Teaching Model for Ventilation-Perfusion Mismatching

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Problem Statement / Client Description

Our client, Dr. Christopher Green, is a pediatric pulmonologist and requested the creation of a model representing the mechanisms underlying ventilation/perfusion (V/Q) mismatching and its various complications, such as hypoxemia and dead space ventilation, to help medical students understand this concept.

Important Design Constraints

- An alveolus and corresponding bronchiole
- Capillary tube for perfusion
- Multiple ratios (High V/Q to low V/Q)
- Large enough to be seen on a projector of a lecture hall containing at least 180 people
- Model ventilation and perfusion mismatching
- Includes an interactive component to display five important V/Q ratios
    - Can be used multiple times during a lecture
- Visible to a lecture hall of 180 people with the use of document camera; no larger than 22 x 27 cm
- Less than 6.8 kg for easy portability and storage
- Withstand long periods of time in storage
    - Service life of 5 years

Broader Impact / Competing Designs

Ventilation and Perfusion mismatching is a difficult concept for medical students to visualize, specifically, how it can lead to dead space ventilation and hypoxemia. A device is needed to help the medical students conceptualize these different ventilation-perfusion ratios and their consequences.
The team wants to provide a physical teaching model rather than the online applications currently available to visualize V/Q ratios.

Competing design

- Circ-Adapt

- Computational (online) model of heart and circulation
- Adjustable parameters
- Focused on cardiac disease [8]

Last Semester - Final Design and Testing

The current prototype for the V/Q mismatching teaching model is a single compartment representation of gas exchange between the alveolus and the bloodstream at the capillary. LEDs were used to represent different levels of oxygen flow using respective colors and flow rates.

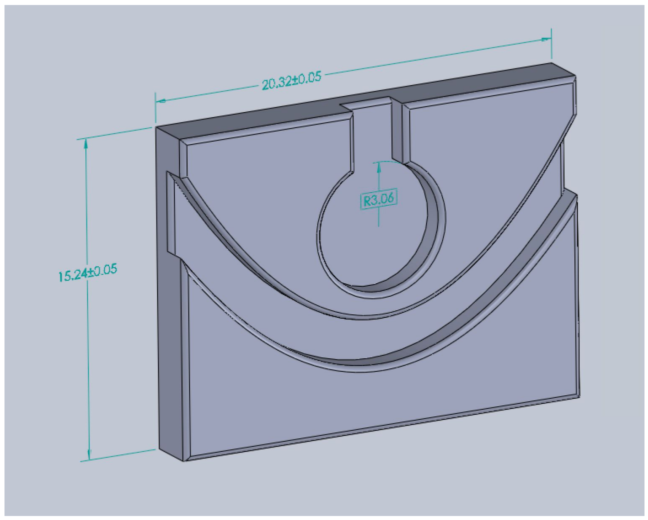

Figure 1. CAD drawing of the base design with dimensions in centimeters. For a more complete set of dimensions, see the drawing in Appendix C.

