

The background is a dark purple gradient. In the center is a large, dark blue circle containing the text. Surrounding this central circle are various geometric shapes: a pink circle with diagonal stripes, a blue circle with diagonal stripes, a pink circle with a dot pattern, a yellow zigzag line, a yellow triangle, a pink triangle, a yellow triangle, a pink pentagon, a yellow triangle with vertical stripes, a pink circle, a yellow triangle, a pink circle with a dashed border, a yellow triangle with a dashed border, a pink circle with a dashed border, a yellow triangle with a dashed border, a pink circle with a dashed border, and a yellow triangle with a dashed border.

# Final Proposal

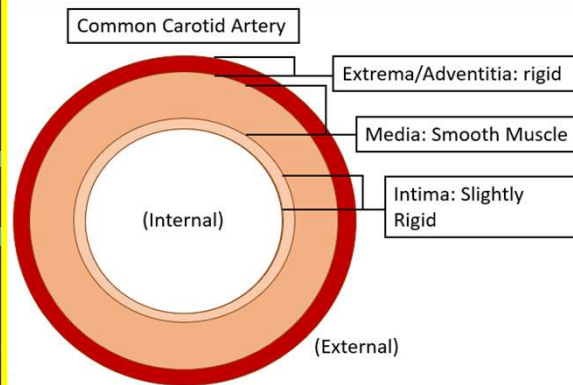
Kathryn Nelson – Luke Nelson  
Aditya Ponugupaty – Isaac Smith

# Project Description

Team BDL/Anevas 3D Printing is tasked with:

Create a 3D printed model that replicates organic tissue measurable to the human carotid artery.

## Human Carotid Artery



## Conduct Tests:

- Tension of specimen
- Specimen compliance
- Lubricity of specimen interior
- Compressive Modulus
  - Shear Modulus
- Specimen Hardness (?)

## Deliverables

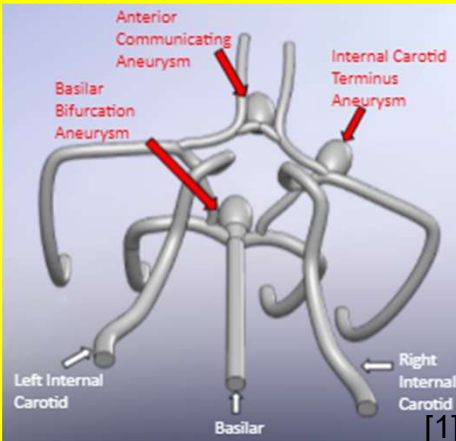
Qualitative data on material properties for each test.

## Repeatable:

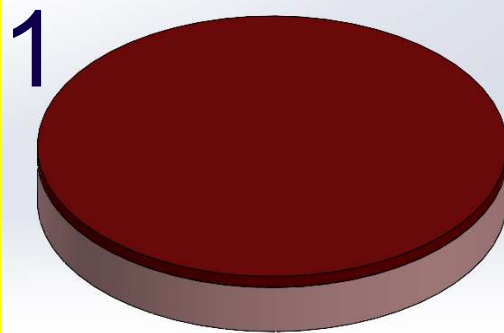
- Manufacturing
- laboratory implementation

# Design Description

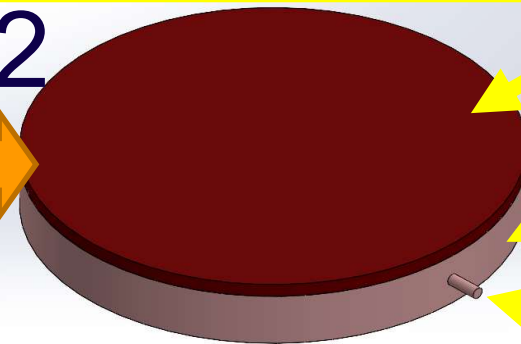
## Original System



## Proof of Concept Model



2



## Subsystems:

Tunica Intima

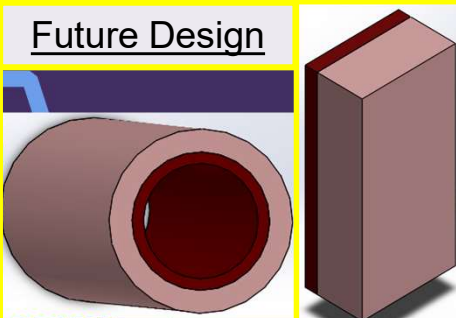
Tunica Media

ID "Nub"

