Operation Feedback

Biomedical Engineering Design 200/300

University of Wisconsin-Madison

Department of Biomedical Engineering

Final Design Report

December 8, 2019

Team Members:

Leader:	Kiley Smith
Communicator:	Ian Schirtzinger
BPAG:	Matt Suzuki
BWIG:	Alec Veal
BSAC:	Billy Brown

Client:	Prof. Kristen Cooley
	University of Wisconsin-Madison, School of Veterinary Medicine
Advisor:	Dr. Block
	University of Wisconsin-Madison, Department of Biomedical Engineering

Abstract

Current models used to train veterinary students on IV placement do not provide feedback regarding whether the needle is in the right position, whether the student moves the needle around too much when placing the catheter, or whether the needle punctures through the bottom of the vein. The aforementioned feedback would allow for IV placement to be precise and minimize damage to surrounding tissue. The proposed design aims to simulate the operation of placing an IV catheter into the cephalic vein of a dog. The model alerts the user when they have entered the vein using a simulated vein filled with a conductive gel that can complete a circuit to turn on an LED. The design provides feedback in the event of excessive or improper needle movement using force sensors surrounding the vein that alert the user when they have exceeded a determined pressure threshold. The goal of the design is to revolutionize the way students train for placing IV catheters.

Table of Contents:

Introduction

Motivation

The lack of applicable training devices for placing a catheter into a canine vein calls for a device that can provide students with feedback on their performance. Existing models do not provide enough performance feedback to students. Existing models either fail to alert students when they have entered the vein or do so with fake blood. Students should be able to know when they have performed the procedure of IV catheter placement correctly. By providing more feedback the students would be able to hone their IV placement on the practice model and cause less discomfort to animals early in their careers.

Existing Models

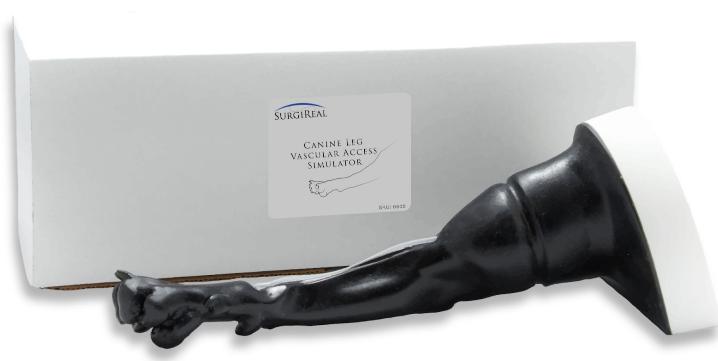

Figure 1: Silicone dog leg with an artificial vein used to train vet students. The vein can be filled with fake blood to give a more realistic feel.

A Canine Leg Vascular Access Simulator can provide students with a model that resembles a dog's leg, but the model requires artificial blood making the cleanup difficult. The vein must be filled and sealed each time the procedure is practiced. Additionally, the model does not have any fur on it, and the silicone quickly becomes adherent. One advantage of this design is that the base is attached to two magnets that secure the device to the metal tables found in veterinary schools. This eliminates the need for a second student to be holding the apparatus while the other practices the procedure [2].

Figure 2: Synthetic dog leg from Life/Form®. The bag of fake blood is held up so that the vein is always filled. It also has a removable area of fur to allow for practice on a shaved and unshaved dog.

There is a model of a fur-covered dog leg from Life/Form® [3]. This model uses artificial blood and a simulated vein to indicate to students when they are in the lumen of the vein. The artificial blood is in a bag suspended above the limb. Gravity is then used to fill the vein with the blood to be subsequently used in the intravascular catheter. The model is covered in fur to better resemble the leg of a dog. The fur around the area of the procedure can be removed to model different scenarios. The main consequence of the simplicity of this model is the students will not be alerted when they damage tissue surrounding the vein.

Figure 3: This is the model that the client created herself for her students to use. The vein is very prominent but it provides no feedback on how well the student is doing.

The client created her own model consisting of plastic tubing with a 0.5 cm rubber tube on the top. This is all covered by imitation fur and skin to hide the vein from students. This device provides inadequate feedback. The student can feel when they have hit the vein but cannot distinguish between being in the lumen, the side, or going completely through the vein.

Problem Statement

The current models that veterinary students use to practice IV and catheter placement require artificial blood to provide feedback as to whether the student is in the lumen of the vein. The use of artificial blood is a messy process resulting in extra cleanup for the students and professors and does not tell the student when they move excessively upon insertion. Additionally, these devices are expensive, despite not providing feedback on the movement of students when inserting needles.

Background

Background Research

Veterinarians frequently give cephalic vein injections in dogs to either obtain blood samples or to place IV catheters for the administration of drugs and fluid therapy. Typically, this procedure will require two staff members, where one is restraining the animal and the other is administering the injection. This model assumes the animal is being properly restrained and thus will be static. Proper preparation and sterilization techniques are essential for maintaining the health of the patient during the procedure, one key step during preparation is the shaving of the anterior antebrachium [9]. Catheters used in this procedure are relatively large being 21G or wider and are inserted at an angle between 15 and 30 degrees. Additionally, a normal blood draw will take between 2-5 ml of blood [9].

Common complications are important for veterinary students to understand before beginning to place an intravenous catheter in live animals. The most common complication seen in canines and other animals during injections is tissue or nerve damage [8]. Inexperienced veterinarians, specifically vet students, will often miss the lumen of the vessel either by puncturing through the vein or missing off to the side entirely. A puncture through the vein is common when administering catheters, as this technique requires a subsequent step in which unintentional force can be easily applied [6]. There are more serious side effects like blood clots and infections, but these are much rarer. These complications can be avoided if the student, or veterinarian, places the needle steadily into the lumen of the vein [8]. Intravenous catheters are placed to administer drugs at a much higher rate than an oral or rectal delivery system. Emergency situations are normally when intravenous injection is much more common than a pill or liquid delivery [8].

Client Information

Kristen Cooley is a professor at the University of Wisconsin-Madison School of Veterinary Medicine. She sees this device as a way to provide more feedback on how well a student is completing the IV placement so that when they perform the procedure on an actual animal they are not experiencing additional discomfort.

Design Specifications

The model should be able to withstand biweekly use for two years, assuming some parts (such as the tubing and gel) are replaced more frequently. The gel-filled tube should be able to last three months to minimize the amount of maintenance that the user has to perform. The intended use would be in a classroom setting, so the design must be portable and easy to set up. It should be under 15 pounds in weight and able to be powered by a laptop or wall outlet. As per the client's request, no dyed fluids should be used. The device should cost under $350 to make it affordable to purchase several models per classroom.

