

Interactive EKG Model

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BME ABET Educational Objectives

An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (ABET Criterion 3c) while incorporating appropriate engineering standards (ABET Criterion 5) (need to assess each of these separately, but since ‘or’ and “such as” not all need to be met separately).

- i) multiple realistic constraints (economic, environmental, social, political, ethical, health and safety, manufacturability) – pages 79-81
- ii) appropriate engineering standards - pages 48-78

An ability to function on multidisciplinary teams (ABET Criterion 3d). pages 1

An understanding of professional and ethical responsibilities (ABET Criterion 3f)

- i) Professional – pages 82-95
- ii) Ethical – pages 80

An ability to communicate effectively (ABET Criterion 3g). pages 39, 46, 51

The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (3h). (both economic AND environmental need to be addressed)

- i) Economic – pages 79
- ii) Environmental – pages 79

A knowledge of contemporary issues (ABET Criterion 3j). pages 15-18, 35-36

Authorship

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1.3 How are we doing this?	Kyla Rodger	Edited by All
1.4 Conclusion	All	Edited by All
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2.2: Anatomical Background	Kyla Rodger	Edited by All
2.3: Electrocardiogram Background	Drafted by Section	Edited by All
2.3.1 12 Lead Electrocardiogram	Elizabeth Paulson	Edited by All
2.3.2 Electrocardiogram Breakdown	Elizabeth Paulson	Edited by All
2.3.3 Cardiac Rhythms	Elizabeth Paulson	Edited by All
2.3.4 Disease Characteristics	Elizabeth Paulson	Edited by All
2.3.5 Ventricular Tachycardia	Elizabeth Paulson	Edited by All
2.3.6 Myocardial Infarction	Elizabeth Paulson	Edited by All
2.4: Current Gold Standard	Adelle Milholland	Edited by All
2.5: Related Patents	Adelle Milholland	Edited by All
2.6: Physical vs Computer Model	Adelle Milholland	Edited by All
2.7: Conclusion	All	Edited by All
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3.2 Initial Client Statement	Adelle Milholland	Edited by All
3.3 Objectives of Project	Elizabeth Paulson	Edited by All
3.4 Constraints	Adelle Milholland	Edited by All
3.5 Revised Client Statement	Kyla Rodger	Edited by All
3.6 Conclusion	Elizabeth Paulson	Edited by All
4. Alternative Designs	Drafted by Section	Edited by All
4.1 Needs	All	Edited by All
4.2 Conceptual Designs	All	Edited by All
4.3 Preliminary Designs	All	Edited by All
4.3.1 Physical Model	Kyla Rodger	Edited by All
4.3.2 Animations of Heart Conditions	Elizabeth Paulson	Edited by All
4.3.3 Light Patterns on Heart Models	Adelle Milholland	Edited by All
4.3.4 Timing Diagrams	Adelle Milholland	Edited by All
4.3.5 LED Sequence Switching Code	Elizabeth Paulson	Edited by All
4.3.6 Lights Mapped on Models	Adelle Milholland &Kyla Rodger	Edited by All
4.4 Preliminary Testing	All	Edited by All
4.5 Design Calculations and Justification	Kyla Rodger	Edited by All
4.5.1 Justification for Usage of Arduino Board	All	Edited by All
4.5.2 Calculations of LEDs Needed	All	Edited by All
4.5.3 Justification for Parallel Circuit	Kyla Rodger	Edited by All

4.5.4 Solution for Current Distribution Issue	Elizabeth Paulson & Kyla Rodger	Edited by All
4.5.5 Power Supply Options for Heart Models	Kyla Rodger	Edited by All
4.5.6 Justification for Wiring Choices	Created by All	Edited by All
4.5.7 Resistance Needed Calculations	All	Edited by All
4.5.8 Circuit Construction of Heat Models	Elizabeth Paulson & Kyla Rodger	Edited by All
4.6 Prototyping	All	Edited by All
5. Design Verification	Drafted by Section	Edited by All
5.1 Resistor Heating	Kyla Rodger	Edited by All
5.1.1 Heat Testing of Resistors	All	Edited by All
5.1.2 Current Testing of Resistors	Adelle Milholland & Kyla Rodger	Edited by All
5.2 Testing Capabilities of Fading LEDs	Elizabeth Paulson & Kyla Rodger	Edited by All
5.3 Luminosity Testing	Adelle Milholland & Kyla Rodger	Edited by All
6. Discussion	Kyla Rodger	Edited by All
6.1: Economics	Kyla Rodger	Edited by All
6.2: Environmental Impact	Kyla Rodger	Edited by All
6.3 Societal Influence	Kyla Rodger	Edited by All
6.4 Political Ramifications	Kyla Rodger	Edited by All
6.5 Ethical Concern	Kyla Rodger	Edited by All
6.6 Health and Safety Issue	Kyla Rodger	Edited by All

6.7 Manufacturability	Kyla Rodger	Edited by All
6.8 Sustainability	Kyla Rodger	Edited by All
7. Final Design and Validation	Kyla Rodger	Edited by All
7.1 Meeting Design Goals	Kyla Rodger	Edited by All
7.2 Large Heart Protocol	Kyla Rodger	Edited by All
7.3 Small Heart Protocol	Kyla Rodger	Edited by All
7.4 Torso Protocol	Kyla Rodger	Edited by All
8. Conclusions and Recommendations	All	Edited by All
9. References	All	Edited by All
10. Appendices	All	Edited by All

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Abstract

This study explores the creation of a teaching tool to better enable medical students to understand the relationship between electrocardiogram (EKG) waves and the electrical activity within the heart. By having a greater depth of knowledge about EKG signals, the medical students should be able to accurately diagnose different cardiac related symptoms. We have designed and built two models which could be used in a lecture hall setting. One model accurately displayed the electrical activity of Ventricular Tachycardia, several Myocardial Infarctions, Ventricular Fibrillation, and Atrial Fibrillation in synchronization with each EKG waveform. A second model indicates the correct placement of EKG leads on a human torso and the various views of the heart that result from these leads.

Terminology

AF-Atrial Fibrillation

A-fib-Atrial Fibrillation

EKG-Electrocardiogram

MI-Myocardial Infarction

Vfib- Ventricular Fibrillation

Vtach- Ventricular Tachycardia

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Chapter One: Introduction

Heart disease is the leading cause of death in the United States¹, knowing the functionality of a patient's heart immediately and accurately allows doctors to provide the best possible care. In order to meet this need hospitals provide electrocardiogram (EKG) machines that use lead lines to measure electrical signals made by the heart². Proper interpretation of EKG signals allow doctors to know the patient's heart rate, number of heart beats per minute, as well as the manner in which the heart is beating². This information allows doctors to make immediate diagnosis of many heart conditions.

The information, provided by the EKG machine, is immediate and invaluable, but in order for it to be of use doctors must be able to correctly interpret the data provided. Medical students take a class on reading EKG outputs as part of their training to be a doctor. According to our sponsor, Dr. Hawthorne, many medical students have difficulty relating the EKG signal output to the mechanics of a heartbeat. The EKG is a complex machine which receives input from ten lead nodes placed at specific locations on the patient's body. These nodes measure the electrical signal passing through the body. The signals measured are the result of electrical impulses through the heart that cause the various sections of the heart to contract, creating a heartbeat and pumping blood throughout the body³. Based on the location of the nodes the measured signals indicate activity in specific walls of the heart. If medical students do not understand the functionality between the electrical activity within the heart and the output EKG signal, this leads to doctors who do not understand which leads to misdiagnoses. In fact *The*

¹ National Center for Health Statistics. "Deaths and Mortality." Centers for Disease Control and Prevention. Centers for Disease Control and Prevention, 14 July 2014. Web. 14 Sept. 2014.

² Cleveland Clinic. "Electrocardiogram (EKG or ECG)." Cleveland Clinic. Cleveland Clinic, Sept. 2013. Web. 11 Sept. 2014.

³ National Heart, Lung, and Blood Institute. "Understanding the Heart's Electrical System and EKG Results." NIH. US Department of Health and Human Services, 09 July 2012. Web. 11 Sept. 2014.

Journal of Pediatrics performed a study in 2011 on 53 doctors and noted that doctors misdiagnose EKGs about 30% of the time⁴. Misdiagnoses are serious because they can lead to patient death or permanent injury.

The goal of our project was to create an interactive electrocardiogram heart model that would assist medical students in learning about how the electrocardiogram leads reflect different electrical activity in the heart walls. The heart model will help bridge the knowledge gap between the output shown on the screen of an EKG and the electrical phenomena occurring within the walls of the heart. The tool depicts the electrical activity of the heart in addition to showing the appropriate EKG wave for the normal cardiac state as well as for various cardiac disease states. The tool also depicts the appropriate locations for each of the limb and precordial EKG lead electrodes, and conveys which lead monitors which section of the heart.

To begin this project, we researched and conducted interviews with various medical personnel, including doctors and medical students, about the current gold standard and what the doctors and medical students would like to see in future models. Our research was broad as we learned about the biological functions of the heart, along with the current electrocardiogram technology, and looked into various models on the market. From our research, our group concluded that there is no current gold standard for our project because no model exists that has the same intended functions as our model. Our interactive EKG heart model, is intended to teach medical students the correlation between the electrical activity within the heart and the output EKG, no other model on the market teaches this concept or has this same intention. All that exists on the market are various anatomical heart models and a few models on EKG lead

⁴ Hill, A., Miyake, C., Grady, S., & Dubin, A. (2011). Accuracy of Interpretation of Preparticipation Screening Electrocardiograms. *The Journal of Pediatrics*, 159(5), 783-788.

placement. This means that our model is unique and fills a need in medical schools and other medical training facilities that teach about EKGs.

Once we completed our research, our team came up with several design ideas for our heart model. The creation of these design prototypes involved more research into types of computer software, manufacturing techniques, and materials. Then we used several different types of evaluations to choose a design idea. The design idea that was chosen affected how the rest of the project went as each idea involved specific processes that the other ideas did not include. We created the prototype of our design and tested it.

For the first round of testing we used the various functions of the model repeatedly looking for any changes in functionality over time and any potential for the device to be unsafe. This round of testing did not involve an IRB because our group conducted this test by ourselves. The next round of testing involved undergraduate students of WPI so an IRB was needed. We invited students to use our model while we observed. This test was focused on user interaction with the model; primarily how much training was necessary before users understood and could use all functions of the model. The third round of testing involved Dr. Hawthorne. We presented our model to her, explained how it is used, and asked her to give a mock lecture using the model as a teaching aid. We then asked for any feedback on how she felt using the model. The final round of testing involved two groups of Dr. Hawthorne's medical students and involved an IRB as well. Each group was given a lecture then a quiz on interpreting EKG waves, the control group had access to the course textbook while the experimental group had access to the textbook and our model. The averaged quiz scores from the two groups was used as a quantitative measure of the success of our model. The students who used the model were also asked to provide feedback on the model.

The ultimate goal of our project was to provide aid to medical students in order to improve the overall standard of health care by making them better doctors. Through bridging the knowledge gap between EKG output and heart activity, we gave medical students a better understanding of the electrical activity within the heart associated with heart conditions and the use of EKGs for diagnosis.