## Prototype Function

- Cannot analyze original system, so we use a smaller specimen for testing.
- Allows for mechanical tests to be conducted with a Rheometer.
- Easy storage and soak – testing requires a 4-day PBS soak.
- Cheap to print; low material usage
- Layers replicate the human vascular layers (Tunica media and intima).
- 8mm diameter, 1.2mm depth; Intima: .26mm, Media: .94mm.

## Future Design



## Design Requirements

### CRs with relative weights:

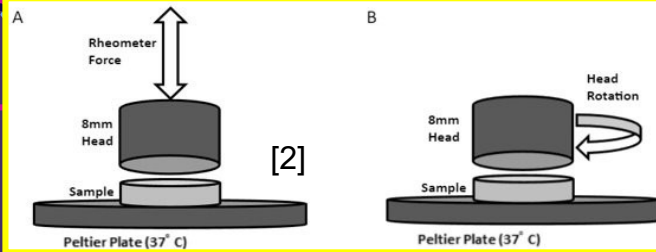
- **Size (3%)**
- **Easy to connect (8%)**
- **Hard interior/Soft exterior (Layered) (25%)**
- **Lightweight (3%)**
- **Material selection (25%)**
- **Retains shape (8%)**
- **Similar properties to organic tissue (25%)**
- **Cost within budget (3%)**

### Top 3 CR's are satisfied

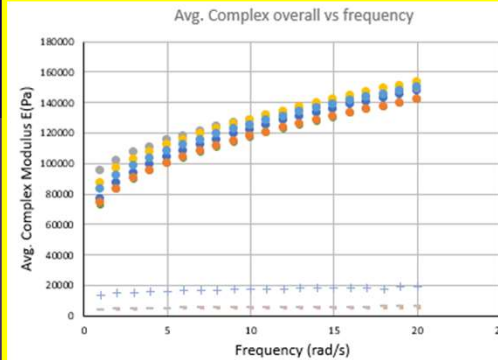
- **Hard interior/Soft exterior (25%)**
  - Layered design provides the ER's for this criterion.
- **Material selection (25%)**
  - Agilus and VC form a good base for human organic tissue
- **Similar properties to organic tissue (25%)**
  - Design considers the layer pattern of organic tissue
  - Design proposes that material will help the mechanical properties to match organic tissue
  - Design is safe to operate

# Proof of Concept

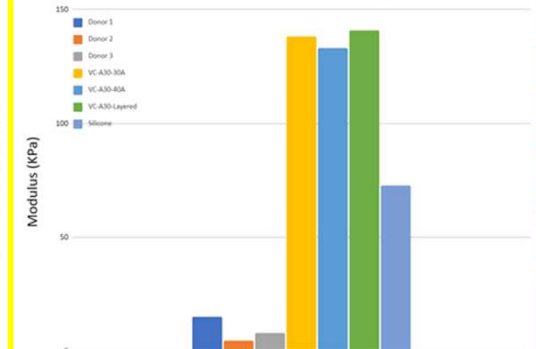
## Compression (A) & Shear (B)