Preliminary Designs

Design One

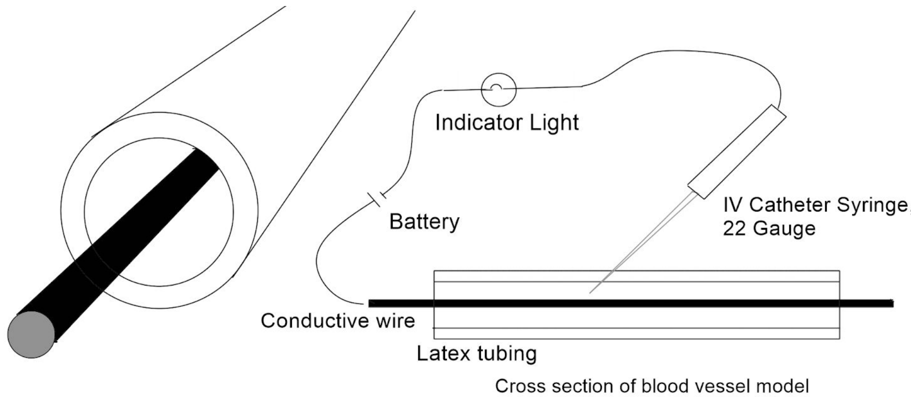

Figure 4: Diagram of Design 1, The wire running concentric to the latex tube makes contact with the needle and completes a circuit. A light then indicates insertion to the user.

The latex tubing shown in Figure 4 models the blood vessel of the dog. Running within the tube is a conductive wire in a circuit with an IV Catheter Syringe. Upon proper insertion of the catheter into the tube, the needle will make contact with the conductive wire in the center of the lumen. This completes the circuit which would cause a light to turn on indicating that the have inserted the needle correctly.

Design Two

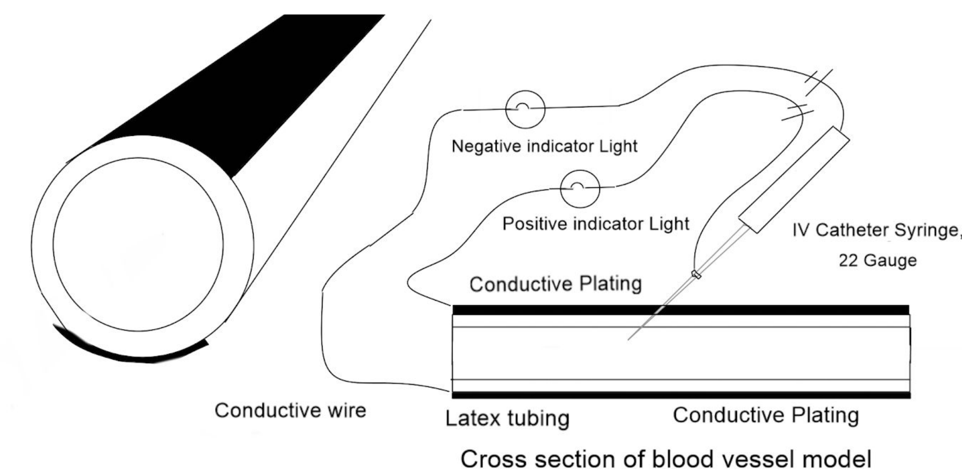

Figure 5: Diagram of Design 2, Conductive plating lining the upper and lower surfaces of a latex tube makes contact with either the needle or the conductive band on the needle to provide a negative or positive indication of insertion, respectively.

The same latex tubing is used in Design Two, as shown in Figure 5. Conductive plating is placed on the upper and lower surfaces of the tube. A conductive band is also mounted to the middle of the needle connected in a circuit with the positive indicator light. When a student inserts the needle at the appropriate insertion angle (between 15-30 degrees) the band will make contact with the conductive plating on the superior surface of the tube, which signals successful insertion to the student via the positive indicator light. In the circumstance that a student inserts the needle beyond an angle of 30 degrees, the needle will make contact with the lower conductive plating, completing the circuit for negative feedback before the conductive band will reach the upper conductive plating.

Design Three

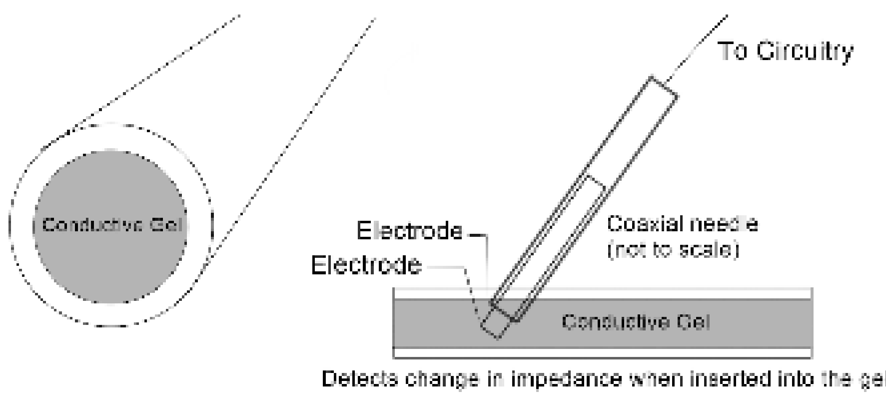

Figure 6: Diagram of Design 3: Coaxial needle measures the change in impedance due to the conductive gel and relays this data to indicate proper insertion of the needle

Design three involves a coaxial needle capable of detecting impedance changes when inserted into a conductive gel. There are two electrodes on the needle, separated by an insulator. When the needle is inserted into the conductive gel, a circuit is completed between the electrodes, and impedance change caused by the gel can be measured. The model is a positive and negative response system. If the impedance is close to the predetermined value indicative of insertion in the conductive gel, a green light will go off to indicate a positive response. If the coaxial needle misses the vein or goes through the vein, the measured impedance not be within the allowed range, and a red light will indicate a negative response.

Preliminary Design Evaluation

Design Evaluation

Preliminary Design Matrix

Criteria	Wire Through	Thin Band	Conductive Gel
Cost (10)	9 (0.9)	8 (0.8)	5 (0.5)
Accuracy (20)	5 (1)	9 (1.8)	10 (2)
User friendly (30)	4 (1.2)	7 (2.1)	9 (2.7)
Durability (20)	10 (2)	6 (1.2)	8 (1.6)
Complexity (20)	8 (1.6)	5 (1)	7 (1.4)
Weighted Score	6.7	6.9	8.2

Figure 7: This design matrix illustrates the criteria used to evaluate each of the possible designs. Each criterion has a different weighting depending on how important it is to the project.