Chapter Two: Literature Review

Section 2.1: Introduction

The heart, arguably the most important organ in the human body, vital to the existence of all creatures, and the focus of our project. For our project, we created an interactive heart model that displayed the electrical activity within different walls of the heart in order to give medical students a better understanding of the relation between an EKG output and what is happening in the heart. It is important that medical students as future medical professionals, learn to read an EKG; a misread EKGs can lead to patient death. One woman's family is suing their local hospital after she died of heart attack when her EKG with slight abnormalities was declared normal by her doctors. Both times the woman went the emergency room, her doctors noted that her EKG was slightly off, but mostly displayed a normal sinus rhythm. If the doctors had had a better understanding of the EKG, they could have caught this woman's condition sooner possibly saving her life.⁵ While there is no current statistic stating the exact number of people who die per year due to EKG misdiagnosis, there are many documented cases of people who have suffered from this. *The Journal of Pediatrics* performed a study in 2011 in which 53 doctors read 18 EKGs of various heart conditions and misdiagnosed about 30% of the time.⁶ Additionally, a misdiagnosed EKG can have a significant effect on one's life. For instance, athletes forced to get EKGs which are often misread and can affect their ability to participate in sports.⁷ Also, misdiagnosed EKGs cost the hospital most money in malpractice suits. According to an article in *Family Practice Management*, "More malpractice dollars are awarded for missed myocardial

⁵ Lubin & Meyer Attorneys. (2011, January 1). Heart Attack Malpractice Settlement Is \$1 Million. Retrieved September 26, 2014.

⁶ Hill, A., Miyake, C., Grady, S., & Dubin, A. (2011). Accuracy of Interpretation of Preparticipation Screening Electrocardiograms. *The Journal of Pediatrics*, 159(5), 783-788.

⁷ Beil, L. (2014, March 21). Sudden death: Proposed EKG Screening for Student Athletes Spurs Medical Debate. Retrieved September 26, 2014.

infarctions than for any other single diagnosis”⁸. Our model will help medical students understand EKGs better by teaching them to read an EKG so that they understand each portion of the EKG wave and its corresponding electrical activity. By improving future doctors’ EKG skills, hopefully the number of misdiagnosis of EKGs can be reduced, preventing deaths and lawsuits for many hospitals.

Section 2.2: Anatomical Background

Before designing, or even thinking about designing, a heart model one must understand the workings of the heart so it can be accurately replicated. For this project our main focus was the electrical activity within the different walls of the heart. To start with, we shall discuss the anatomy of the heart.

The heart is divided into four chambers. These chambers are named after their location. The top chambers are known as atria while the bottom chambers are known as ventricles. Additionally, the heart is divided into left and right meaning the four chambers are known as right atrium, right ventricle, left ventricle, and left atrium. These four chambers are responsible for movement of both oxygenated and deoxygenated blood throughout the heart and the rest of the body.⁹

Now that the bulk anatomy of the heart has been established, the next section covers the smaller but equally as vital portions of the heart that are related to the conduction of the electrical signals within the heart. Located in the upper right of the right atrium is a collection of cells that compose the sinoatrial node or sinus node. The sinus node, also known as the SA node, is responsible for starting the electrical signal within the heart and setting the heartbeat. It sends off

⁸ Davenport, J. (2000, October 7). Documenting High-Risk Cases to Avoid Malpractice Liability. *Family Practice Management*. Retrieved September 19, 2014

⁹ The Heart (Human Anatomy): Diagram, Definition, Location in the Body, and Heart Problems. (2009, January 1). Retrieved September 26, 2014, from <http://www.webmd.com/heart/picture-of-the-heart>.

the signal about sixty to one hundred times per minute in a healthy individual (this varies depending on health of individual including fitness level and preexisting health conditions). From the SA node, the electrical signal travels through the right and left atria. The electrical signal travels through the walls of the heart muscle in the atria causes the atria to contract which pushes the blood into the ventricles.¹⁰

Now the blood is in the ventricles and the electrical signal has reached the atrioventricular node (AV node). The AV node is a group of cells located between the atria and the ventricles. At this point, the signal slows down while passing through the AV node. The electrical signal then leaves the AV node and travels to the bundle of HIS. The bundle of HIS is a group of fibers located centrally inside the heart. These fibers help carry electrical impulses through the heart.¹¹ The electrical signal travels from the bundle of HIS to the Purkinje fibers surrounding the right and left ventricles. When the signal travels through these fibers, the ventricles contract and pump blood through the rest of the body.

Above demonstrates how a heart operates when healthy, however there are a number of medical conditions that interfere with the functionality of the heart. To start off, we look at heart conditions that specifically affect the electrical conduction system of the heart. Any heart rate that is abnormal or has an off rhythm, is known as an arrhythmia. Arrhythmias have various levels of seriousness, as some arrhythmias still allow a person to have a relatively normal life while other arrhythmias will kill a person in minutes. There are six main types of arrhythmias.

The first type of arrhythmia is known as supraventricular tachycardia, or SVT. SVT occurs when the heartbeat is not being controlled by the SA node. Instead another part of the

¹⁰ Understanding the Heart's Electrical System and EKG Results. (2012, July 9). Retrieved September 26, 2014.

¹¹ "His Bundle Electrography: MedlinePlus Medical Encyclopedia."

heart overrides the SA node causing the heartbeat to accelerate. The electrical signal still originates from above the ventricles, so each electrical signal reaches the ventricles meaning the whole heart contracts at the new accelerated heartbeat (which is between one hundred and forty beats per minute and two hundred and forty beats per minute). SVT usually comes about in episodes ranging from a couple of minutes to a couple of hours. Sometimes people suffer from SVT several times a day while others only experience SVT a few times per year. While this condition does pose several health risks, people can lead a relatively normal life.

The second type of arrhythmia is called atrial fibrillation, or AF. AF occurs when various parts of the atria begin to fire off random electrical impulses. This causes the atria to fibrillate (partially contract). Not only do the atria fibrillate but they do so at a much higher rate than normal (about four hundred beats per minute). Since the atria only partially contract and they are sending off electrical impulses so rapidly, the ventricles only receive some of these impulses. Usually the ventricles will contract between one hundred and sixty to one hundred and eighty beats per minute, but they do so with varying force. Since there are varying rates of contraction with varying force, the blood is not always being pumped fully and completely to the other parts of the heart or throughout the whole body, which can cause other health issues. Once AF develops, it's usually permanent.

The third type of arrhythmia is ventricular tachycardia. Ventricular tachycardia occurs when the ventricles electrical impulse rate speeds up (usually between one hundred and twenty to two hundred beats per minute). This is a rare condition as the SA node usually determines the heartbeat for the whole heart and for this to occur another major heart condition (such as a heart attack) has to occur. Unfortunately this condition is deadly the electrical impulse is not reset to proper conditions in a few minutes.

The fourth type of arrhythmia is known as ventricular fibrillation (VF). VF is when the ventricles of the heart fire off random electrical impulses from various locations in the ventricles. Fibrillation occurs and the weak contractions are not enough to push the blood out of the heart. Without the blood pumping throughout the body, cardiac arrest can occur, and fatality will occur unless condition is corrected quickly.

Heart block is the fifth type of arrhythmia and it is subdivided into three categories. A heart block occurs when the electrical impulses are either partially or fully blocked when communicating between the atria and the ventricles. This means that the SA node is working properly and firing the correct number of electrical impulses but the heart's contraction depends on how many electrical impulses are received by the ventricles. The first type of heart block, or first degree heart block, occurs when there is a delay in the electrical impulse between the atria and the ventricles. Each impulse does get through to the ventricles and the heart contracts normally. The second degree heart block occurs when not all electrical impulses reach the ventricles. Ventricle contraction is therefore slower than normal as it is not receiving as many electrical impulses as normal. Third degree heart block is when no electrical impulses are conducted between the atria and the ventricles and the ventricles are forced to use their own ventricle rhythm (which is about twenty to forty beats per minute). This means the heartbeat is much slower than normal.

The final type of arrhythmia is called sick sinus syndrome. Sick sinus syndrome occurs when the SA node is damaged. Typically the heartbeat is slowed and sometimes misses beats but there have been cases where the heartbeat is faster than average.¹²

¹² Arrhythmias (Abnormal Heart Rhythms). (n.d.). Retrieved September 26, 2014, from <http://www.patient.co.uk/health/abnormal-heart-rhythms-arrhythmias>

While arrhythmias are heart conditions of their own, they are usually symptoms of another condition within the heart that interferes with the electrical conduction system causing the arrhythmia. Our group chose several heart conditions that display one or more of these arrhythmias and that have a significant health effect for our model to display.

One condition our group has chosen is myocardial infarction. Myocardial infarction occurs when a portion of the heart is blocked off so that area is deprived of oxygen and cell death of surrounding myocardial tissue, if the heart tissue dies the heart will stop functioning and death will occur. The most common cause of myocardial infarction is coronary heart disease mixed with other risk factors like smoking, poor diet, and lack of exercise. Depending on the severity of the heart attack there are different treatment options available but it is important to get treatment quickly.¹³ Heart attacks can lead to several different types of arrhythmias including atrial tachycardia, sinus tachycardia, ventricular tachycardia¹⁴, and ventricular fibrillation¹⁵. Due to the various types of heart attacks that can occur and the variety of arrhythmias and EKG symptoms, heart conditions are extremely dangerous. Every year roughly 720,000 people in the United States have a heart attack. About 600,000 people in the United States die from coronary heart disease per year. Of these deaths, forty-seven percent of sudden cardiac deaths occur inside a hospital.¹⁶ In the case of a heart attack, it is not only important that the condition be diagnosed but that the type of arrhythmia the heart attack is causing and output EKG are closely examined

¹³ Myocardial Infarction (Heart Attack). (n.d.). Retrieved September 26, 2014, from http://www.hopkinsmedicine.org/heart_vascular_institute/conditions_treatments/conditions/myocardial_infarction.html

¹⁴ Atrial Fibrillation. (n.d.). Retrieved September 26, 2014, from http://www.heart.org/HEARTORG/Conditions/Arrhythmia/AboutArrhythmia/Tachycardia-Fast-Heart-Rate_UCM_302018_Article.jsp

¹⁵ Ventricular fibrillation. (n.d.). Retrieved September 26, 2014, from <http://www.mayoclinic.org/diseases-conditions/ventricular-fibrillation/basics/causes/con-20034473>

¹⁶ Heart Disease Facts. (2014, August 18). Retrieved September 26, 2014, from <http://www.cdc.gov/heartdisease/facts.htm>

because these can clue a physician in to where the blockage is in the heart allowing for better patient treatment.

The second heart condition chosen (which is also a type of arrhythmia) is ventricular fibrillation. Ventricular fibrillation occurs when random electrical impulses in ventricles cause the ventricles to quiver which means blood is inefficiently pumped through the heart and body. This condition is very serious because if not caught and fixed in a matter of minutes, the patient will die. When a person suffers from ventricular fibrillation, they are experiencing sudden cardiac arrest.¹⁷ A person is at risk for ventricular fibrillation if they have a congenital heart defect, have had a heart attack before, or have a heart muscle disease. The only way to treat ventricular fibrillation is through CPR or AED defibrillation, both of which must be done by trained professionals. Once an attack has occurred patients are asked to adjust their lifestyles and are often put on medication. Over 300,000 people suffer from sudden cardiac arrest per year in the United States alone.¹⁸ Ventricular fibrillation can also occur from a person drowning or being electrically shocked. If a person is suffering from cardiac arrest due to V-fib, but is not in shock and receives immediate medical attention, they have a 95% chance of recovery. If the person suffers from shock or heart failure due to V-fib, even if they receive immediate medical treatment, 70% of people die after being resuscitated without ever gaining normal function.¹⁹ Due to the high number of people who suffer from Ventricular Fibrillation and the fatality of the condition if not diagnosed and treated immediately, our group thought it was vitally important that medical students be taught this condition.

¹⁷ Ventricular Fibrillation. (n.d.). Retrieved October 15, 2014.

¹⁸ Diseases and Conditions: Ventricular. (n.d.). Retrieved October 15, 2014.

¹⁹ Mitchell, L. (2012, November 1). Ventricular Fibrillation. Retrieved October 15, 2014.