## Our data



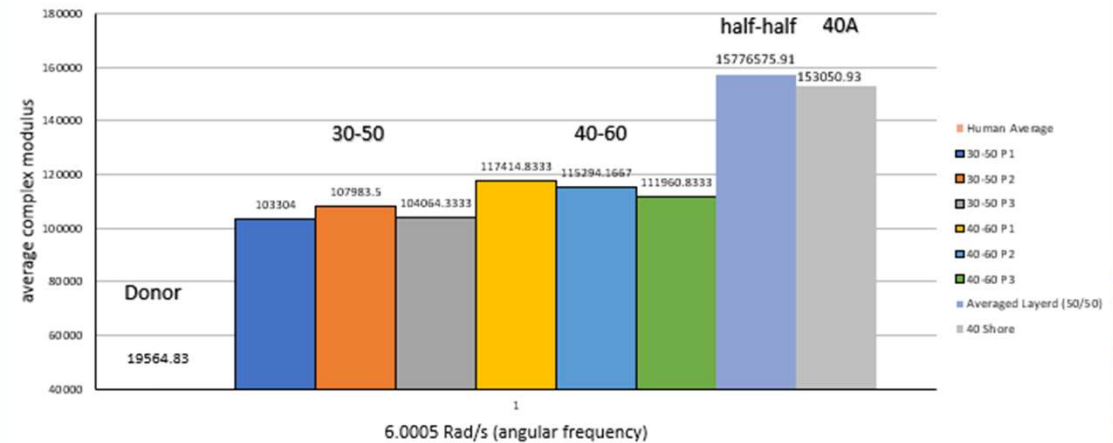
## Prior Research Graph



## Conclusion

- Shear in polymers is significantly greater than shear in vasculature.
- Our ratio came closer to human shear than previous studies.
- Proof of concept: Validated that ratio change may influence the polymer reaction to be closer to human vascular response.
- Compression is the next test to be conducted.