Cost: A low score represents an expensive design, while a high score represents a more affordable design. This rating is based on the estimated materials cost. Cost only accounts for 10% of the weighted score since the client does not have a specified budget and none of these designs are predicted to cost upwards of $350.

Accuracy: Lower scores imply the model does not replicate a realistic process of implementing a catheter into a dog's vein. On the other hand, a high score indicates that the model is very realistic. This is a more important factor to consider since the product should mimic the feel of a real animal.

User-friendly: User-friendly is the most important category since the students must be able to repeatedly use the design with minimal set-up. This also factors in the reliability of the procedural feedback. The device should be able to consistently alert the user on their completion or shortcomings during the procedure.

Durability: This rating describes the estimated time that the design will properly operate. The designs are anticipated to have some replacements to maintain accuracy and feel but the maintenance should be minimal and easy to complete which makes it an important factor. Designs with a high score indicate that a design that will last long.

Complexity: Describes the difficulty of the fabrication process. Those designs with a higher score are anticipated to be easier to create.

Weighted Score: The number next to each category describe how highly we value the criteria. The total weight adds up to 100, and each category has a maximum of ten unweighted points. Each number is equal to the percent value associated with the category. As shown above, the green highlighted boxes show which models score highest for the individual criteria. To continue, the weighted number next to each criterion will be multiplied, as a percentage, with the value derived by the group. For example, the conductive gel was given a score of five for cost which is weighted at 10%, five multiplied by 0.1 equates to one half. These values are then summed to give the total weighted score.

Proposed Final Design

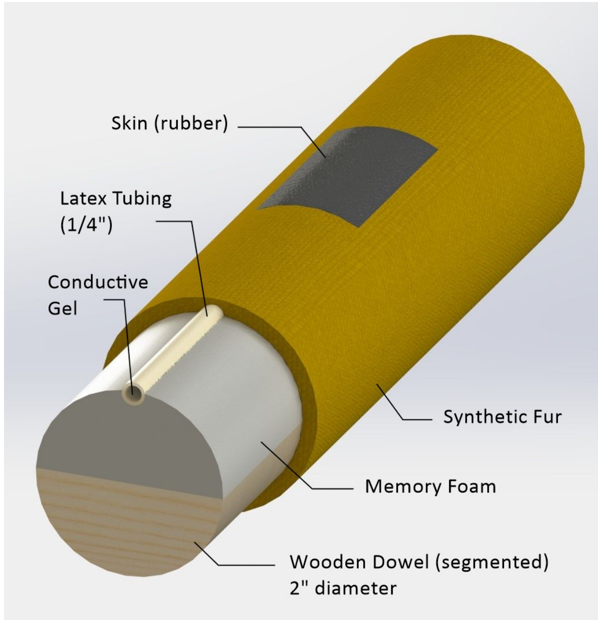

Figure 8: Final design incorporated into the model dog limb: Latex tubing containing conductive gel rests upon a layer of memory foam that is supported by a segmented wooden dowel. This structure is sheathed in synthetic fur and skin.

Design three, the Conductive Gel, will be pursued as the intended final product. This model has the highest upside when it comes to accuracy and user feel which are two of the most important design considerations. This model will be the most realistic simulation because if the user is anywhere inside the lumen, the coaxial needle will read an impedance level indicative of positive feedback, while the alternative would result in negative feedback. "User-friendly" is essentially criteria for how realistically our model can simulate the leg and vein of a dog. The Conductive Gel method will not have any obvious hindrances such as the wire being threaded through the middle of the lumen or conductive plating being placed above and below the vessel. Using a conductive gel will result in as close to a real feel as possible while still being able to complete an electrical circuit. Additionally, this design will have very few parts and a relatively simple circuit design, increasing its longevity and durability.

Development Process

Changed Final Design

The proposed final design differed from the final prototype for several reasons. The main reason stemming from a conversation with Dr. Chris Brace regarding ablation needles or needles that measure impedance. He stated that ablation needles were too small and flexible to use in a device such as this since they are often used within the heart to correct cells that beat out of time. Ablation is the process of burning away cells so if the needle were to be connected to a circuit, the tip of it would become hot which could damage the device. They would also be too expensive for a training device such as this. Creating a needle to detect changes in impedance within the period of a semester was improbable and unnecessary to accomplish the goals of this project.

These challenges redirected this project towards other methods. The idea of using an indicator light for when the user inserts the needle into the lumen was kept but the methodology of how was changed. The vein was now filled with conductive gel commonly used to attach electrodes to skin and pressure sensors were to measure the force the user applied to the tissue surrounding the vein.

Materials

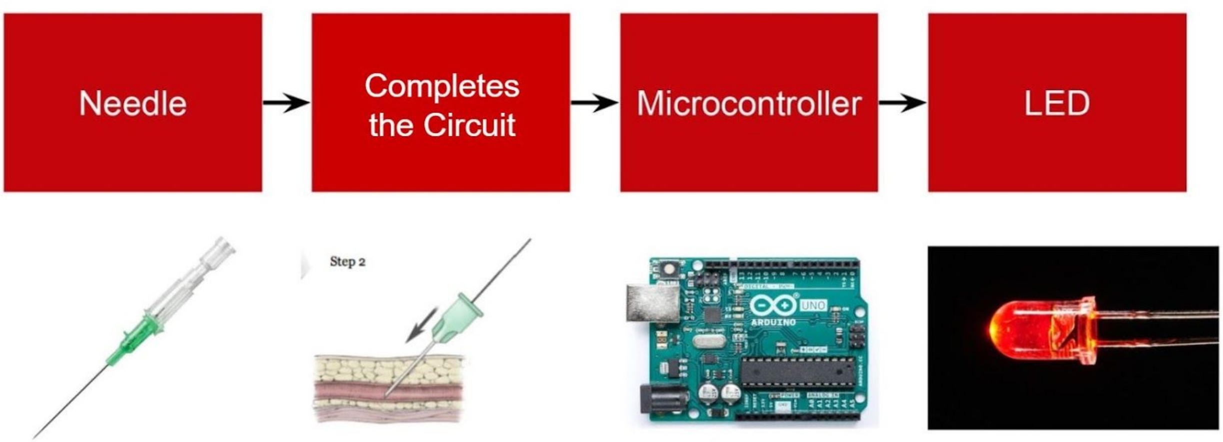

Figure 9: The needle will be used to complete a circuit once it is inserted into the lumen of the artificial vein. This insertion will trigger an LED to go on letting the user know they are in the vein.