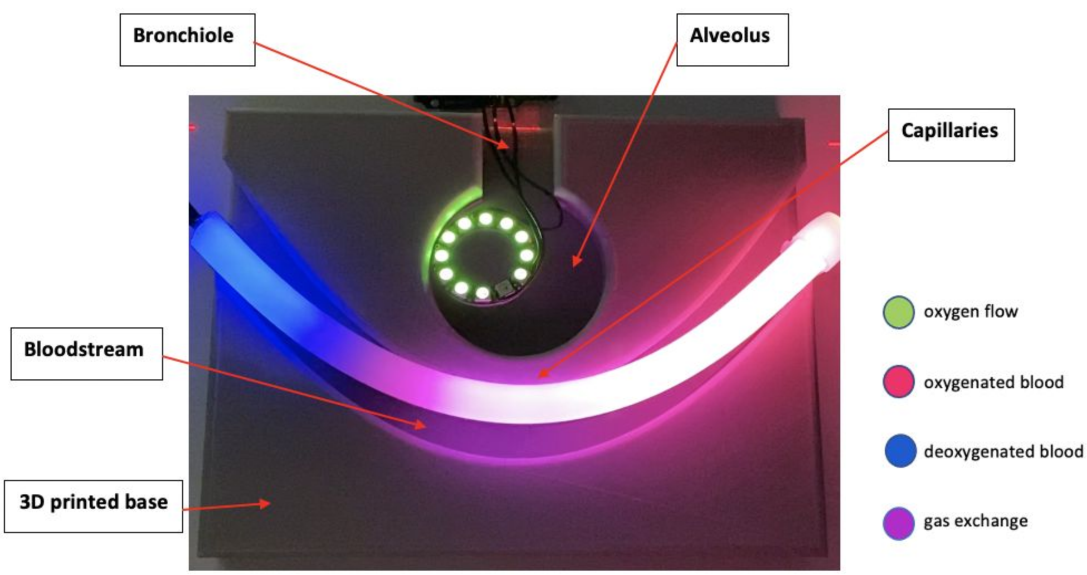

Figure 2. 3D printed base modeling the alveoli and bloodstream along with the ring and silicon strip LEDs to show the oxygen gradient for the V/Q ratios.

Features
- Base: 3D printed SolidWorks base modeling a single alveolus and bloodstream
- Ring LED: Inserted into the alveolus to represent oxygen present using the color green and different blinking rates
- Circle LED: Inserted into the bloodstream with the use of red, purple, and blue to represent the oxygenation of blood from the alveolus
- Arduino microcontroller: Programmed to alter LED brightness and flow

Testing
- 2 tests: alveolus and capillary, at 7 different LED brightness ranging from Arduino values of 10-255
- Took photos of the LEDs projected onto the screen
- Measured the intensity with ImageJ

Linear Regression T-Test
- Test to determine if a linear relationship between LED brightness(independent) and measured intensity(dependent) exists
- Linear relationship statistically significant for Circular LEDs but not applicable to Silicon LEDs

Results
- Need to perform more trials of tests at different brightness levels to get significant results
- Need to reevaluate Silicon LEDs design to ensure that different brightness levels can be distinguished through a document camera

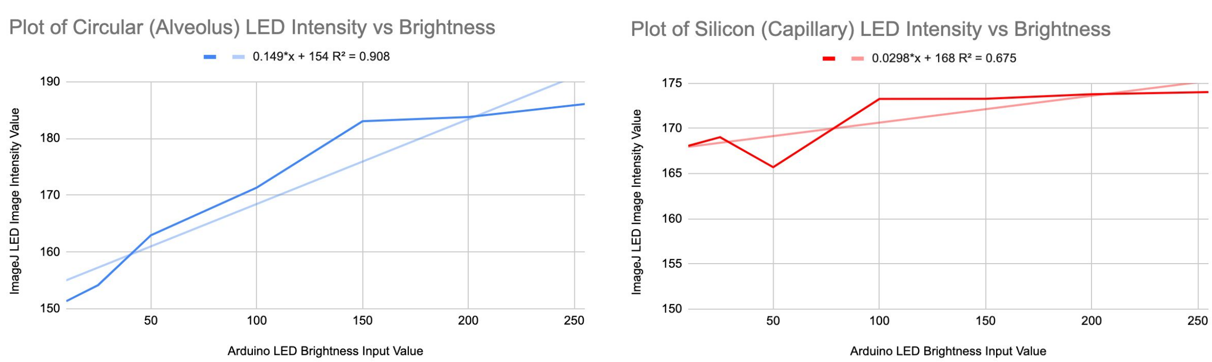

Figure 3 and 4. Image J testing results for circular LED and silicone LED with a linear trendline.