Ventricular Tachycardia was the third chosen heart condition. This condition is started by a sudden rapid heartbeat in the ventricles. The typical heart rate for someone in this condition is over 100 beats per minute. Ventricular Tachycardia usually occurs in episodes that can be caused by a number of other heart conditions such as heart failure and cardiomyopathy. The symptoms of this condition are chest discomfort, fainting, light-headedness, and shortness of breath. Treatment of Ventricular Tachycardia depends on the condition causing it. Usually Ventricular Tachycardia can be treated with anti-arrhythmic medications but sometimes CPR or electrical defibrillation is needed.²⁰

The final heart condition our group decided to use in our model was atrial fibrillation. Previously in this paper we discussed that arrhythmias are often symptoms of another heart condition. This is true as atrial fibrillation can be triggered by various other conditions and arrhythmias, such as sick sinus syndrome²¹. However, atrial fibrillation can be a condition on its own as it can occur without another heart condition triggering it and it has significant health effects. Often called “quivering heart” A-fib is an arrhythmia that can cause blood clots, strokes, and/or heart failure. It is caused by the atria sending out random electrical impulses so blood is not moved effectively into ventricles. Once a person has A-fib, it does not go away, but it can be treated by getting rid of the underlying cause such as curing a person’s hyperthyroidism²². Roughly 2.2 million Americans have intermittent or sustained A-fib. Both men and women have the same risk of dying from A-fib²³. Fifteen percent of people who suffer from strokes have strokes because they also have A-fib and three out of four of those A-fib strokes are

²⁰ Ventricular tachycardia: MedlinePlus Medical Encyclopedia. (n.d.). Retrieved February 11, 2015.

²¹ Atrial fibrillation. (n.d.). Retrieved September 26, 2014.

²² Atrial Fibrillation (AF or A-fib). (2014, September 3). Retrieved September 26, 2014.

²³ Benjamin, E., Wolf, P., D'agostino, R., Silbershatz, H., Kannel, W., & Levy, D. (1998). Impact of Atrial Fibrillation on the Risk of Death: The Framingham Heart Study. *Circulation*, (1998), 946-952.

preventable²⁴. Since atrial fibrillation can happen on its own and because by other heart conditions while also being able to cause lifelong health problems, it is important that a doctor be able to recognize this arrhythmia.

Section 2.3: Electrocardiogram Background

The electrocardiogram (EKG) is an invaluable diagnostic tool for doctors and medical professionals. The use of the EKG can determine the position and size of the chambers of the heart, how fast the heart is beating and the overall condition of the patient's heart. This, of course, includes the identification and diagnosis of many cardiac conditions with the appropriate characteristic EKG wave output.

The practical EKG, the one which forms the foundation for the instruments built today, was invented by the Dutch scientist Willem Einthoven in 1903. He received a Nobel Prize for his work in the field of Medicine for this invention in 1924. The founding theory behind the EKG is the principle of vectorcardiography. Vectorcardiography treats the electrical impulses of the heart as individual vectors, and combines them to form the EKG wave output.

An EKG is able to sense the electrical activity of the heart by reading the small changes in the electrical potential of the skin as the heart depolarizes and repolarizes. The electrodes are circular metallic conductors that rest in the center of a sticky patch that is applied to the patient's skin. The electrodes are able to detect these electrical changes from the surface of the skin with values even below one millivolt, and transmit the electrical signals from the skin to the EKG machine.

A 12-lead EKG has 10 electrodes that are placed in specific locations on the patient's body based upon their anatomical features. The electrodes are each given a designation (RL, LL,

²⁴ Atrial Fibrillation. (n.d.). Retrieved September 26, 2014, from <http://www.stroke.org/site/PageServer?pagename=A-fib>

RA, LA, V1, V2, V3, V4, V5 and V6) and a location. The electrodes are split into two categories: the limb electrodes (RA, LA, RL, and LL) and the precordial electrodes (V1, V2, V3, V4, V5, and V6). The limb electrodes are placed as follows: RL above the right ankle and below the torso, serving as the grounding electrode, RA between the right shoulder and the elbow, LL above the left ankle and below the torso, and LA between the left shoulder and elbow. As shown in Figure 1²⁵, the six precordial electrodes are placed on the chest as follows: V1 in the 4th intercostal space to the right of the sternum, V2 in the 4th intercostal space to the left of the sternum, V3 halfway between V2 and V4, V4 in the 5th intercostal space at the midclavicular line, V5 in the anterior axillary line, level with V4, and V6 at the midaxillary line at the same level as V4 and V5²⁶. When placing the electrodes, bone plated areas and areas with frequent muscle movement are avoided due to the potential for altering the signal²⁷.

Electrode Placement

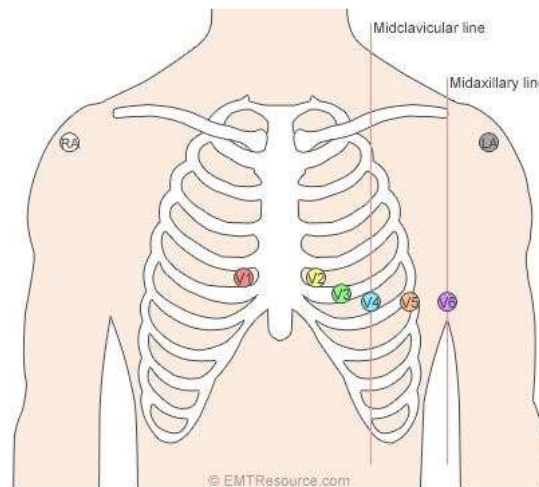


Figure 1: Electrode Placement²⁵

²⁵ EMTRResource.com. (2014, April 27). Retrieved September 12, 2014

²⁶ ibid

²⁷ ibid

When the leads are placed incorrectly, the EKG can be altered and false results can occur. For example, when V1 and V2 electrodes are placed in a location that is more superior to the correct position, the EKG output can appear similarly to that of a patient experiencing myocardial infarction. If any of the precordial electrodes are misplaced, the amplitude of the wave output can be altered and lead to misdiagnoses²⁸.

Section 2.3.1: 12 Lead Electrocardiogram

A lead is defined as an axis of electrical signals between two electrodes. This is useful because having multiple “views of the heart” from different directions can allow medical professionals to know which chamber of the heart is affected, and where. When the electrodes of the 12 lead EKG are placed, it essentially created 12 different “views” of the patient’s heart by monitoring the electrical activity, and characterizing the flow of the electrical potential within the heart as vectors. The “view” produced by the lead creates a vector that goes from the negative to the positive. The leads are: I, II, III, AVL, AVR, AVF, V1, V2, V3, V4, V5 and V6. The leads are split into 2 different groups, the 6 precordial leads (V1, V2, V3, V4, and V5 and V6) and the 6 limb leads (I, II, III, AVL, AVR, and AVf). The limb leads are split into two sub-groups: the 3 bipolar leads and the 3 unipolar leads. The three bipolar limb leads are recorded as I, II, and III. I is the lead that records potential differences between the left and right shoulders, with the left shoulder holding the positive electrode. II records the potential between the left leg and the right shoulder, with the left leg holding the positive electrode. This gives an inferior view of the heart. III records the potential difference between the left leg and the left shoulder with the left leg holding the positive electrode. This gives an inferior view of the heart.

²⁸ *ibid*

Unipolar limb leads record the potential at the right shoulder, the left shoulder and the left leg. (AVL, AVR and AVF). The letter A stands for augmented and the letter V stands for voltage. This is because these leads must be augmented (the signals must be enhanced) in order to achieve greater deflection on the EKG graph due to their small potentials. AVL is recorded at the left shoulder and gives a lateral view of the heart. AVR is located at the right shoulder and is the “grounding” lead. AVF sits at the left leg and gives an inferior view of the heart.²⁹

The precordial leads are each located at their respective electrode. V1 and V2 both give a septal view of the heart. V3 and V4 give anterior views of the heart. V5 and V6 both give lateral views of the heart.³⁰

Section 2.3.2: Electrocardiogram Breakdown

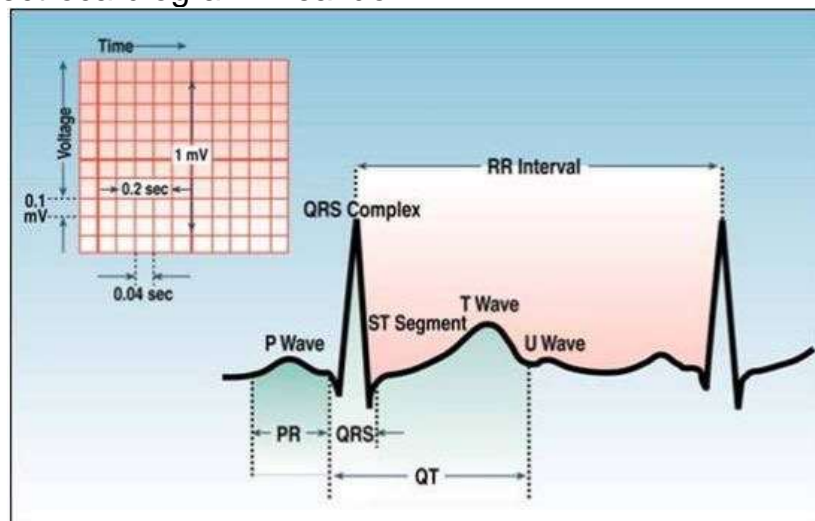


Figure 2: EKG Waveform³⁰

²⁹ Anand, R. (2010). EKG Leads. In *A practical approach to EKG interpretation* (1st ed., pp. 16-17). Chicago, IL: Independent Publisher Services].

³⁰ EMTRResource.com. (2014, April 27). Retrieved September 12, 2014, from <http://www.emtresource.com/resources/EKG/12-lead-EKG-placement/>

As shown in Figure 2³¹, the EKG wave is made up of several parts that indicate electrical activity in different parts of the heart. This wave output is created by treating the electrical impulses of the heart as vectors and then graphing them. The y-axis of the graph represents the voltage in mV, and the x-axis represents time in seconds. The “view” produced by the lead creates a vector that goes from the negative to the positive. This causes the depolarization within the heart (approaching the positive lead from the negative, or repolarizations moving away from the positive lead) to appear as an upward trace on the graph, while the downward traces are just the opposite.³² The P Wave depicts the depolarization of the right and left atria. The QRS complex shows the depolarization of the right and left ventricles. The T Wave shows ventricular repolarization, and the U wave represents the repolarization of the atria. The U wave is often not apparent on the EKG graph due to the strength of the other signals. The PR interval represents the time between depolarization of the atria and the ventricles, and the RR interval represents the time it takes for a full heartbeat.³³

The 12-lead EKG is typically printed on EKG paper which is scaled with lines. Each vertical line is one mm apart, and the recordings are printed at 25 mm/second. The 12 signals are printed together on the graph so that they can be analyzed side-by-side.³⁴

³¹ EMTRResource.com. (2014, April 27). Retrieved September 12, 2014, from <http://www.emtresource.com/resources/EKG/12-lead-EKG-placement/>

³² Anand, R. (2010). EKG Leads. In *A practical approach to EKG interpretation* (1st ed.). Chicago, IL: Independent Publisher Services].

³³ Anand, R. (2010). EKG Leads. In *A practical approach to EKG interpretation* (1st ed.). Chicago, IL: Independent Publisher Services].

³⁴ Anand, R. (2010). EKG Leads. In *A practical approach to EKG interpretation* (1st ed.). Chicago, IL: Independent Publisher Services].