A needle that is normally used to administer IVs was modified to attach to wire connected to the circuit. Another wire was connected to the inside of the artificial vein which contains conductive gel. The circuit is open when the needle is not inserted preventing any current from flowing through. Once the needle is inserted into the vein, the circuit will be completed. This completion is recognized by the microcontroller which triggers an LED to go on. In order to connect all the aspects, a circuit pegboard and wires are used in place of a circuit board.

Without a place to house the electronics, the device cannot function successfully. The housing consists of two components: the leg and electronics housing. The leg will hold the vein and will be the site of the procedure. The base will stabilize the leg so it does not rotate or move around on the user. It will also hold the electronic components. Both will be 3D printed with PLA. The foam will fill the leg in order to mimic the resistance that the other tissue within the leg.

Methods

The first step in constructing the device was to 3D print the housing for the electronics and the form for the leg. The print was made out of PLA and then filed down in order to fit together and allow for more room within the device. Our original final design plan was to construct the leg and housing out of wood or PVC piping but upon further consideration, we determined that 3D printing would create a better product in terms of accessibility and finished look. The fake leg is a five-centimeter diameter cylinder with an inner diameter of three and a half centimeters and is 25cm long. Using the existing model provided by the client, an eight by three and a half centimeter rectangle was removed from the outside to mimic the shaved area on a dog’s leg used to perform this procedure. This allows for access to the artificial vein and insertion of the needle.

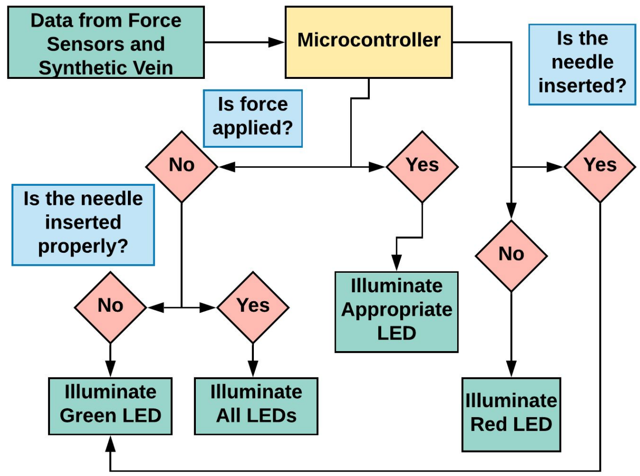

Figure 10: Data Collection Flowchart illustrating what the microcontroller is taking in, and how it responds to certain situations.

The device needed to be able to give feedback on two different aspects of IV insertion: is the needle in the vein and is the user moving around and applying pressure to the surrounding tissue. These are the two aspects that the microcontroller is always checking. In order to provide feedback to the user on their progress, the microcontroller then

The fake skin and fur were glued together so that the skin covered the extruded area while the fur covers the rest. This material is attached to the device with velcro which allows for easy removal. The device can be more easily repaired if need be.

Testing

<u>Pressure threshold</u>

Testing on the pressure-sensitive strips was done to determine how much force is required to reach the threshold and turn on the respective LED. The voltage drop for each pressure strip was recorded in response to one weight as well as two shown in Figure 11**.** Each of these weights was applied to each of the three resistors 20 times. The average voltage change, from the application of one weight to the application of two, was calculated over the twenty trials. The reason the focus was on the voltage change after the addition of a second weight was that in the final model the pressure strips always have some pressure applied. This voltage drop was then used to determine the average change in resistance (Ohms) corresponding to the applied weight (Newtons).

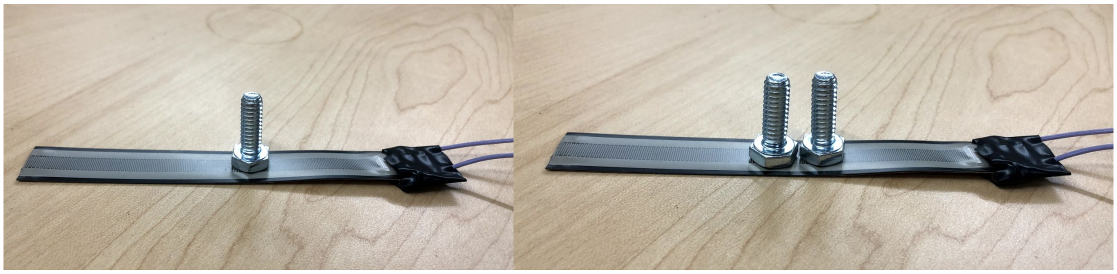

Figure 11: Shows how the force testing was done by first placing one screw on the resistor followed by another in close enough proximity that they were touching

The picture on the left shows how the initial resistance was recorded for each resistor. A 3.13 gram screw is placed in the center of the resistor. The picture on the right shows how the second resistance was recorded, with the addition of a second screw weighing 3.18 grams. Since the Arduino cannot measure resistance directly, the voltage divider equation was applied to each of these average output voltages to determine the resistance.

Change in voltage during needle insertion

At first contact of the needle with the conductive gel, the distance between the tip of the needle and the wire at the end of the vessel is a maximum. This distance is shortened during the insertion and is at a relative minimum once the needle is inserted the full 3.5 cm. The resistance of the conductive gel decreases with a decrease in distance between the needle tip and wire, this drop in resistance corresponds to a drop in voltage.

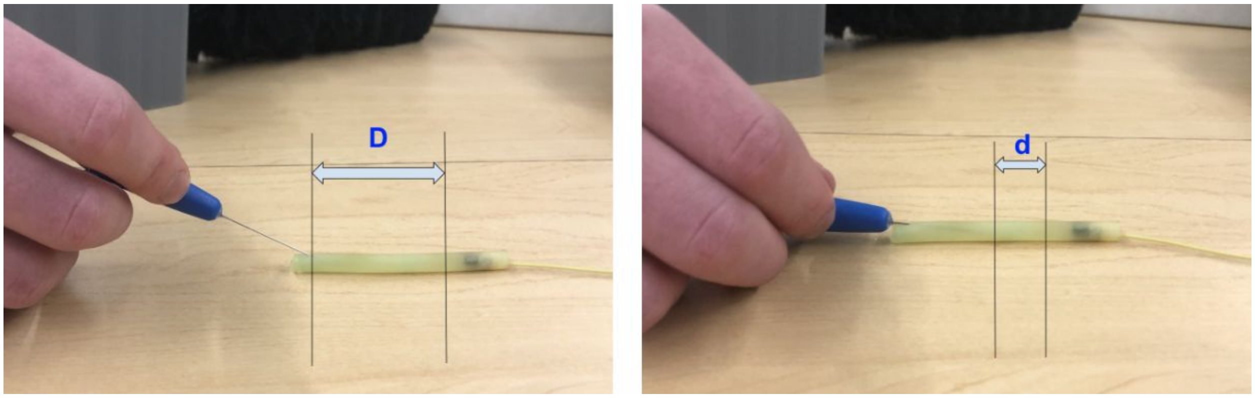

Figure 12: The voltage was first measured when the needle was at distance D and then measured again once the needle was inserted completely at distance d.