## average complex modulus vs frequency



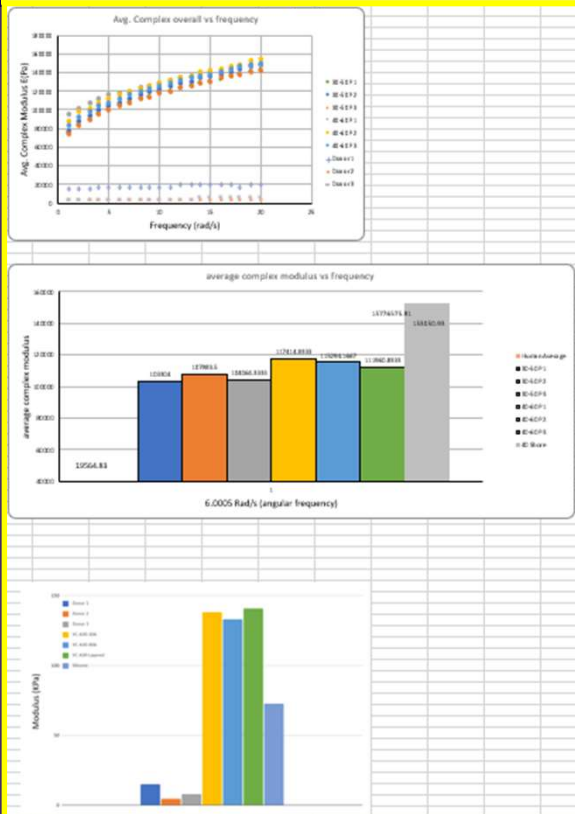


# Data Accumulation/ Proof of Analysis

## Our Data Collection

Sample	Frequency	Modulus	Phase	...
1	1000	1.0000	0.0000	...
1	2000	0.9998	0.0000	...
1	3000	0.9994	0.0000	...
1	4000	0.9988	0.0000	...
1	5000	0.9980	0.0000	...
1	6000	0.9970	0.0000	...
1	7000	0.9958	0.0000	...
1	8000	0.9944	0.0000	...
1	9000	0.9928	0.0000	...
1	10000	0.9910	0.0000	...
1	11000	0.9890	0.0000	...
1	12000	0.9868	0.0000	...
1	13000	0.9844	0.0000	...
1	14000	0.9818	0.0000	...
1	15000	0.9790	0.0000	...
1	16000	0.9760	0.0000	...
1	17000	0.9728	0.0000	...
1	18000	0.9694	0.0000	...
1	19000	0.9658	0.0000	...
1	20000	0.9620	0.0000	...
1	21000	0.9580	0.0000	...
1	22000	0.9538	0.0000	...
1	23000	0.9494	0.0000	...
1	24000	0.9448	0.0000	...
1	25000	0.9400	0.0000	...
1	26000	0.9350	0.0000	...
1	27000	0.9298	0.0000	...
1	28000	0.9244	0.0000	...
1	29000	0.9188	0.0000	...
1	30000	0.9130	0.0000	...
1	31000	0.9070	0.0000	...
1	32000	0.9008	0.0000	...
1	33000	0.8944	0.0000	...
1	34000	0.8878	0.0000	...
1	35000	0.8810	0.0000	...
1	36000	0.8740	0.0000	...
1	37000	0.8668	0.0000	...
1	38000	0.8594	0.0000	...
1	39000	0.8518	0.0000	...
1	40000	0.8440	0.0000	...
1	41000	0.8360	0.0000	...
1	42000	0.8278	0.0000	...
1	43000	0.8194	0.0000	...
1	44000	0.8108	0.0000	...
1	45000	0.8020	0.0000	...
1	46000	0.7930	0.0000	...
1	47000	0.7838	0.0000	...
1	48000	0.7744	0.0000	...
1	49000	0.7648	0.0000	...
1	50000	0.7550	0.0000	...
1	51000	0.7450	0.0000	...
1	52000	0.7348	0.0000	...
1	53000	0.7244	0.0000	...
1	54000	0.7138	0.0000	...
1	55000	0.7030	0.0000	...
1	56000	0.6920	0.0000	...
1	57000	0.6808	0.0000	...
1	58000	0.6694	0.0000	...
1	59000	0.6578	0.0000	...
1	60000	0.6460	0.0000	...
1	61000	0.6340	0.0000	...
1	62000	0.6218	0.0000	...
1	63000	0.6094	0.0000	...
1	64000	0.5968	0.0000	...
1	65000	0.5840	0.0000	...
1	66000	0.5710	0.0000	...
1	67000	0.5578	0.0000	...
1	68000	0.5444	0.0000	...
1	69000	0.5308	0.0000	...
1	70000	0.5170	0.0000	...
1	71000	0.5030	0.0000	...
1	72000	0.4888	0.0000	...
1	73000	0.4744	0.0000	...
1	74000	0.4598	0.0000	...
1	75000	0.4450	0.0000	...
1	76000	0.4300	0.0000	...
1	77000	0.4148	0.0000	...
1	78000	0.3994	0.0000	...
1	79000	0.3838	0.0000	...
1	80000	0.3680	0.0000	...
1	81000	0.3520	0.0000	...
1	82000	0.3358	0.0000	...
1	83000	0.3194	0.0000	...
1	84000	0.3028	0.0000	...
1	85000	0.2860	0.0000	...
1	86000	0.2690	0.0000	...
1	87000	0.2518	0.0000	...
1	88000	0.2344	0.0000	...
1	89000	0.2168	0.0000	...
1	90000	0.1990	0.0000	...
1	91000	0.1810	0.0000	...
1	92000	0.1628	0.0000	...
1	93000	0.1444	0.0000	...
1	94000	0.1258	0.0000	...
1	95000	0.1070	0.0000	...
1	96000	0.0880	0.0000	...
1	97000	0.0688	0.0000	...
1	98000	0.0494	0.0000	...
1	99000	0.0298	0.0000	...
1	100000	0.0100	0.0000	...

## Graph Analysis



## Comparison Data

Sample	Frequency	Modulus	Phase	...
1	1000	1.0000	0.0000	...
1	2000	0.9998	0.0000	...
1	3000	0.9994	0.0000	...
1	4000	0.9988	0.0000	...
1	5000	0.9980	0.0000	...
1	6000	0.9970	0.0000	...
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1	14000	0.9818	0.0000	...
1	15000	0.9790	0.0000	...
1	16000	0.9760	0.0000	...
1	17000	0.9728	0.0000	...
1	18000	0.9694	0.0000	...
1	19000	0.9658	0.0000	...
1	20000	0.9620	0.0000	...
1	21000	0.9580	0.0000	...
1	22000	0.9538	0.0000	...
1	23000	0.9494	0.0000	...
1	24000	0.9448	0.0000	...
1	25000	0.9400	0.0000	...
1	26000	0.9350	0.0000	...
1	27000	0.9298	0.0000	...
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1	29000	0.9188	0.0000	...
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1	31000	0.9070	0.0000	...
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1	55000	0.7030	0.0000	...
1	56000	0.6920	0.0000	...
1	57000	0.6808	0.0000	...
1	58000	0.6694	0.0000	...
1	59000	0.6578	0.0000	...
1	60000	0.6460	0.0000	...
1	61000	0.6340	0.0000	...
1	62000	0.6218	0.0000	...
1	63000	0.6094	0.0000	...
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1	70000	0.5170	0.0000	...
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1	96000	0.0880	0.0000	...
1	97000	0.0688	0.0000	...
1	98000	0.0494	0.0000	...
1	99000	0.0298	0.0000	...
1	100000	0.0100	0.0000	...