Section 2.3.3: Cardiac Rhythms

Normal cardiac rhythm has the heartbeat at 60-90 beats per minute, shown in Figure 3³⁵. The PR Interval sits from 0.12- 0.20 seconds. The QRS Complex spans from 0.06-0.10 seconds. The QT Interval is approximately 0.40 seconds. Using the 12-lead EKG, the P waves in normal sinus rhythm must be upright in leads I and II if the rhythm is coming from the SA node. The P wave lasts less than 0.12 seconds and has an amplitude of less than 2.5 mm. Seeing a notched P wave in the frontal plane is not unusual. The QRS complex is completed in less than or equal to 0.10 seconds. The amplitude of the wave, which represents the strength of the action potential is variable based upon the size of the ventricular chambers (the bigger the chambers, the bigger the voltage) and how close the precordial electrodes are to the ventricular chamber. If the electrodes are close to the chamber, the voltage reading is larger. The T wave usually follows the same direction as the QRS Complex in leads I, II, and V3-6. The T wave is always inverted in the AVR lead.³⁶

Normal Sinus Rhythm

- **Rate:** 60-100 bpm
- **Rhythm:** Regular
- **P Waves:** Identical in shape and before each QRS complex
- **PR Intervals:** Normal and equal
- **R-R Intervals:** Equal
- **QRS Complexes:** Normal and after each P wave



Figure 3: EKG Waveform of Normal Sinus Rhythm³⁵

³⁵ Grier, J. (2006, November 2). EHeart: Introduction to EKG EKG. Retrieved September 10, 2014, from <http://www.ndsu.edu/pubweb/~grier/eheart.html>

³⁶ Grier, J. (2006, November 2). EHeart: Introduction to EKG EKG. Retrieved September 10, 2014, from <http://www.ndsu.edu/pubweb/~grier/eheart.html>

Section 2.3.4 Disease Characteristics

While the normal cardiac rhythm is very well known, cardiac diseases often cause alterations to this rhythm, known as arrhythmias. There are several types of arrhythmias, as described in the section covering heart anatomy. In this section, the EKG output characteristic of some of these arrhythmias will be discussed.

Atrial fibrillation, or AF, is characterized when electrical impulses are sent from the atrial muscle at a rate faster than 350 impulses per minute and vary in the strength of the action potentials. The stronger potentials are conducted through the AV node, while the weaker impulses are not. As shown in Figure 4³⁷, this arrhythmia is easily identified by its irregular R-R interval which is caused by this partial AV block³⁸.

³⁷ Anand, R. (2010). EKG Leads. In *A practical approach to EKG interpretation* (1st ed.)pp 66. Chicago, IL: Independent Publisher Services].

³⁸ Anand, R. (2010). EKG Leads. In *A practical approach to EKG interpretation* (1st ed.). Chicago, IL: Independent Publisher Services].

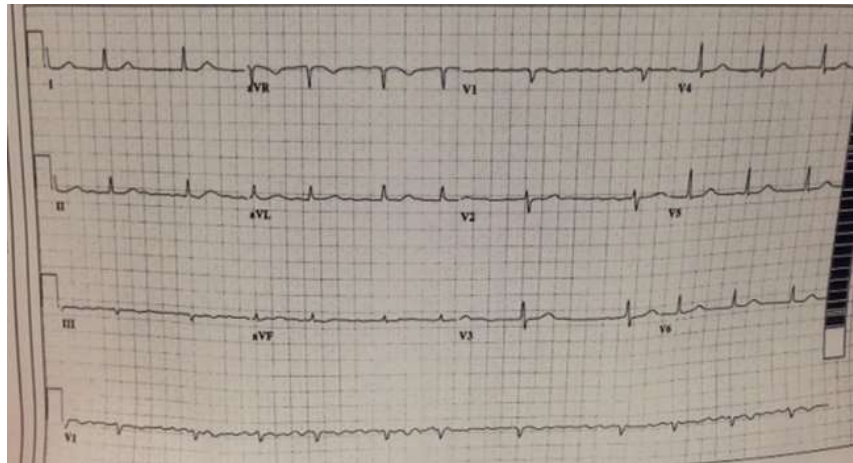


Figure 4: EKG Waveforms of Atrial Fibrillation³⁷

Ventricular tachycardia, or VT, is typically identified by a regular, wide QRS complex greater than 0.16 seconds, with all of the QRS complexes from V1-V6 are in the same direction, and sometimes a definitive absence of the RS complex in leads V1-V6³⁹.

Section 2.3.5 Ventricular Fibrillation

In ventricular fibrillation, the ventricles of the heart attempt to suddenly contract outside of the normal cardiac rhythm. This is caused by rapid and irregular electrical activity originating from the ventricles, and causes almost all cardiac output to stop. The contraction of the ventricles becomes weak and highly irregular, making it impossible for the heart to be an effective pump. Ventricular fibrillation can be identified on an EKG by loss of identifiable P waves, QRS complexes and T waves, the chaotic and irregular deflections shown on the chart, a heart rate of anywhere between 150 and 500 beats per minute, and a subsequent decrease in amplitude of the EKG wave as it continues and the heart becomes weaker.⁴⁰

³⁹ 5. EKG Rhythm Abnormalities. (n.d.). Retrieved October 10, 2014, from <http://EKG.utah.edu/lesson/5>

⁴⁰ Ventricular Fibrillation. (n.d.) Life In the Fast Lane. Retrieved March 3, 2015, from <http://lifeinthefastlane.com/EKG-library/ventricular-fibrillation/>

Section 2.3.6 Myocardial Infarction

As demonstrated in Figure 5⁴¹, myocardial infarction has very distinct characteristics that include an inverted T wave, elevation of the ST segment, and eventual loss of R wave and appearance of the Q wave. The ST and T changes to the morphology of the EKG wave output indicate that there was some injury to the myocardial tissue and release of intracellular enzymes into the bloodstream. These changes are reversible. The loss of the R wave, however, is irreversible and indicates myocardial necrosis⁴².

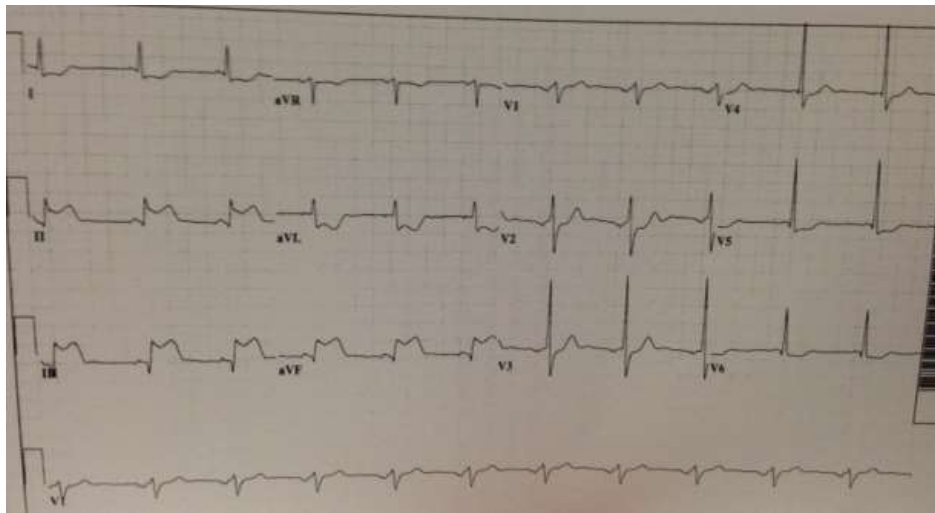


Figure 5: EKG Waveform of Myocardial Infarction⁴¹

Section 2.4: Current Gold Standard

When Dr. Hawthorne determined that the students in her EKG class were struggling she endeavored to find new ways of presenting the material to make it easier to learn. The greatest

⁴¹ Anand, R. (2010). EKG Leads. In *A practical approach to EKG interpretation* (1st ed. pp.175). Chicago, IL: Independent Publisher Services].

⁴² ibid

difficulty for students seemed to be relating activity in the heart with its linear representation on an EKG display. Without understanding this correlation students cannot understand why certain EKG waves depict certain heart activities they can only struggle to memorize lists of EKG waves.

The traditional teaching method of lecturing with a PowerPoint was proving insufficient for students. Using a physical model as a demonstrative tool was Dr. Hawthorne solution. She predicted that having a physical model showing heart activity and how it relates to the EKG output would improve student learning. To that end she endeavored to find a model of the heart that would show how electrical activity was measured by the EKG leads and converted into an EKG wave output. The best model she was able to find showed only a model of a heart and the relative placement of the EKG leads. There was no indication of activity in the heart and no EKG output component. Unsatisfied with this product Dr. Hawthorne approached Worcester Polytechnic Institute (WPI) in order to request an MQP group to produce a model more suited to her needs.



Figure 6: Current Model

Section 2.5: Related Patents to Current Gold Standard

One of our initial branches of research was related patents and products. There were a variety of patents pertaining to EKG machines. Most of these patents detailed a possible

improvement to the design of the machine, but a few dealt with improving user understanding or making the output more understandable. A patent for a “Method and apparatus for quantitative assessment of cardiac electrical events” described a program that would take an input EKG wave and display a 3D model of a heart beating accordingly⁴³. While similar to our project this design has a few key differences from our intended prototype. Firstly this device works in the opposite direction from ours, converting an EKG wave into heart activity and secondly the device had no physical component. Another patent for an “Apparatus for assisting the understanding of electrocardiography and vector-cardiography” details a box that utilizes mirrors to display a set of 2D images meant to assist in learning vector cardiography⁴⁴. Understanding vector cardiography was only a very small part of our project making the patent of little practical use to us. A third related patent was for an “Electrocardiographic process simulator” used cells to create a heart in order to simulate EKG data⁴⁵. While related to EKG data this patent did not pertain to our goal of improving the teaching of EKG interpretation.

Section 2.6 Physical vs Computer Model

In the course of brainstorming design alternatives for our project we considered the pros and cons of computer and physical heart models. The computer heart model would have been easier to modify to show multiple heart conditions, easily portable, and could have been potentially be available to students outside of class. The physical heart model would have been easier to construct based on the expertise of our group, and a recent study indicates that students taught with a physical model learn better than those taught with a computer model. The study

⁴³ Vajdic, LUNGINOVIC, Hadzievski, and Bojovic (2012). *U.S. Patent No. US8311618 B2*. Washington, DC: U.S. Patent and Trademark Office

⁴⁴ Benjo (1979). *U.S. Patent No. US4175337 A*. Washington, DC: U.S. Patent and Trademark Office

⁴⁵ Musha, Harumi, Wei, and Yamada (1990). *U.S. Patent No. EP0383697 A2*. Washington, DC: U.S. Patent and Trademark Office.

was based on students learning physiology and anatomy; students taught with a physical model scored an average of more than 20% higher than students who learned with a computer model or no model⁴⁶. Based on these results we ultimately decided to create a physical heart model for our project.

Section 2.7: Conclusion

The heart is a complex organ important to the continued existence of every living being on the planet. While the anatomy of the heart is precise in its electrical function and transport of blood and oxygen throughout the body, there are various conditions which can affect the efficiency of the heart. Our group went into detail about four of these heart conditions which have significant health effects on a person and are widespread amongst the American population because we felt that these conditions had the most relevance towards medical students. For the purpose of our project it is also important to understand what an EKG is, how it works, what the EKG signal means, and the EKGs of diseased hearts. The true significance of our project is only understood once the current gold standard or lack of is stated. The products currently available are not sufficient to function as a teaching aid for students learning to interpret EKG signals. The literature review was used to go over vital information important to understanding our project, along with establishing the need for our project.

⁴⁶ Preece, D., Williams, S., Lam, R., & Weller, R.