Second (Current) Semester

Goals - Timeline

Fabrication
- Integrate 4 buttons into the existing circuitry to allow for the increase and decrease of both ventilation and perfusion rates in the model
    - https://www.adafruit.com/product/367

- https://www.adafruit.com/product/4188
- https://www.adafruit.com/product/1439

Figure 5. Three types of buttons are under consideration for integration into the existing circuit to modulate V/P rates.

- Integrate an LED display into the existing circuitry to portray varying ventilation and perfusion rates as well as the V/Q ratio
  - https://www.adafruit.com/product/1912
  - https://www.adafruit.com/product/2088

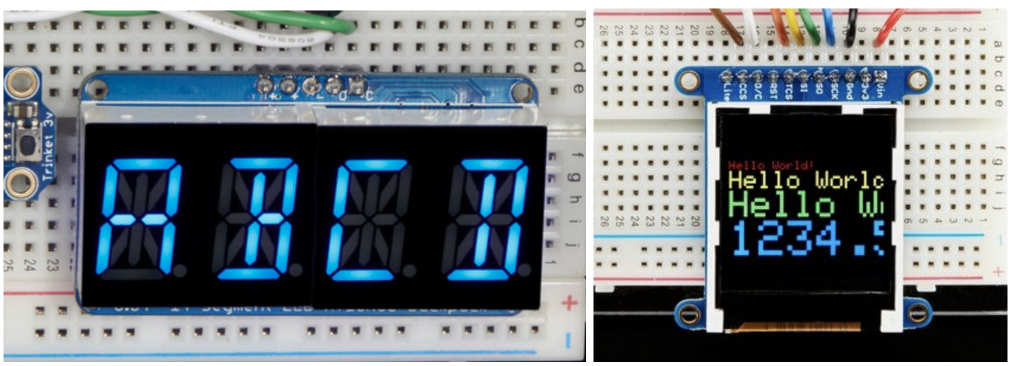

Figure 6. Two types of displays will be evaluated for integration into the existing circuit to display V/P ratios.

- Modify circular LEDs to represent varying breathing cadences with blinking rates instead of modulating brightness
  - Including 4 circular LEDs of different diameters fit inside one another
- Add a silicone diffusing layer to the circular LEDs in the alveolus
- Create a new, more concise board for the circuit
- Add housing for the circuit/wiring to the back of the base design

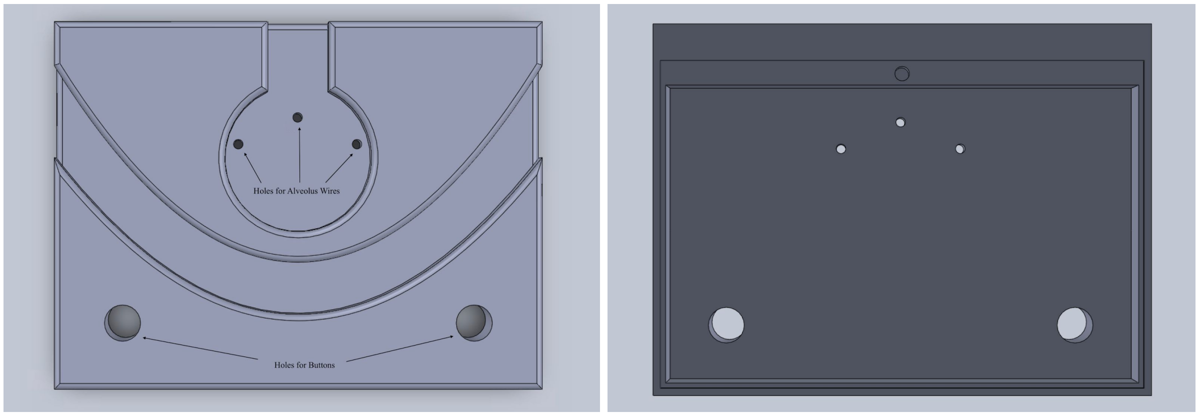

Figure 7. CAD drawing incorporating holes for wires and buttons as well as a compartment in the back for storage.