As seen in Figure 12, the needle is initially inserted at a variable distance D from the end of the wire. Once the needle is inserted completely, the distance from the tip of the needle to the wire decreases to a distance of d which is slightly less than D - 3.5 cm due to the angle of insertion.

<u>The longevity of Conductive Gel</u>

The viscosity of the conductive gel was tested to determine how long the imitation vein will last. A two and a half-inch tube was filled with gel and left exposed to the air. The gel was checked on biweekly for 4 weeks.

Final Prototype

Figure 13: The final design. From the left: the design with the fur sleeve on, the design with the sleeve off, and a view from the backside where all of the electronics are held.

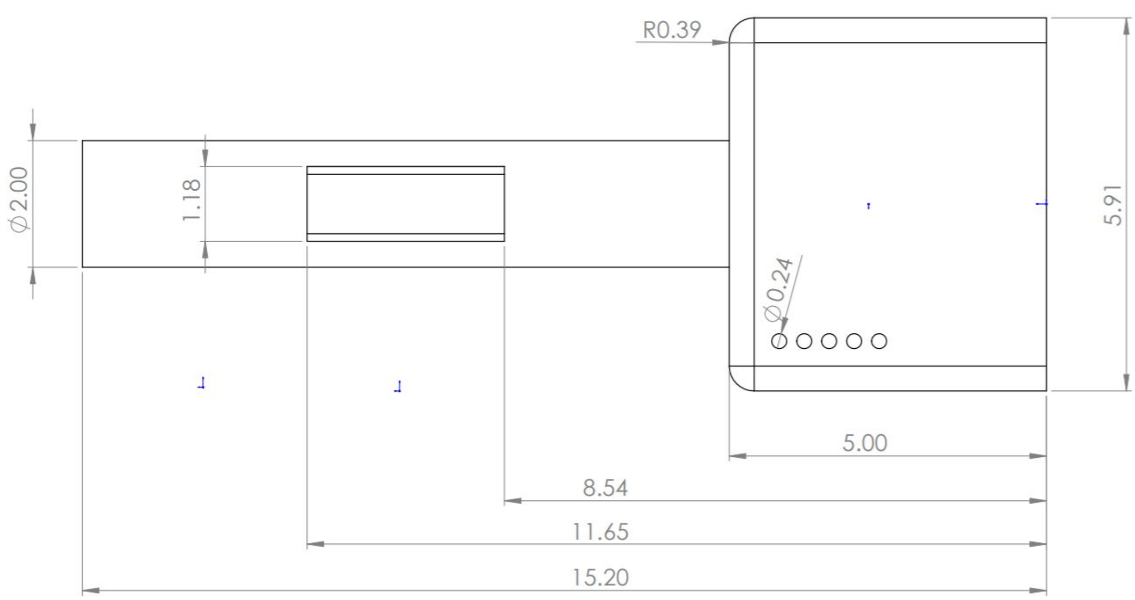

Figure 14: Top view dimensioned drawing of the final design of the 3D printed model. All dimensions are in centimeters.

The fur sleeve on the final design allows for an accessible and replaceable imitation vein and provides a realistic feel on the artificial canine leg. It is easy to slide on and off and is secured with velcro at either end to minimize slippage of the sleeve while in use. When detecting a vein before the procedure of needle insertion, a student must feel a dog's shaved leg for the vein. As seen in the left image of Figure 13, the artificial vein protrudes from the rest of the device for the user to not only feel but see as well.

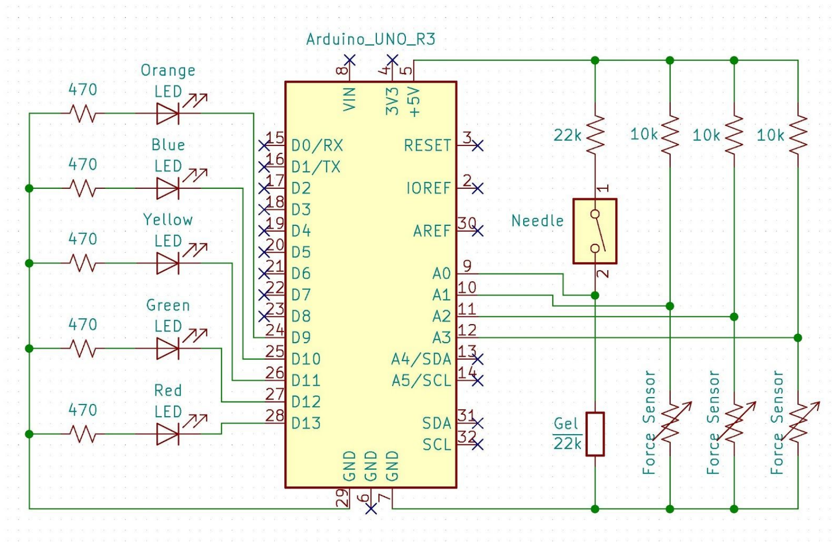

Figure 15: Circuitry Schematic showing the four voltage dividers measuring force and needle location powered by the five-volt pin. The LEDs are connected to the digital pins.

The circuitry of the final device consists of four voltage dividers, one for each pressure sensor and one for the needle and conductive gel. The gel has a relatively high resistance of 51.3 kilo-ohms if the needle was inserted all the way at the end of the tube, so it is connected in series with a 22 kilo-ohm resistor. This circuit is only completed once the needle is inserted. The analog pin is constantly checking the output voltage between the resistor and the gel. Once the needle is inserted it registers the completion of the circuit and turns off the red LED and turns on the green LED.