Chapter 3: Project Strategy

Section 3.1: Introduction

Our project addresses a need identified Dr. Hawthorne of UMass Medical School. As a practicing internist Dr. Hawthorne works with medical students ensuring that they have the knowledge necessary for success in their studies. She took over teaching the class on EKG interpretation and electrode placement after it was identified as too challenging for students. In teaching this class she has identified the major difficulty experienced by students is a lack of understanding how electrical activity in the heart correlates with the output EKG wave. She believes that including in the lecture a model that shows visually how heart activity is monitored by the EKG leads and converted into the wave output will improve student comprehension. She endeavored to find such a model but was unsatisfied with the currently available selection. Unable to find a satisfactory model available for purchase she approached WPI asking for students to design and create one for her as an MQP project.

Section 3.2: Initial Client Statement

The initial client statement given to use was that:

“Medical students learning the interpretation of EKG’s have a difficult time visualizing how the various EKG leads reflect the electrical activity of the different walls of the heart.”

Section 3.3: Objectives of Project

The primary objectives of our project were that the device be safe, convey understandable content, convey pertinent information, be easy to use, be accurate and precise as well as marketable. The objectives were developed as a result of an ongoing conversation with Dr. Hawthorne, who made us aware of what she, as our client and likely our end user, needed for the class. Shown below is the team’s Objectives Tree, which gives all of the primary, secondary and further sub-objectives.

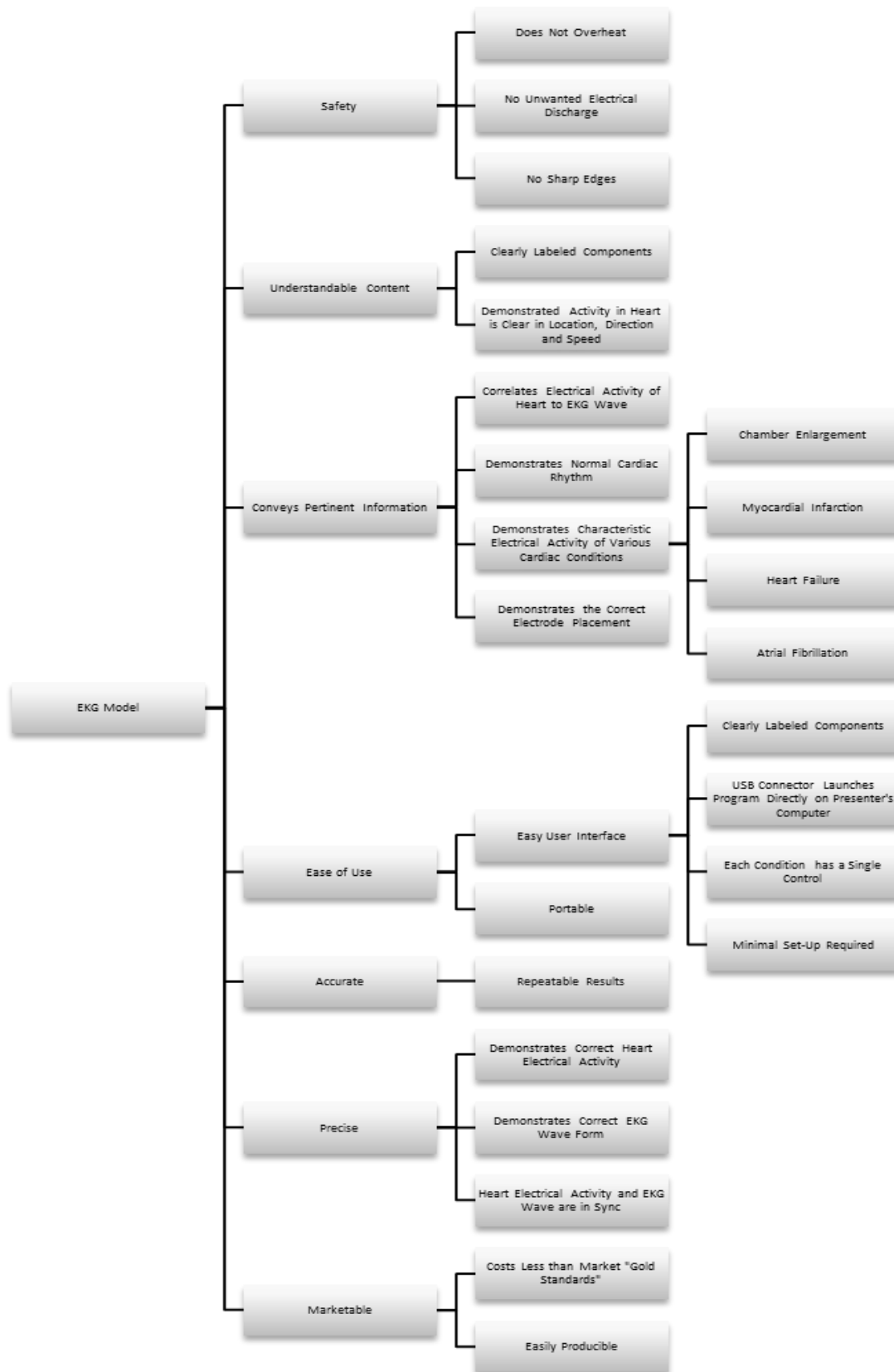


Figure 7: Objective Tree: Depicts the Primary, Secondary, and Tertiary Objectives of the Project

Any device that is to be used for learning is useless if it harms the end user. Therefore, it must meet certain standards of safety. Under the overarching theme of safety, there must be objectives to qualify “safe”. These include, the elimination of any unnecessarily sharp edges and proper engineering/wiring of the final product. Since the final product was a physical model, it inspected to insure that it was properly wired and would not overheat and start a fire or shock or injure the final user.

The model that the group was creating will be used to help teach Dr. Hawthorne’s class on the EKG, so it needed to convey pertinent information of the course by covering some of the topics that are incorporated into the lecture about the machines and how they work. The objective of conveying pertinent information also has many secondary objectives that must were met. First, the device correlated the electrical activity within the walls of the heart with the EKG wave output. It showed the normal cardiac rhythm as well as the signals and specific characteristic electrical activities of Ventricular Tachycardia, Myocardial Infarction, Ventricular Fibrillation, and Atrial Fibrillation. Finally, the device showed the correct electrode placement and indicated which lead gives which view of the heart.

In order to be easy to use, the device was one that students, and anyone who has any familiarity with a 12 lead EKG could use as a learning tool with little to no training whatsoever. Under this theme, for the purposes of our product, all of the components needed to be clearly labeled. Each individual heart condition as well as the normal cardiac rhythm needed a single, easily activated control. Any computer interface needed to be simplistic and self-starting. This objective also implied that the device is easily portable, and the set-up is an easy and short process that required little to no training.

The model is both precise and accurate. Any action that is done by the model gives the correct response and the same, repeatable feedback every time. This means that it gives the correct feedback for each selection of the disease state and the electrical output of the heart and the EKG wave are in sync for precision, and it is the same every time for accuracy.

Finally, the device should be one that was marketable. This implied that the device fills a need in the industry and is competitive within its specific field. Under the topic of marketability, the device had to be easily producible and low-cost in order to compete with any current “gold standards” on the market.

Shown below is the team’s pairwise comparison charts of the primary and secondary objectives. The secondary objectives were shortened to fit in the chart according to the key also shown below.

Table 1: Pairwise Comparison of Primary Objectives

	Accurate	Precise	Safe	Marketable	Easy User Interface	Understandable Content	Conveys Pertinent Information
Accurate		0	1	0	1	1	0.5
Precise	1		1	0	1	1	1
Safe	0	0		0	0	0	0
Marketable	1	1	1		1	1	1
Easy User Interface	0	0	1	0		1	1
Understandable Content	0	0	1	0	0		0.5
Conveys Pertinent Information	0.5	0	1	0	0	0.5	
Total:	2.5	1	6	0	3	4.5	4

Table 2: Pairwise Comparison of Secondary Objectives

	Heat	Discharge	Edges	Labels	Clear Activity	Correlation	N Rhythm	HC Rhythm	E Placement	Interface	Portable	Repeatable	Correct EA	Correct WF	Sync	Cost	Producible
Heat	-	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discharge	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Edges	0	1	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Labels	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1	1
Clear Activity	1	1	1	1	0	-	0	0	0	0	0	1	0	0	0	0	0
Correlation	1	1	1	1	1	0	-	0	0	1	1	0	0.5	0.5	0.5	0	0
N Rhythm	1	1	1	1	1	1	-	1	0	1	0	0	0.5	0.5	1	0	0
HC Rhythm	1	1	1	1	1	1	0	-	0	0	0	0	0.5	0.5	1	0	0
E Placement	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	0	0
Interface	1	1	1	1	1	0	0	1	0	-	0	0.5	0	0	0	0	0
Portable	1	1	1	1	1	0	1	1	0	1	-	1	1	1	1	0	0
Repeatable	1	1	1	1	1	1	1	1	0	0.5	0	-	0	0	1	0	0
Correct EA	1	1	1	1	1	0.5	0.5	0.5	0	1	0	1	-	0.5	1	0	0
Correct WF	1	1	1	1	1	0.5	0.5	0.5	0	1	0	1	0.5	-	1	0	0
Sync	1	1	1	1	1	0.5	0	0	0	1	0	0	0	0	-	0	0
Cost	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	0.5
Producible	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.5	-
Total	14	16	15	0	11	9.5	7	9	3	10.5	5	8.5	7	7	11	1.5	1.5

Table 3: Key for Shortening Secondary Objectives

Heat	Does Not Overheat
Discharge	No Unwanted Electrical Discharge
Edges	No Sharp Edges
Labels	Clearly Labeled Components
Clear Activity	Demonstrated Activity in Heart is Clear in Location, Direction and Speed
Correlation	Correlates Electrical Activity of Heart to EKG Wave
N Rhythm	Demonstrates Normal Cardiac Rhythm
HC Rhythm	Demonstrates Characteristic Electrical Activity of Various Cardiac Conditions
E Placement	Demonstrates the Correct Electrode Placement
Interface	Easy User Interface
Portable	Portable
Repeatable	Repeatable Results
Correct EA	Demonstrates Correct Heart Electrical Activity
Correct WF	Demonstrates Correct EKG Wave Form
Sync	Heart Electrical Activity and EKG Wave are in Sync
Cost	Costs Less than Market "Gold Standards"
Producible	Easily Producible

With these, we were able to rank the objectives, both primary and secondary, by importance. As a group, we had an extended discussion about what we wanted our project to do, and how we wanted to do it based upon our objectives. We decided that our first priority should be the safety of the end user. Then, we decided that the next most important objective for the model be that it has understandable content, followed closely by conveying pertinent information. We prioritized understandable content because if the content was not understandable, then it really would not matter if it was pertinent or not. Conveying pertinent information is important to make the device useful for Dr. Hawthorne's class. Next, we prioritized having a device that was easy to use. This is because in order to be effective, the device should be user friendly. This device would need to be transferred from storage to the lecture hall, and time is precious. It would not serve to waste precious lecture time setting up a tool that is supposed to supplement the lecture experience. Finally, we prioritized accuracy, then precision and lastly marketability. This is because having a device that did not give the same

output every time for the same cardiac condition would make it imprecise by default, and while marketability helps guide our part of the design, it is not ultimately necessary for a single end user.

Section 3.4 Constraints

There were a few very important constraints on the creation of the interactive model that are also guiding the decision-making process of the design. These constraints, also in order of importance, were: the project timeline, the project budget, the materials and tools available, and finally, the size of the display. Inherent to the nature of the MQP is the project timeline. As a team, we only had the 28 weeks of the school year to research, design and then create and test this model. We had a relatively generous budget thanks to the inclusion of part of Dr. Hawthorne's teaching budget, allowing us to utilize both that and WPI's reimbursement policy and giving us a final budget of approximately \$1,000 - \$1,500. This was not necessarily fixed, but \$1,500 was the cap that the team placed on all project spending. That made the creation of this model something of a challenge, because, in comparison, one of the closest "gold standard" models on the market costs nearly \$5,000 USD and only covers one of the functions that we wanted the final product to provide. The materials and tools we used in this project were also constrained but that was mostly due to the main constraints such as cost and time. We may have wanted a certain material but our cost constraint limited what materials we could get. Finally, the size of the display itself was our last constraint. The display must be able to be seen by all of the students within a large lecture hall (sits approximately 150-200 people), and therefore must be appropriately visible.