Fabrication Testing Protocol

Buttons

- A test will be conducted on the three buttons shown above in Figure 5 to determine which will be used to increase and decrease ventilation and perfusion rates.
- The testing will verify that they can be incorporated into the existing circuitry without debouncing problems.
    - Hypothesis: The buttons should be capable of increasing or decreasing a set value by the corresponding amount of times they are pressed.
    - Brief protocol: Deliminate a few numbers of presses given to each button; 1, 3, 5, and 7. Run multiple trials for each number and record the amount of presses each button captured. Compare this to the actual number of presses performed and select a button based on the results.
    - Statistical Tests/Analysis: Linear Regression T-Test to determine if the number of times a button is pressed(independent) correlates to how many times it records being pressed(dependent).
- The results from this testing will verify that the buttons can increase and decrease a set value by the amount of times pressed without introducing debouncing or other errors.

Human Subjects Testing Protocol

1. Flow rate / Blinking rate

- The rate of change in flow/blinking in the capillary/alveolus will be tested to determine if a notable difference can be observed by the user of the model. A human subjects test will be administered.
    - Hypothesis: Human subjects will be able to distinguish between differences in flow and blinking rates in the model in order to understand V/Q ratios.

- Brief protocol: First, two videos showing different levels of flow/blinking rates on the model will be provided. Then, the subject will answer whether or not they see a noticeable difference between the two videos. This will be repeated with all of the chosen values for flow/blinking rates to determine if a noticeable difference exists. The sample size will be at least 10 human subjects to generate meaningful results.
- Statistical Tests/Analysis: To analyze the data, we will perform a One-Sample T-Test of Proportions to compare the difference in means of questions answered correctly for the observed group to 0.5 or the probability of answering questions correctly at random.

- The results from this testing will determine if the rate of change in flow and blinking rate generates a noticeable difference for the human eye.

2. Model validation

- A test to determine if the device is able to improve upon a human subject's understanding of ventilation/perfusion ratios by graphically displaying what occurs when the rates are modulated.
    - Hypothesis: The model improves a human subjects's understanding of ventilation/perfusion ratios.
    - Brief protocol: The human subjects used for this testing will be medical students with prior knowledge of ventilation/perfusion mismatching. This test will feature a series of two multiple choice tests; one administered before viewing the model and one administered after. The questions will be similar in nature to assess whether the model increased understanding.
    - Statistical Tests/Analysis: Difference of Means Hypothesis Test to compare the initial test score to the final test score for each subject. If our model did not show improvement in understanding, we would expect to find a difference of 0 when initial and final scores are compared. Therefore, we will be observing whether the final test scores increased significantly compared to the initial.
- The results from this testing will verify that our model achieves the goal of being able to help medical students understand ventilation/perfusion mismatching.

Project Goal	Deadline	Team Assigned	Progress	Completed
Meet with Client	02-05	All		X
Order Materials	02-05	Jenna		X
Outreach Seminar	02-05	All		X

Complete button circuit	02-12	Brittany and Kaitlin	X	
Write Testing protocols	02-12	Jenna and Zoe		X
Preliminary Presentations	02-12	All		
Find diffuser for circular LED	02-19			
Continue with Testing protocols	02-26			
Preliminary Deliverables (4:00 pm)	03-03	All		
Finalize Base Design	03-12	Kaitlin		
Complete Testing protocols	03-19	All		
Combine electronics into concise space	03-26			
Continue Testing	04-02			
Combine all elements of the model	04-09			
Executive Summary	04-16	All		
Analyze Testing Data	04-16	All		
Poster Presentations (10:00 am on website, 12:00-2:05 pm)	04-23	All		
Final Deliverables (4:00 pm)	04-27	All		

Budget

Table 1. Semester Expenses. Summary of expenses for the model from the past and current semesters.