The three other voltage dividers consist of a ten kilo-ohm resistor and a variable resistor that decreases in resistance when force is applied. When there is no force applied the Arduino measures an output resistance of five volts. Each voltage divider has its own unique resting resistance since there is some pressure applied to each purely from the other components touching it. When other pressure is applied to the sensors, the corresponding LED (blue, orange, or yellow) will light up telling the user that they are off track. The reason behind using three variable resistors is it gives the user more specific feedback since once can be placed on the left, bottom, and right sides of the vein.

Results

Pressure Threshold

Force required to turn on pressure-sensitive LEDs	
Pressure strip	Pressure threshold (Newtons)
Resistor 1 (Left)	4.6×10^{-4} +/- 1.7×10^{-3}
Resistor 2 (Bottom)	1.9×10^{-4} +/- 1.4×10^{-3}
Resistor 3 (Right)	3.2×10^{-4} +/- 2.28×10^{-3}

Figure 16: Required force to turn on LEDs

A threshold of 0.2 volts was set within the Arduino after testing, once this threshold is reached one of the pressure-sensitive LEDs turned on. This 0.2 Volt change is equivalent to a change in resistance of 416.67 Ohms. For each of the three resistors, the average force in Newtons is shown along with its standard deviation. These values were obtained over the course of twenty trials for each resistor. All of these forces, in Newtons, are just slightly more than the force due to an average house fly's mass (1.7×10^{-4} N). The equation shown below was then used to calculate the force, in Newtons, required to reach the threshold.

$$\mathbf{X = F / (RP1 - RP2) * 416.67}$$

In this equation, X is the force required to reach the pressure strip threshold in Newtons, F is the known weight added of the additional screw in Newtons, RP1 is the resistance measured within the resistive strip when only one weight is applied, RP2 is the resistance measured within the resistive strip when both weights are applied, and the constant 416.67 is the value in Ohms required to reach threshold. The results of this equation can be seen in Figure 15.

Change in Voltage During Needle Insertion

Over the course of ten trials, there was an average voltage drop of 0.402 Volts. Using this value as a reference, the threshold was set at 0.35 volts. The Arduino was programmed to record the initial voltage upon needle insertion, and then continuously check for a drop of 3.5 volts from that reference point. Once the needle is fully inserted the voltage differential drops enough to be detected by the Arduino, and all of the lights light up to indicate successful insertion of the needle.

	Vout1	**Vout2**	**Vout1-Vout2**
Average	2.888 ± 0.1188 V	2.486 ± 0.1734 V	0.402 ± 0.08175

Figure 17: The results of the change in voltage testing for the insertion of the needle in the conductive gel.

Although the initial and final voltages changed based on how far away the needle was inserted from the end of the vein, the change in voltage was relatively constant. Instead of the code looking for a change of at least 0.402 volts from once the needle was inserted into the vein, the code looked for a change of 0.31 volts. Since the 0.402 volts is the average, there are some values that are below that change and in order to ensure that the code recognized the majority of completed procedures, 0.31 volts was used as the threshold instead. This was determined by subtracting the standard deviation from the average and lowering the value to 0.31 since the Arduino only checks up to two decimal places.

The longevity of Conductive Gel

For as long as four weeks of testing the viscosity, the gel remained in its gelatinous form. Therefore, the conductive gel will remain viable for at least a month inside of the model. Based on these observations, it is not predicted that the gel will dry out or harden within three months.

Conclusion

The tube filled with conductive gel and surrounded by force-sensing resistors used in this model is an effective alternative to existing IV and catheter insertion training models. Not only does it mimic the feel of the procedure, but it also provides easily understood feedback on the user's progress. It is easily portable which will make it ideal for training situations and movement around the classroom and can be plugged into any USB port on a computer for power.

This design successfully solves many of the issues that arise from existing models through its elimination of the need for artificial blood and by providing feedback. When pressure was applied to the sides of the vein, an indicator light would go off. However, due to the relatively large size of the sensors compared to the vein, the side resistors would sometimes be set off along with the bottom one due to the bottom resistor hitting them. This is a relatively minor problem though because the user is still getting feedback that they made an error in the procedure. Additionally, the red-green indicator lights for the insertion of the needle changed appropriately every time the user inserted or removed the needle from the device. Furthermore, the device is cost-effective. The cost of the final product was approximately 33% of the cost of current models [2]. These aspects of the design provide students with feedback that will enhance learning IV catheter insertion.

In the future, many improvements could be made. A display of results on a computer screen could be added to provide more detailed feedback on a student's performance. It would replace the existing LEDs and could display messages such as, “Warning: Too much pressure applied to the left side,” or “Procedure complete.” This display could also be used to give the students a score which represents how well they performed the procedure. Every time a force sensor is triggered would result in a deduction from their score. After the device registers the completion of the procedure, it would display their score. This would allow students to track their progress over time and could be used for grading as well.

A mechanical aspect to add would be to create a jerking response to the user's actions. Dogs tend to recoil when IVs are inserted, especially when done so poorly. This movement could be mimicked so that if the user applies too much pressure, the leg moves away from them. There could be certain pressure points to represent more sensitive areas on dogs or it could occur if a larger than normal force is applied while inserting the IV.

For increased convenience for the client and students who use the device, and longevity of the device itself, the imitation vein should be more easily replaceable. This coincides with the idea to increase the length of the rectangle in the top of the leg to decrease the amount that the vein arches. The way the wire and vein are currently connected and pushed to the top of the device causes the vein to create an arch. By lengthening the rectangle this arch would be decreased. This would also make it easier to replace the parts since there is more room to access the device.

Citations

[1] Avma.org. (2019). COE Accreditation Policies and Procedures: Requirements. [online] Available at: https://www.avma.org/ProfessionalDevelopment/Education/Accreditation/Colleges/Pages/coe-pp-requirements-of-accredited-college.aspx [Accessed 7 Oct. 2019].

[2] SurgiReal Products. (2019). Canine Leg Vascular Access Simulator. [online] Available at: https://surgireal.com/products/canine-leg-vascular-access-simulator [Accessed 7 Oct. 2019].

[3] "Life/form® Canine IV Leg." [Online]. Available: https://www.gtsimulators.com/Nasco-Lifeform-Canine-IV-Leg-p/lf01016u.htm. [Accessed: 06-Oct-2019].

[4] D. J. Hernandez *et al.*, "Measurement of bio-impedance with a smart needle to confirm percutaneous kidney access," *J. Urol.*, vol. 166, no. 4, pp. 1520–1523, Oct. 2001.