Section 3.5: Revised Client Statement

By conducting research and ranking our objectives and constraints of this project, we were able to modify our client statement so it more accurately reflected the content of our project with the new information we had obtained. The revised client statement was created to reflect both the goal and objectives of our project while also providing sufficient detailed information on the features of our project so that readers could better understand the exact direction the project is going and what our project will entail. Our revised client statement reads:

“Design, develop, and test a physical interactive heart model that will **help teach medical students to interpret electrocardiogram signals** by including the best teaching tools of several types of models. It should also be designed so that the model can be viewed by a lecture hall of roughly 150 people. The model should **demonstrate the electrical activity within different walls of the heart during various heart conditions and provide the subsequent electrocardiogram signals**. The heart conditions that model will demonstrate are **Ventricular Tachycardia, Myocardial Infarction, Ventricular Fibrillation, and Atrial Fibrillation.**”

The revised client statement is obviously very different from the initial client statement. The initial client statement was very short, general, and only provided the reasoning behind the project and not what the project itself would be or what it would include. When the client statement was revised, we made sure to include the key concept of why this project was created. It is always important to understand why a project has been created, in this case it is to help medical students better understand the electrical activity within the walls of the heart in relation to the output EKG signal. We added more detail to the client statement by saying how we would help students understand, through the design and creation of a physical heart model. Through our research our group realized that there are certain advantages to having a computer model too, and made sure to include in our client statement that we would be using the better qualities of other

types of models in our physical model. We also made sure to elaborate on how our model would help medical students learn, by demonstrating electrical activity within different walls of the heart and their output EKG signals. Finally, we made sure to include the heart conditions that our model will definitely demonstrate. Our group chose the heart conditions Ventricular Tachycardia, Myocardial Infarction, Ventricular Fibrillation, and Atrial fibrillation based on feedback from our client, Doctor Mary Hawthorne, information from the lecture that Doctor Mary Hawthorne gives all medical students during their EKG class at UMass Memorial, and online statistics about the severity and health effects of these heart conditions.

Section 3.6: Conclusion

As a team, this term we have learned a lot about the heart and the EKG, and created a plan to produce a model to aid medical students in their learning of how to read an EKG. With continued research and increasing interest in this project, we hope to provide a product that has never before been seen in the teaching tool market. This device will provide medical students with yet another tool to help them succeed at their academic careers, and will hopefully aid them in their future as medical professionals.

Chapter 4: Alternative Designs

Section 4.1: Project Needs

From our initial interview with Dr. Hawthorne, our group came up with a several needs that our design had to meet in order to complete our project goal. The first need design had to satisfy was to display heart activity. The final design also had to display EKG waves. Since the point of this project was to enhance medical student education by helping them learn the correlation between electrical heart activity and their EKG waves, the two should be in sync. Our group also wanted to display several heart activities with their synced EKG waves so the design also needed a way to select which heart activity would show.

These basic needs stayed the same throughout the project, but additional needs were added once our group made several design decisions. Earlier in the paper we discussed how our group chose a physical model design over a digital design. This means our needs changed to reflect this decision such as having a design for a physical model. Also mentioned in our paper is that we decided on four different heart conditions to display which means our needs changed to the design must show electrical heart activity and corresponding EKG wave for normal cardiac rhythm, Ventricular Tachycardia, Myocardial Infarction, Ventricular Fibrillation, and Atrial Fibrillation.

Section 4.2 Conceptual Designs

From the needs of the project arose several design ideas. For the first design, called the Heart In Design, we designed a clear plastic human torso that is 2-3 times larger than life-size. The torso would contain attachment points for the 10 electrodes of the 12-lead EKG and a heart on the same scale as the torso would rest within. The heart, after much discussion and debate on ways to relate the electrical activity, would be composed of plastic and would be lit electrically. The lights on the heart would surround the circumference of the model organ and would have

two colors that would make a cascading motion to show the depolarization and repolarization of the heart as it beats. This would be relayed to the user's laptop via a USB connection and a single EKG waveform output would be shown, which could then be projected onto a presentation screen. This component remains the same for all of our designs because it seemed to be the most feasible and user-friendly option. Some of the advantages of this design over the others were that the model would have only one component, and therefore would be easier to carry and that the model would show the relative position of the heart to where the electrodes are placed. Some of the disadvantages of this model are that the size of the torso would make it harder to obtain/produce and would make the design less realistic for the placement of the electrodes, the bulky size would make it more difficult to transport than something that was life-size, the view of the heart would be partly obstructed by the internal wiring as well as the position of the plastic torso, and having the electrical components inside of the torso could lead to overheating if ventilation is not included.



Figure 8: Heart Design #1⁴⁷⁴⁸

⁴⁷ Lead placement for the ECG - General Practice Notebook. (n.d.). Retrieved October 10, 2014

⁴⁸ Models. (n.d.). Retrieved October 10, 2014, from <http://www.indiamart.com/kkgsuppliers/models.html>

For the second design (called the Heart Out Design) the group considered was very similar to the first; however, instead of having a larger-than-life clear torso, the model would have a life-size, flesh colored torso with 12 lead EKG electrode attachments and would have a separate larger-than-life heart that would sit outside the body and have its own stand/holder. This would function in the same manner as the first, and would contain the USB connector for the computer. Some of the advantages of this design included the fact that the model would be more easily transportable due to the fact that the components would be relatively small in size, the torso would be more realistic than the larger model and would allow medical students to find the appropriate positions for the electrodes by touch rather than looking and seeing exactly where they should be, and finally, that having the heart sit outside of the chest would allow students to see a 360 degree view of the heart while it is in operation. Some of the disadvantages of this design were that it assumes a typical body type and heart position, contains a component that is easily breakable (the USB), and it does not show the relative position of the electrodes to the heart inside of the torso.



Figure 9: Heart Design #2⁴⁹⁵⁰

⁴⁹ Models. (n.d.). Retrieved October 10, 2014, from <http://www.indiamart.com/kkg suppliers/models.html>

⁵⁰ Lead placement for the ECG - General Practice Notebook. (n.d.). Retrieved October 10, 2014

The final design concept, known as the Two Hearts design, that the group considered was a combination of the first two. The model would include a life sized, clear plastic torso that would contain the EKG electrode attachment points and would have a visible life-size heart within. The heart within the chest would serve only to depict the relative positions of the electrodes to the heart. This model would also include a second heart that would be the same as the previous model design to allow the students to see the electrical activity of the heart in comparison to the EKG wave, even from a distance within the classroom. Some advantages of this model were that it shows both the position of the heart relative to the electrodes and the electrical activity of the heart, it would be likely more easily transported and stored than the first model due to its size, and would provide ease of use.

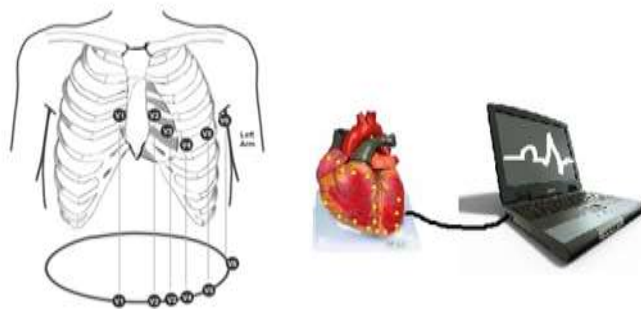


Figure 10: Heart Design #3⁵¹⁵²

Our group met up with Doctor Hawthorne and presented these designs to her. Based on her teaching experience she chose the first design model with a 2-3 times life size chest with the

⁵¹ Lead placement for the ECG - General Practice Notebook. (n.d.). Retrieved October 10, 2014

⁵² Models. (n.d.). Retrieved October 10, 2014, from <http://www.indiamart.com/kkgsuppliers/models.html>

heart inside. She was confident that the interior heart will be of greater benefit to student learning. Based on this decision our group started prototyping the design.

It came to our attention rather quickly, that the first design had many flaws. To begin with, we quickly learned that making a heart model would be difficult and expensive so we resolved to buy one. While buying a two to three times life-size heart is plausible, the issue became the torso. A clear two to three times life-size torso was simply not available on any market we looked into. Our group decided to try to design a torso and create one from scratch. However, this task was much bigger than we thought it would and after consulting with our advisor, Professor Mendelson, we decided not to continue with the first design. Instead, we decided to focus on just the several times larger-than-life heart model and the electrical heart activity it would display as we thought this was the crux of our project.

Section 4.3: Preliminary Designs

After talking with Doctor Hawthorne about the changes that needed to be made to the project design, she indicated that she thought the torso was still an essential part of our design. We changed our design to the “Two Hearts” design as this would still allow for a torso, but one that was real-life size and easier to acquire. Additional modifications were made to the design as well to account for communication and power between the heart, the torso, and the computer. We inputted a design criteria known as the box. The box will contain an Arduino board, a way to store the code, and the power for the device. Additionally, by pressing buttons on the box we would also be able to simultaneously send the code to the heart and a signal to the computer to start the EKG wave videos.

Section 4.3.1: Physical Model

Since our group was now going with the Two Hearts design we had to adapt our original design. This design called for a large heart that would display all the electrical activity of the

heart under the stated heart conditions; a small heart that would display the different views of the heart; and a life-size torso that would hold the small heart but also indicate where the EKG leads would be placed. We chose the large heart to be approximately four times life-size as we felt that would be large enough for students in a lecture hall to see without the size of the heart being overwhelming. Instead of creating the hearts and torso from scratch, we ordered models that fit our specifications.⁵³ The hearts came from Shopanatomical.com while the torso came from Mannequin Madness.

Section 4.3.2: Animations of Heart Conditions

After finalizing the design, we moved onto mapping the electrical patterns of the heart that would be displayed on our design. Our five heart conditions were: normal cardiac rhythm, Ventricular Tachycardia, Ventricular Fibrillation, Atrial Fibrillation, and Myocardial Infarction. We created a series of animations that mapped out the electrical activity within the heart during each of these conditions. These animations gave us an idea of how to lay the lights out on the large heart. After creating these animations, we met up with Doctor Hawthorne to gain her input on the animations and clarify a few points on electrical activity within certain conditions. Doctor Hawthorne helpfully advised us and our group could now move onto further designing our model by mapping out the pattern of lights on the model heart.

Section 4.3.3: Light Patterns on Heart Models

The next portion of the project entailed figuring out where lights should be placed on the four times life-size heart model. This involved analyzing the animations of the electrical activity of each heart condition and seeing what electrical activity the heart conditions had in common and what differed. Our group decided to divide the lights into two groups. The first group are

⁵³ Budget Jumbo Heart Model - Anatomy Models and Anatomical Charts. (n.d.). Retrieved February 20, 2015, from http://www.shopanatomical.com/Budget_Jumbo_Heart_Model_p/acc-ch3.htm

blue lights and display normal activity that starts in one of the nodes of the heart. The second groups are red lights and display electrical activity that starts in the tissue of the heart instead of a node. Two images were created, one for each light group. We chose red LEDs because red light is easiest to see from a distance due to its large wavelength. In order to prevent color blindness issues, we chose blue LEDs. Additionally, the blue LEDs provided a crisp contrast from the red LEDs.⁵⁴ To ensure that the lights could be seen from an optimal distance, LEDs ordered had the highest brightness setting available.