Item	**Part Number**	**Link**	**Description**	**Vendor**	**Cost**	**Quantity**	**Subtotal**
Neopixel Flex Strip with Silicone Tube	3869	https://www.adafruit.com/product/3869?gclid=CjwKCAiw5p_8BRBUEiwAPpJO6-iskV-hGOTETEw9-UiGUYAAeoXBLnH974c0ATku9Am6wkZcOHl-LRoC3n8QAvD_BwE	LED Strip with silicone diffuser cover that is 1m long	Adafruit	$34.95	1	$34.95
Neopixel Ring with 16 LEDs	1463	https://www.adafruit.com/product/1463	Circular LED ring powered by 5V	Adafruit	$9.95	1	$9.95
12V DC Wall plug adapter	12V2A0823	https://www.amazon.com/Adapter-100-240V-Transformers-Switching-Adaptor/dp/B07GRZB5Y9/ref=sr_1_1?dchild=1&keywords=12V+DC+2A+power	12V wall plug for silicone LEDs with 2 amps	Amazon	$9.99	1	$9.99

		+supply+adapter+with+2.1+mm&qid=1603983837&sr=8-1					
Breadboard Friendly Female DC Power Barrel Jack	B074LK7G86	https://www.amazon.com/DIKAVS-Breadboard-friendly-2-1mm-Barrel-Jack/dp/B074LK7G86/ref=sr_1_1?dchild=1&keywords=barrell+jack+adapter+for+breadboard&qid=1603983934&sr=8-1	Barrel Jack for 12V power supply to be integrated into the circuit for silicone LEDs	Amazon	$9.99	1	$9.99
Arduino Uno Microcontroller	A000066	https://www.amazon.com/Arduino-A000066-ARDUINO-UNO-R3/dp/B008GRTSV6/ref=sr_1_3?crid=26WY4EDJSCJMI&dchild=1&keywords=arduino+uno+microcontroller&qid=1607324751&sprefix=arduino+Uno+micr%2Caps%2C227&sr=8-3	Microcontroller to power and control LEDs	Amazon	$23.00	1	$23.00
ELEGOO 3pcs MB-102 Breadboard 830 Point Solderless Prototype PCB Board Kit	B01EV6LJ7G	https://www.amazon.com/EL-CP-003-Breadboard-Solderless-Distribution-Connecting/dp/B01EV6LJ7G/ref=sr_1_5?dchild=1&keywords=breadboard&qid=1612919041&sr=8-5	Long breadboards to fit all electronics	Amazon	$9.99	1	$9.99
Mini Nano V3.0	B00NLAMS9C	https://www.amazon.com/ATmega328P-Microcontroller-Board-Cable-Arduino/dp/B00NLAMS9C/ref=asc_df_B00NLAMS9C/?tag=hyprod-20&linkCode=df0&hvadid=309776868400&hvpos=&hvnetw=g&hvrand=17043686169300655896&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9018948&hvtargid=pla-593018008274&psc=1	Microcontroller to power and control LEDs	Amazon	$9.99	2	$19.98
1.44” color LCD display	2008	https://www.adafruit.com/product/2088?gclid=Cj0KCQiAgomBBhDXARIsAFNyUqNVz_2Y6bdeOxecKVJgMEziOet_mG9W9xiGz0KYxVGgmN3bENCZ9kkaAiMEEALw_wcB	Display for ventilation/perfusion ratios and rates.	Adafruit	$14.95	1	$14.95
Quad Alphanumeric Display - Blue	1912	https://www.adafruit.com/product/1912	Display for ventilation/perfusion ratios and rates.	Adafruit	$13.95	1	$13.95
Green Triangular Buttons	4188	https://www.adafruit.com/product/4188	Buttons for varying ventilation/perfusion ratios.	Adafruit	$3.95	2	$7.90
Blue Triangular Buttons	4187	https://www.adafruit.com/product/4187	Buttons for varying ventilation/perfusion ratios.	Adafruit	$3.95	2	$7.90

Total Cost: $162.55