- Plus more from comparison data

# Design Validation

## Testing Procedures

- Lubricity: a wire is looped through a tube sample that is secured to a wheel that is placed on a table a distance away from the rheometer and a water filled syringe is tied to the end of the wire, as the syringe slowly lowers, the friction force of the sample is measured
- Tension: a sample is pulled until it experiences an axial force of 100 mmHg to measure how resistant the sample is to stretching
- Compliance: a tube sample is slowly filled with thick liquid, increasing volumetric pressure, and images are taken with the x-ray to see how much the sample can swell from internal pressure
- Compression: axial force of .9-1.4 N is applied to the sample to measure the elastic modulus of the sample
- Shear: a continuous oscillation force is applied to the sample to measure the sample's shear modulus

## Location

Bioengineering Lab

## Equipment

- Rheometer
- X-ray
- Polyjet Printer

Kathryn, 11/1/2021,  
BDL/Aneuvás, 21F05

# Potential Failure Mode and Effects Analysis

Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Impact deformation	deforms puck	Prevents pucks from testing properly	56	0
Tearing	rips puck	Prevents pucks from testing properly	16	0
Improper mesh	creates holes in model	Improper complicate testing	8	0

Fig 13: Simplified FMEA

## Potential Failures

- Experiencing excess force during testing, causing deformities of the samples
- The materials not fully meshing while printing, causing leakage in the models
- Tearing or popping during testing, ruining the sample
- Two are the failures are caused by human error

## Failure Prevention

- Check samples right after printing to ensure completed meshing
- Work slowly when testing to make sure that samples don't experience more force than they can handle