The images below show a two dimensional representation of a heart that has been divided into sections. Each section is numbered and any light that is placed within the section will be wired to the channel of the same number. Combining the sections/channels together in specific patterns will emulate the electrical activity within the heart during our chosen heart conditions.

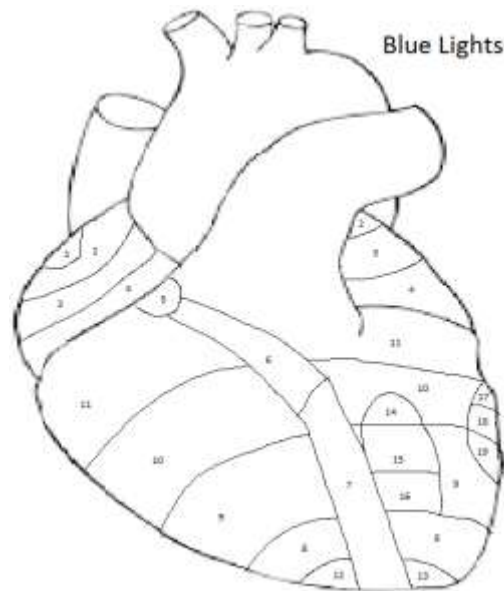


Figure 11: Blue Light Diagram

⁵⁴ Seeing colour. (n.d.). Retrieved February 17, 2015, from http://web.atmos.ucla.edu/~fovell/AS3/theory_of_color.html

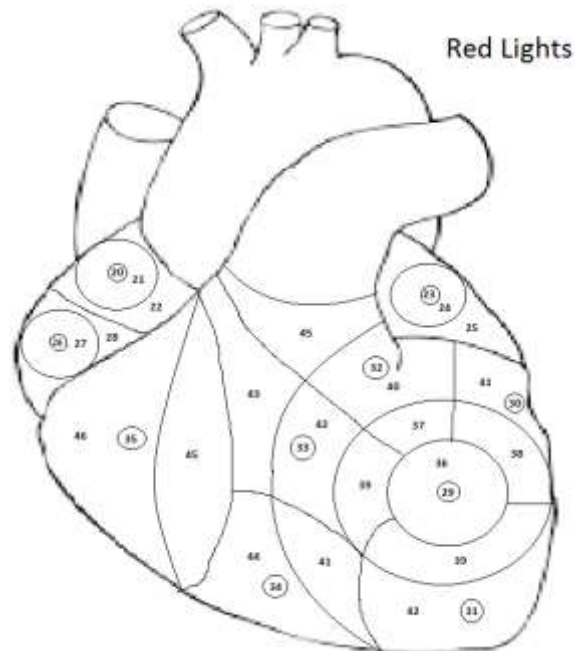


Figure 12: Red Light Diagram

After figuring out the light placement on the four-times life-size heart, we had to figure out the light placement on the life-size heart. The life-size heart would be placed inside the torso and would light up to show the various views of the heart and their corresponding EKG leads. These views were the Septal view, the Anterior view, the Inferior View, and the Lateral view. We marked areas on the life-size heart where the lights for each view would go and labeled them accordingly. Since the life-size heart was only going to light up one view at a time, there was no need for large complicated diagrams.

Section 4.3.4: Timing Diagrams

After creating the zone light diagrams of the heart, our group knew what channels on the circuit board would cause what sections of the heart to light up. From this information, we were able to create timing diagrams that displayed in what pattern the channels turn on, how long each channel turned on, and when each channel turned off. The full and complete timing diagrams for each heart condition are located in the appendices. Below is an example of the timing diagram for the normal cardiac rhythm.

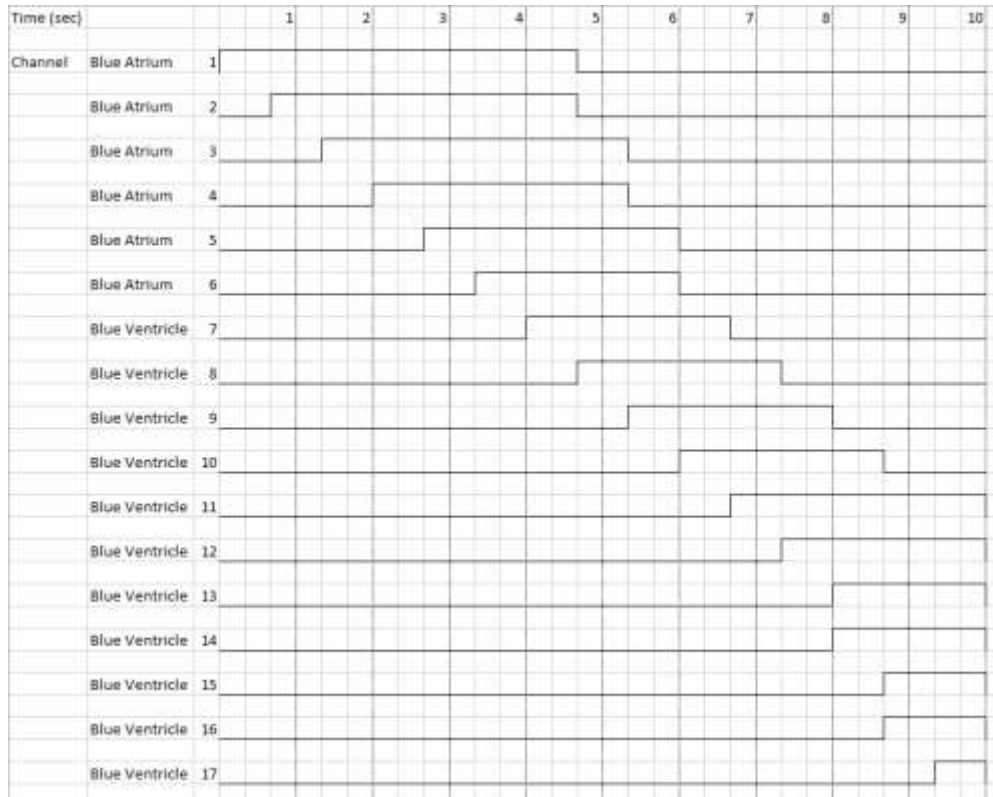


Figure 13: Timing Diagram for Normal Cardiac Conduction

Section 4.3.5: LED Sequence Switching Code

With the timing diagrams complete, we were able to easily create a C++ code on the Arduino board for each heart condition. The full copy of each code is located in the appendices.

Below is an example of the code for the normal cardiac rhythm.

```
digitalWrite(led1, LOW);
delay(1000);
digitalWrite(led9, HIGH);
digitalWrite(led10, HIGH);
digitalWrite(led2, LOW);
digitalWrite(led3, LOW);
delay(1000);
digitalWrite(led11, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led4, LOW);
digitalWrite(led5, LOW);
delay(1000);
digitalWrite(led13, HIGH);
digitalWrite(led6, LOW);
digitalWrite(led7, LOW);
delay(1000);
digitalWrite(led8, LOW);
digitalWrite(led9, LOW);
digitalWrite(led10, LOW);
digitalWrite(led11, LOW);
```

Figure 14: Example of Normal Cardiac Conduction Code

Section 4.3.6: Lights Mapped on Models

Based on the zone diagrams, timing diagrams, and code; our group was able to map out where each individual light would be placed on the four times life-size heart model. We did this by marking the placement of each individual light with tape on the heart model. Each piece of tape was labeled with what zone that light belonged in. We began with the blue lights by placing a piece of blue tape for each light.

After we mapped out the blue lights, our group mapped out the red lights. To make the red lights recognizably different, we used orange tape. Once again we made sure to label each piece of tape with the number of the zone that light would be in.



Figure 15: Light Mapping on Front of Large Heart



Figure 16: Light Mapping on Back of Large Heart

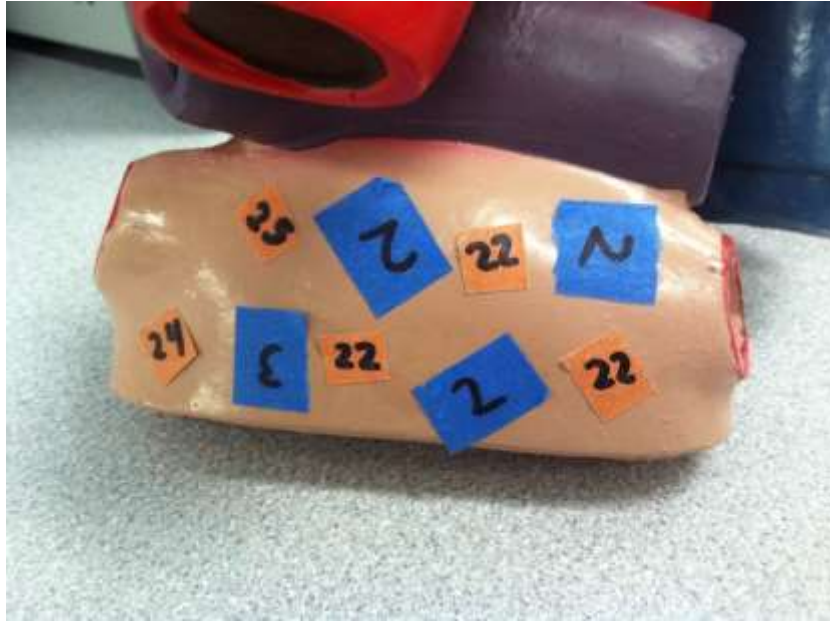


Figure 17: Light Mapping on Back of Large Heart

Section 4.4: Preliminary Testing

To verify that our design would work we performed some preliminary testing. This testing involved uploading a basic code to our Arduino board and completing a small circuit with several LEDs from the lab. Then we plugged in the Arduino board and watched to make sure that our LEDs lit up in the same order as the code dictated. We were able to conclude our experiment a success as we were able to create, upload, and observe several codes.

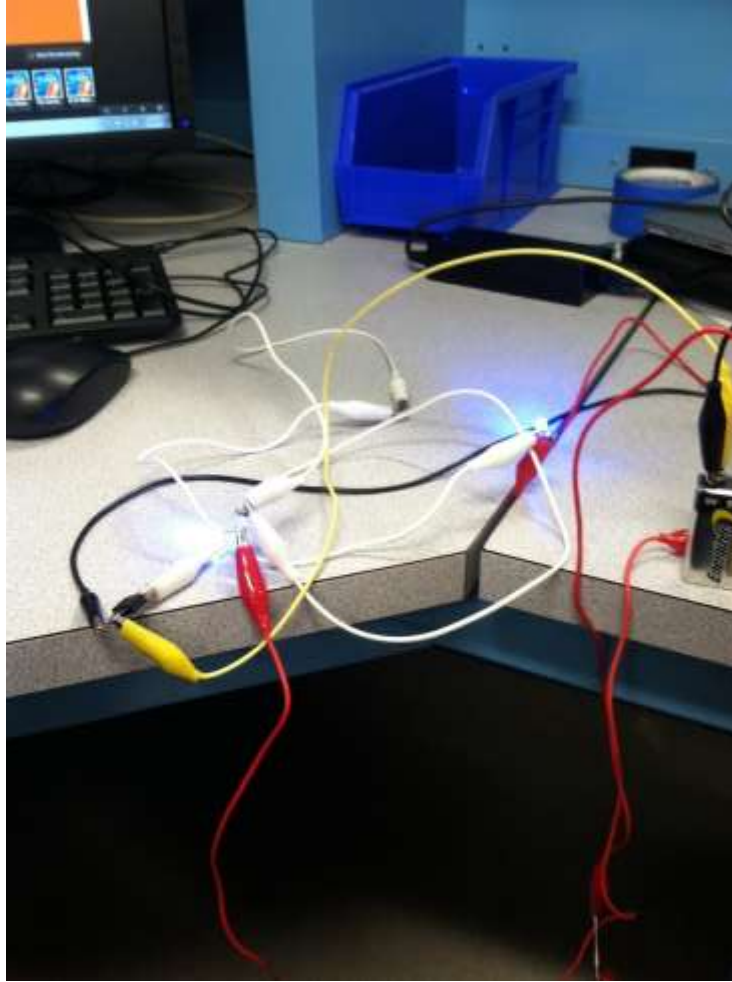


Figure 18: Preliminary Testing

Section 4.5: Design Calculations and Justification

Now that our group established that our design worked, we needed to plan out the details of the circuitry based on the design criteria.

