	Purchased	1 Week	N/A	N/A	Purchased	$42.83
Articulating Arm Connector	1530N12	2	McMaster Carr	McMaster Carr	Purchased	1 Week	N/A	N/A	Purchased	$48.68
Articulating Arm Links	1530N15	1	McMaster Carr	McMaster Carr	Purchased	1 Week	N/A	N/A	Purchased	$24.04
Articulating Arm Links	1530N16	1	McMaster Carr	McMaster Carr	Purchased	1 Week	N/A	N/A	Purchased	$27.45
Articulating Arm Mount Plate	1530N24	1	McMaster Carr	McMaster Carr	Purchased	1 Week	N/A	N/A	Purchased	$35.22
Articulating Arm Locking Levers	1530N14	2	McMaster Carr	McMaster Carr	Purchased	1 Week	N/A	N/A	Purchased	$25.63
Safety Shroud	N/A	1	N/A	Chris	Manufactured	1 Day	VeroCyan	BDL	To be manufactured	$0.00
Lens for Camera		1			Purchased		N/A	N/A	To be Purchased	######
Camera Filter		1			Purchased		N/A	N/A	To be Purchased	$300.00

Thank you
Any questions?

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