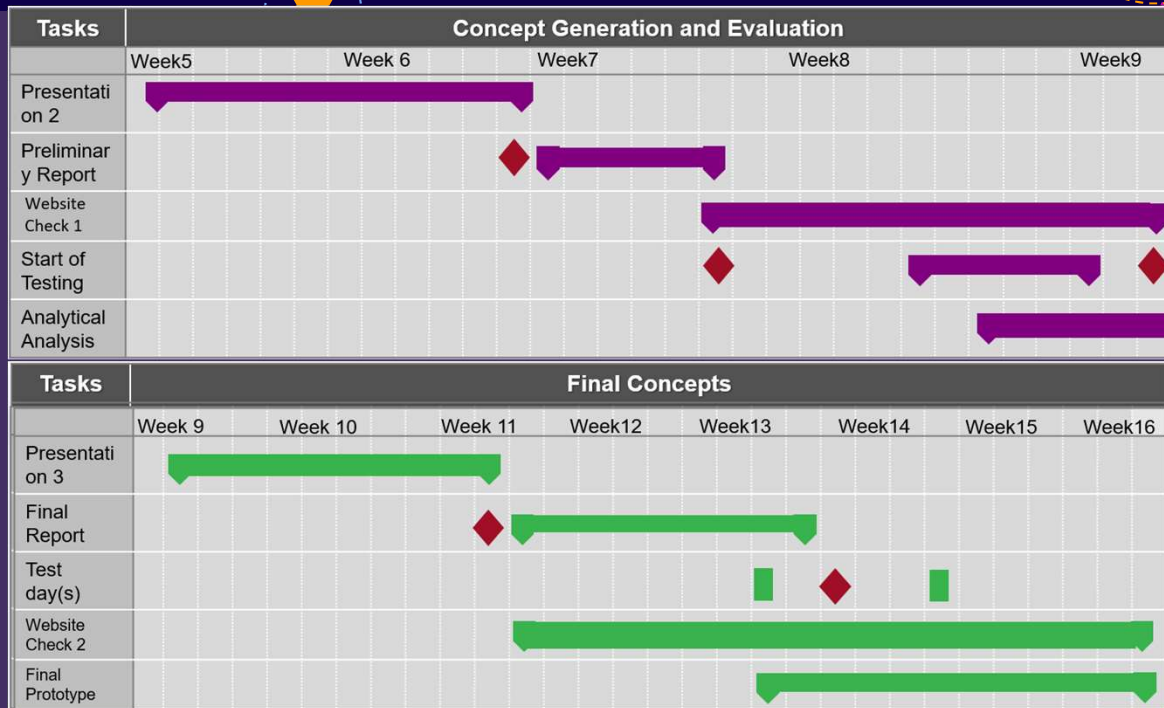
# Schedule

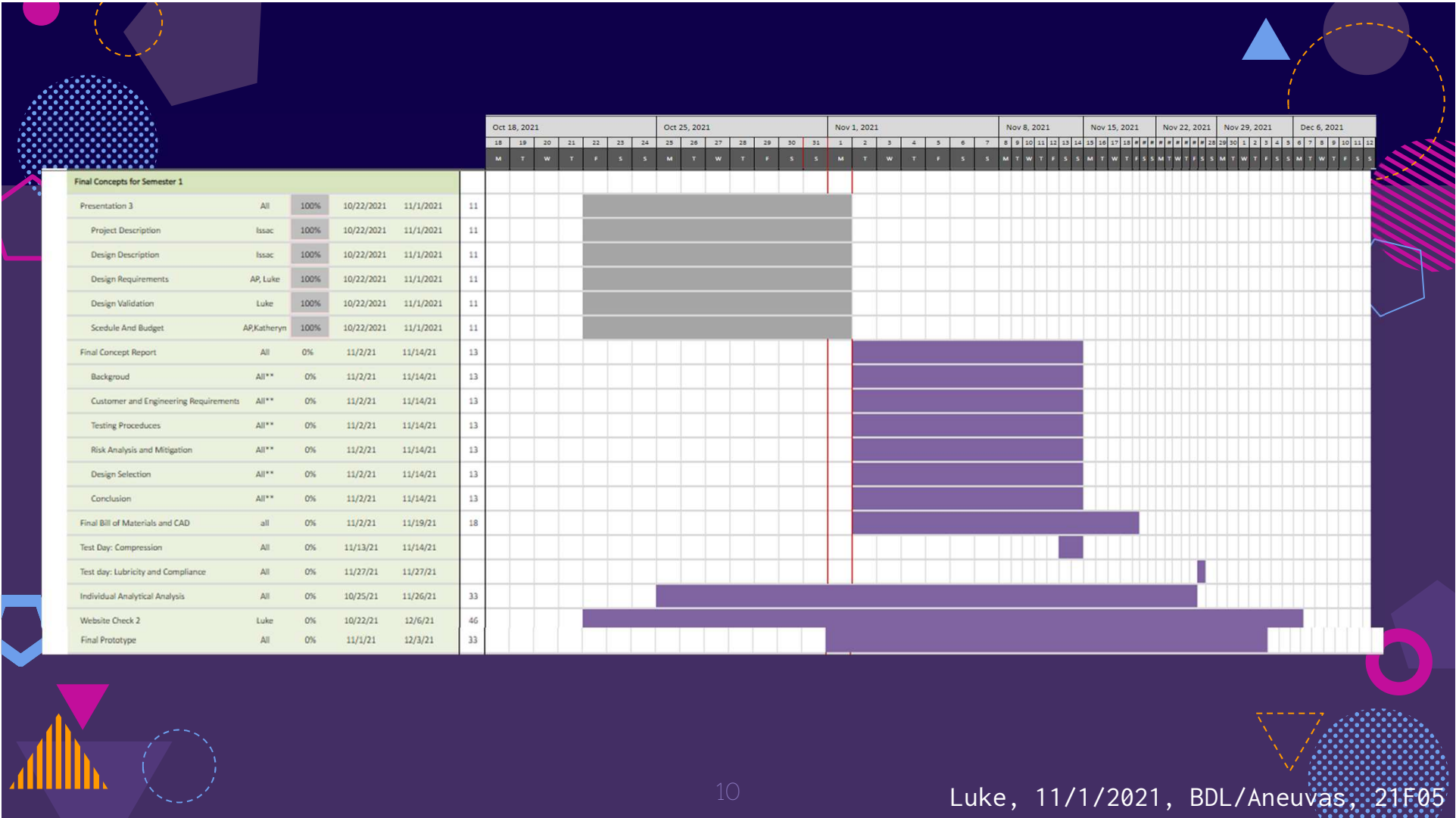
## Ahead of Schedule!