[5] "Your home electrical system: how long can it last?" [Online]. Available: http://www.improvementcenter.com/electrical/home-electrical-system-how-long-can-it-last.html. [Accessed: 06-Oct-2019].

[6]https://vetnurse.com.au/2018/03/07/placing-iv-catheters/

[7] "Haptic technology: The next frontier in video games, wearables, virtual reality, and mobile electronics," *New Atlas*, 16-Jan-2015. [Online]. Available: https://newatlas.com/haptic-tech-vr-wearables-games-sightlence/35616/. [Accessed: 11-Sep-2019].

[8]"About Intravenous Medication Administration," *Healthline*. [Online]. Available: https://www.healthline.com/health/intravenous-medication-administration-what-to-know. [Accessed: 06-Oct-2019].

[9] "Dog: Cephalic vein (non-surgical) | NC3Rs." [Online]. Available: https://www.nc3rs.org.uk/dog-cephalic-vein-non-surgical. [Accessed: 08-Oct-2019].

[10] "Barcelonetta | Half Yard Faux Fur | 18' X 60' Inch | Craft Supply, Costume, Decoration (Dark Grey)," *Amazon*. [Online]. Available: Barcelonetta | Half Yard Faux Fur | 18" X 60" Inch | Craft Supply, Costume, Decoration (Dark Grey).
Available:

https://www.amazon.com/Barcelonetta-Craft-Supply-Costume-Decoration/dp/B07VNVV2K9/ref=pd_bxgy_201_img_2/147-8984887-7044169?_encoding=UTF8&pd_rd_i=B07VLQB8MV&pd_rd_r=63678a96-23aa-4eb5-a09a-63423099ed2b&pd_rd_w=2HikN&pd_rd_wg=Wk4oJ&pf_rd_p=09627863-9889-4290-b90a-5e9f86682449&pf_rd_r=2DYC8Q3TMTBZXKXTE155&refRID=2DYC8Q3TMTBZXKXTE155&th=1

[11]“Amazon.com: Premium Chamois Cloth for Car - 2 Pack - Mini Car Shammy (17 x 13 inches) - (Two Tubes + One Extra Shammy Towel for Car): Automotive.” [Online]. Available: https://www.amazon.com/Premium-Chamois-Cloth-Car-Shammy/dp/B07TW7STZY/ref=sr_1_3?keywords=shammy&qid=1570411826&sr=8-3. [Accessed: 06-Oct-2019].

[12]“Amazon.com: Mxfans 1m Red Silicone Fuel Pipeline RC1:10 N10255 for Oil Truck Model: Toys & Games.” [Online]. Available: https://www.amazon.com/Mxfans-Red-Silicone-Fuel-Pipeline/dp/B07QKQPH4K/ref=sr_1_20?keywords=0.5+cm+rubber+hose&qid=1570411963&sr=8-20. [Accessed: 06-Oct-2019].

[13]“Amazon.com: HANKEY Memory Foam Pillow, Orthopedic Support Prevents Back and Neck Pain Washable Cover: Home & Kitchen.” [Online]. Available: https://www.amazon.com/HANKEY-Memory-Foam-Pillow/dp/B07DNRWHVW/ref=sr_1_23?keywords=memory+foam+pillow&qid=1570413193&sr=8-23. [Accessed: 06-Oct-2019].

[14]“Parker Labs Spectra 360 Electrode Conductivity Gel.” [Online]. Available: https://www.google.com/shopping/product/10262531372084007784?q=conductive+gel+comparisons&rlz=1C5CHFA_enUS757US757&sxsrf=ACYBGNRI_ShULd2MSB2NwncS6Knwlqxp5A:1570413790190&biw=1154&bih=635&prds=epd:13415110899494764845,prmr:3&sa=X&ved=0ahUKEwiZ7uGjh4nlAhUHgK0KHbioD4sQ8wIIjAM. [Accessed: 06-Oct-2019].

[15]“Linear SoftPot (Ribbon Sensor) - 100mm,” *Adafruit*. [Online]. Available: https://www.adafruit.com/product/178.

Appendix

PDS

1. Physical and Operational Characteristics
    a. Performance requirements: The device should be able to be used repeatedly with minimal degradation. Since it is a training device, it should be able to last at least five years without needing to have any parts replaced. It will most likely be used several times a month depending on when the procedure is being practiced.
    b. Safety: The device will involve an electrical circuit and therefore all wiring must be properly insulated. The voltage supplied will be 5 volts in order to ensure proper function from the Arduino while avoiding overheating [1]. This device will contain a sharp-tipped needle that presents its own safety hazards. This will be labeled and expressed clearly as a potential safety hazard.
    c. Accuracy and Reliability: The device should be able to determine that it is in the lumen of the vein 95% of the time.
    d. Life in Service: The device will be able to withstand bi-weekly use for two years. Expected use will consist of repeated vessel punctures for roughly 15 minutes. Replacement of the vessel and conductive gel is expected once every two months.
    e. Shelf Life: Copper wiring would be a cheap and effective wire, as the life-span could be anywhere from 50-100 years (4). With typical wear and tear this could drop down to 20-25, but this time frame still does not create a problem. The plastic tubing that replicates the vain would need to be replaced after about 350 injections, to be careful. The environment should not affect the model while in storage. Depending on the battery size, but if we use a nickel-cadmium battery the shelf life, that is without use, should be around 18 months. If we were to use a typical lithium double-A battery, the shelf life would be upwards of 5 years.
    f. Operating Environment: The device will be operated at room temperature in a classroom environment. May be exposed to potential damage from gel leakage and needle puncturing

g. Ergonomics: Uses should be restricted to supervised classrooms only. The needle should never be inserted towards the user.
h. Size: The maximum size of the leg and total model will not be any larger than a 2 foot by 1.5 foot
i. Weight: The device should be portable. The model should be under 15 pounds. There are no problems with a model that is too light.
j. Materials: Materials are intended to mimic the real feel of a dog's leg while being able to withstand repeated puncture.

Material	**Source**	**Cost**
Arduino Microcontroller	Arduino.com	$22.00
22 Gauge Catheter	Client	$0.00
Imitation Fur (20x30cm)	Hobby Lobby [10]	$16.99
Imitation Skin (Chamois Cloth)	Amazon [11]	$12.95
0.5 cm Diameter Rubber Tubing	Amazon [12]	$6.07
3 cm Diameter Wooden Dowel	Team Lab	$0.00
Wires and LEDs	Personal Supplies	$0.00
Coaxial Needle or Equivalent	Unknown	~$100.00
Memory Foam	Amazon [13]	$17.96
Conductive Gel	Parker Labs [14]	$7.50

Total:		$183.47

k. Aesthetics, Appearance, and Finish: Resembles the leg of a dog. Potential fur-like finishing outside of the blood vessel region.

2. Production Characteristics:
    a. Quantity: Only one prototype is required.
    b. Target Product Cost: The expected total product cost is $183.47 if all expected materials are purchased. In general, the cost should stay below $350.
3. Miscellaneous
    a. Standards and Specifications: The imitation vein that is used should comply with the size provided with a 0.5 cm outer diameter.
    b. Customer: Dislikes the use of fluid as a positive indicator within the tube that models the blood vessel since it dyes the operator's hands.
    c. Patient-related Concerns: The device should not need to be sterilized, as the needles will not be used on humans. The people using the device must be careful when using the needle, or when they put the needle away as to not poke themselves.
    d. Competition: There are a few models that use a fluid solution to replicate blood but only one that uses an electrical system we are proposing and that is by the game operation [2].

PDS Sources

[1] "Arduino Uno Rev3." [Online]. Available: https://store.arduino.cc/usa/arduino-uno-rev3. [Accessed: 09-Oct-2019].

[2] "Life/form® Canine IV Leg." [Online]. Available: https://www.gtsimulators.com/Nasco-Lifeform-Canine-IV-Leg-p/lf01016u.htm. [Accessed: 06-Oct-2019].

[3] D. J. Hernandez *et al.*, "Measurement of bio-impedance with a smart needle to confirm percutaneous kidney access," *J. Urol.*, vol. 166, no. 4, pp. 1520–1523, Oct. 2001.

[4]"Your home electrical system: how long can it last?" [Online]. Available: http://www.improvementcenter.com/electrical/home-electrical-system-how-long-can-it-last.html. [Accessed: 06-Oct-2019]

Raw Arduino Pressure Testing Data

	Arduino raw output	
Pressure strip	One screw (3.13 g)	Two screws (6.31 g)
Resistor 1 (Left)	778.5 ± 73.8	667.5 ± 40.5
Resistor 2 (Bottom)	862.7 ± 19.8	705.0 ± 41.7
Resistor 3 (Right)	705.6 ± 36.8	659.4 ± 33.1

Figure 17: Raw data from the Arduino used for "Pressure threshold" testing.

All the values in this table can be converted to a voltage by multiplying by 5 and then dividing by 1023.

Code

```
//Initializes the analog and digital pin numbers for the appropriate pin
int gel = A0;
int pressure1 = A1;
int pressure2 = A2;
int pressure3 = A3;
int redLED = 13;
int greenLED = 12;
int blueLED = 10;
int yellowLED = 11;
int orangeLED = 9;
float gelVout1 = 0;
float gelVout2 = 0;
float gelDif = 0;

void setup() {
  //Initializes the pins for output
  pinMode(greenLED, OUTPUT);
  pinMode(redLED, OUTPUT);
  pinMode(blueLED, OUTPUT);
  pinMode(yellowLED, OUTPUT);
  pinMode(orangeLED, OUTPUT);
  Serial.begin(9600);
}

void loop() {
  //Converts the voltage
```

```
float voutGelTemp = analogRead(gel) * 5.0 / 1023.0;
float vout1 = analogRead(pressure1) * 5.0 / 1023.0;
float vout2 = analogRead(pressure2) * 5.0 / 1023.0;
float vout3 = analogRead(pressure3) * 5.0 / 1023.0;

//Checks if the voltage for the gel voltage divider is below the threshold
if (voutGelTemp < 3.5) {
  //Turns the red light off and the green light on
  digitalWrite(redLED, LOW);
  digitalWrite(greenLED, HIGH);
  //Sets the initial voltage value the second the needle is inserted
  if (gelVout1 == 0) {
   gelVout1 = voutGelTemp;
   Serial.println(gelVout1);
  }
  //Checks the change in output voltage
  else {
    gelVout2 = voutGelTemp;
    gelDif = gelVout1 - gelVout2;
  }
  Serial.println(gelDif);
}
//Turns the red light on and resets the values
else{
  digitalWrite(redLED, HIGH);
  digitalWrite(greenLED, LOW);
  gelVout1 = 0;
  gelVout2 = 0;
  gelDif = 0;
}
//Checks that none of the pressure sensors were triggered and that the
//change in voltage from once the needle is inserted is above the threshold
if (vout1 > 3.0 && vout2 > 3.1 && vout3 > 2.0 && gelDif > 0.31){
  digitalWrite(blueLED, HIGH);
  digitalWrite(yellowLED, HIGH);
  digitalWrite(orangeLED, HIGH);
  digitalWrite(greenLED, HIGH);
  digitalWrite(redLED, HIGH);
}
//Turns on if pressure is applied to one of the force sensors
else {
  if (vout1 < 3.0) {
    digitalWrite(blueLED, HIGH);
```

```
    }
    else {
      digitalWrite(blueLED, LOW);
    }
    if (vout2 < 3.3) {
      digitalWrite(yellowLED, HIGH);
    }
    else {
     digitalWrite(yellowLED, LOW);
    }
    if (vout3 < 2.0) {
      digitalWrite(orangeLED, HIGH);
    }
    else {
      digitalWrite(orangeLED, LOW);
    }
  }
 delay(400);
}
```

Average Change in Voltage in Conductive Gel Testing Results

Trial	**Vout 1**	**Vout 2**	**Vout 1 - Vout 2**
1	2.66	2.2	0.46
2	2.9	2.41	0.49
3	2.78	2.33	0.45
4	2.87	2.32	0.55
5	2.9	2.5	0.4
6	2.79	2.46	0.33
7	2.93	2.61	0.32
8	3.05	2.74	0.31
9	3.01	2.65	0.36
10	2.99	2.64	0.35
Average	2.888	2.486	0.402
Stand Dev	0.1188650028	0.1734743017	0.0817584518

			2

Materials Cost

Material	**Source**	**Cost**
Arduino Microcontroller	Arduino.com	$13.99
22 Gauge Catheter	Client	$0.00
Imitation Fur (20x30cm)	Amazon [10]	$19.90
Imitation Skin (Chamois Cloth)	Amazon [11]	$12.95
0.5 cm Diameter Rubber Tubing	Amazon [12]	$12.08
Wires and LEDs	Personal Supplies	$0.00
Memory Foam	Amazon [13]	$13.21
Conductive Gel	Parker Labs [14]	$10.52
Pressure Sensitive Resistor Sheets	Adafruit [15]	$30.63
Total:		$114.01