Future schedule includes testing, testing, and more testing!

## Work Breakdown

**Testing:**  
Isaac & AP  
**Data Analysis:**  
Kathryn & Luke





# Schedule for 2nd semester

## BDL/ANEUVAS CAPSTONE Semester 2

NAU ME Capstone  
Project Lead: Isaac Smith

Project Start:

Display Week:

\*\* As of date of making

TASK	ASSIGNED TO	PROGRESS	START	END	DAYS
<b>Semester 2 Start-up</b>					
Talk to client	All		1/14/2022	1/14/2022	1
Post Mortem of Final report from S1	All		1/14/2022	1/14/2022	1
Delegate testing days and start on final design	AP		1/14/2022	1/14/2022	1
Project Update and First report delegation	Issac		1/14/2022	??	#####
Website Updates	Luke		1/14/2022	1/14/2022	1
Finalize BOM for testing with client	Katheryn		1/21/2022	1/21/2022	1
Individual Analytical Analysis	All		1/10/2022	2/1/2022	23
Midpoint Presentation and Report	All		2/1/2022	??	#####
Testing days	Issac, AP		Multiple Days: TBD	Multiple Days: TBD	#####
Test data analysis	Luke, Katheryn		Dependent on above	Dependent on above	#####
Final Product and Design Summary	All		4/1/2022	4/15/2022	15
Final Report	All		4/15/22	5/6/22	22

## Budget

<b><u>This Semester</u></b>	
<i>Current Amount Spent</i>	
Initial Instruments Prep.	\$16.85
Newest Sample Mat.	\$1.65
Total	\$18.50
<i>Potential Spending for Rest of Term</i>	
Possible Printed Models	\$61.90
<i>Total Spent:</i>	
With models	\$80.40
No Models	\$18.50
<i>Leftover:</i>	
With Models	\$919.60
No Models	\$981.50

<b><u>Next Semester</u></b>	
<i>Potential Prints</i>	
3 Full Models	\$185.70
10 Samples	\$185
<i>Additions</i>	
Equipment Rent	\$300
<i>Total Spent:</i>	
With Models	\$751.10
No Models	\$503.50
<i>Leftover:</i>	
With Models	\$248.90
No Models	\$496.50

## References

- [1] C. Settanni, "In Vitro Neurovascular Model Development for Liquid Embolic Implant Simulation," *Google*. [Online]. Available: [https://docs.google.com/presentation/d/14mdgqx2XWuA98fz6Ufh07s\\_CHWN\\_08-w/edit#slide=id.p9](https://docs.google.com/presentation/d/14mdgqx2XWuA98fz6Ufh07s_CHWN_08-w/edit#slide=id.p9). [Accessed: 10-Oct-2021].
- [2] N. G. Norris, W. C. Merritt, and T. A. Becker, "Application of nondestructive mechanical characterization testing for creating in vitro vessel models with material properties similar to human neurovasculature," *Journal of biomedical materials research. Part A*, 17-Sep-2021. [Online]. Available: <https://pubmed.ncbi.nlm.nih.gov/34617389/>. [Accessed: 13-Oct-2021].

The End