Section 4.5.1: Justification for Usage of Arduino Board

For preliminary testing, our group used an Arduino Uno because it was readily available in the lab and could be programmed using C++. However, the Arduino Uno only has fourteen I/O pins meaning only fourteen channels. The Arduino Uno also only provides an output of 40 mA per I/O pin. From our light placement diagrams, we knew we wanted about forty-seven channels and that the lights per channel ranged from 1 to 22. Additionally, the Arduino Uno only

had a flash memory of 32 KB.⁵⁵ Our group decided to use an Arduino Mega as the microcontroller for our project. The Arduino Mega has 54 I/O pins and a flash memory of 128 KB. While it still had the same current output as the Arduino Uno per I/O pin, our group knew there were ways to circumvent this limitation.⁵⁶

Section 4.5.2: Calculation of LEDs Needed

From the light placement done on the heart models, our group was able to count the total number of lights needed for both the blue and red lights. For our project we needed 250 blue lights and 150 red lights. Our group decided to use 3mm LEDs in our design because we had worked with previously for our prototype. As a group we decided that the AV node and SA node needed to stand out from the other lights. We decided to use 5mm LEDs for the nodes as it would provide a noticeable different without looking out of place. Our group ordered 4 5mm blue lights for the nodes. An important factor for our lights was brightness. We knew that our model would be displayed in a lecture hall setting that could sit up to 150 people. This means that the LEDs had to be visible for a distance. To ensure this, when our group ordered lights we made sure to order lights with brightest luminosity available. Additionally, we ordered brackets for the lights to help secure the placement of the lights in our model.⁵⁷

Section 4.5.3: Justification for Parallel Circuit

Now that our group was aware of the exact number of lights and the specs of the lights, we decided on what type of circuit to use: parallel or series.

Circuits in series will pull voltage for each light in the series, but will only pull the current equivalent to one light per channel. When placed in series the red LEDs only need a

⁵⁵ Arduino - ArduinoBoardUno. (2015, January 1). Retrieved February 20, 2015, from <http://arduino.cc/en/main/arduinoBoardUno>

⁵⁶ Arduino - ArduinoBoardMega. (2015, January 1). Retrieved February 20, 2015, from <http://arduino.cc/en/Main/arduinoBoardMega>

⁵⁷ Mouser Electronics - Electronic Components Distributor. (n.d.). Retrieved February 24, 2015, from <http://www.mouser.com/>

current of 20 mA, but each LED will pull a voltage of 2.2 V. This means if we have 22 red LEDs in one channel (the maximum per channel in our design) that one channel will pull 48.4 volts per channel.

$$22 \text{ LEDs/channel} \times 2.2 \text{ V/LED} = 48.4 \text{ V/channel}$$

When placed in series the blue LEDs also only need to use 20mA of current, but each LED will pull a voltage of 3.5 V. This means if we have 22 blue LEDs in one channel, it will use 77 V.

$$22 \text{ LEDs/channel} \times 3.5 \text{ V/LED} = 77 \text{ V/channel}$$

Parallel series pull the equivalent voltage of one LED per channel, but a current for each LED in the channel. When placed in parallel the red LEDs will only use 2.2 V for one channel, but each LED light will pull a current of 20mA. Therefore for one channel of 22 red LEDs, 440 mA or .44 A are used.

$$22 \text{ LEDs/channel} \times 20 \text{ mA/LED} = 440 \text{ mA/channel}$$

The same applies for the blue LEDs because the same amount of current can be pulled no matter the color of light. However, the channel with blue LEDs will pull 3.5 V.

In the end, our group decided to go with a parallel circuit. We made this decision based on several factors: voltage requirements, current requirement, and ease of use. The series circuit required a large amount of voltage just to light one channel, while the parallel circuit required a more easily accessible amount of voltage. Additionally, while the current requirement for the circuit in parallel is higher, the LEDs drain a rather small amount of current each. Additionally, due to wiring, if one light goes out in series the whole row goes out. In parallel, if one light goes out the rest of the LEDs continue working. This was especially important for our project because we did not want to have Dr. Hawthorne testing each individual LED when a row went out. For these reasons, we decided that a parallel circuit fit our project better.

Section 4.5.4: Solution for Current Distribution Issue

The Arduino Mega only provides 40 mA of current from each I/O pin. This limits the amount of lights per I/O pin, in this case only 2 LEDs can be used per pin. For this reason, our group had to find a way to supply current that worked around the I/O pin. Our solution ended up being a Transistor, IRFZ44N, N-Channel Power MOSFET. The N-Channel Power MOSFET works by having three prongs and tab that connect to a source, a gate, and a drain. By connecting to a separate power source other than the Arduino Mega and only using the Arduino Mega as a gate to control when signal is sent to the LEDs, we were able to circumvent the limitation of the I/O pins. The N-Channel is also capable of handling 60 V and 35 A and by having a parallel circuit we were well within the range.⁵⁸

Section 4.5.5: Power Supply Options for Heart Models

The main issue of our design was power. Our design has strict current and voltage requirements which the power source must be able to satisfy. We evaluated several power options to make sure that we fit both the voltage and current requirements while also being cost effective. Before proceeding, it is important to note the individual voltage and current requirements per LED. There are approximately 182 blue 3mm LED lights and 132 red 3mm LED lights on our giant model heart. The blue LEDs will pull a voltage of 3.5 V and a current of 20 mA per LED. The red LEDs will pull a voltage of 2.2 V and 20 mA per LED. The maximum number of channels on at one time is 22 and the maximum number of lights per channel is 22. The total number of channels being used is 47. The maximum lights on any time is 164 LEDs. For each power scenario, the power option was evaluated under worst case scenario.

⁵⁸ International Rectifier. (n.d.). Retrieved February 19, 2015, from <http://www.irf.com/>

To begin, our group looked into a battery power option. There were several ways we could use batteries. We could use one giant battery, a small battery per channel, or several channels sharing one battery.

The overall amount of power the four times life-size heart could possibly use is 77 V. This is if the max number of channels used in the design (22), the circuit it's LEDs in parallel, and if the channels all have blue LEDs.

$$22 \text{ channels} \times 3.5 \text{ V/channel} = 77 \text{ V}$$

The heart will probably never use that amount of voltage at once because not every channel uses blue LEDs, some use red LEDs which use less volts. However, we were looking for a battery source that can handle worse-case scenario. The biggest commercial battery readily available at a small size is the Eveready 416 and it can only handle 67.5 Volts. Additionally, the Eveready 416 also only has a mAh of 110. In parallel series with the max number of LEDs designed to be on at one time, the current needed is 3.28 A.

$$164 \text{ LEDs} \times 20 \text{ mA/LED} = 3280 \text{ mA} = 3.28 \text{ A}$$

Thus the amount provided from the Eveready is far below what is needed⁵⁹. Even though the cost and size would be reasonable, the Eveready 416 did not fit our requirements.

If each channel had its own battery the max voltage needed would be 3.5 V and the max current needed would be 440 mA. The closest battery in voltage requirements if the 4.5 V battery. There are two types of 4.5 volt batteries Alkaline and carbon-zinc.⁶⁰ Alkaline has 6100 mAh, which is more than enough. Carbon-Zinc has 1200mAh which is also more than enough⁶¹.

⁵⁹ Replacement Eveready 416 Industrial Battery. (n.d.). Retrieved February 17, 2015, from <http://www.batterymart.com>

⁶⁰ List of battery sizes. (n.d.). Retrieved February 18, 2015, from http://en.wikipedia.org/wiki/List_of_battery_sizes

⁶¹ Energizer Eveready Super Heavy Duty 6V 510 Zinc Battery (510S). (n.d.). Retrieved February 19, 2015, from <http://www.batteryjunction.com>

Table 4: Power Supply Comparison

Type	Volts	Ampacity	Cost	Website
Energizer Eveready Super Heavy Duty	6	1200 mAh	\$2.78 each for 24 plus	http://www.batteryjunction.com
4.5V Duracell plus Alkaine	4.5	6100 mAh	\$5.50 each	http://www.ebay.com

If we brought 47 batteries, it would cost us \$130.66 (not including shipping) for the carbon-zinc battery and \$258.5 for the alkaline battery.

$$\text{Carbon Zinc: } 47 \text{ batteries} \times \$2.78/\text{battery} = \$130.66$$

$$\text{Alkaline: } 47 \text{ batteries} \times \$5.50/\text{battery} = \$258.50$$

Out of the two types of batteries for the channel per battery option, the carbon-zinc battery provides more current and costs less.

The next size up in batteries is a 9 V, which covers the voltage of two channels of blue LEDs or three of red LEDs. Since the 9 V battery can cover the voltage of two channels of LEDs, ideally it would also cover the current of two channels of LEDs. One channel of LEDs with the maximum number of lights per channel is 440 mA. That means for the 9 V battery to cover two channels of LEDs it has to have a current of at least 880 mA. The only type of 9 V battery which has enough mAh to cover the current of more than two channels is lithium batteries. The Duracell 9V Ultra Lithium batteries are \$5.25 each. Since each battery has 1200 mAh, there is enough for 2 channels of LEDs. Assuming 2 channels per battery, 24 batteries would be needed which would cost \$126.⁶²

$$47 \text{ channels} \div 2 \text{ channels/battery} = 23.5 \text{ batteries} = 24 \text{ batteries}$$

⁶² Duracell 9V Ultra Lithium Batteries - BatteryJunction.com. (n.d.). Retrieved February 19, 2015, from <http://www.batteryjunction.com>

$$24 \text{ batteries} \times \$5.25/\text{battery} = \$126$$

Out of all the battery options, the Duracell 9 V Ultra Lithium batteries cost the least amount of money while still providing the current and voltage needed.

However, the low feasibility of attaching several batteries together to operate as one power source made our group rethink this option. Our group instead decided to use a plug-in wall adapter that supplied 6 volts of battery and amps required to make the circuit run.

Section 4.5.6: Justification for Wiring Choices

The max amount of current being drawn through our design at any time is 3.28 A, and our power source provides up to 3.42 A. Based on the amount of current, we selected a wire gauge. Wire gauges' thickness determines the amount of current it can hold. Since our design requires a low amount of ampacity, we were able to use a smaller wire gauge. Our group chose to use a size 31 gauge wire as it had a power transmission which was in our range.⁶³ After choosing the size of wire, we had to decide whether we would use multiple-stranded wire or solid conductor wire. Stranded wire is more malleable while solid conductor has a smaller radius.⁶⁴ Since stranded wire is less likely to break due to bending, we decided to buy stranded wires.

Section 4.5.7: Resistance Needed Calculations

Now that we were aware of the amount of voltage and current used by each channel of LEDs, we were able to calculate the ohms and wattage of the resistors in our project. To

⁶³ Wire Gauge and Current Limits Including Skin Depth and Strength. (n.d.). Retrieved February 19, 2015, from http://www.powerstream.com/Wire_Size.htm

⁶⁴ Fundamentals of Electricity. (n.d.). Retrieved February 19, 2015, from <http://epb.apogee.net/foe/fbwss.asp>

calculate the ohms of resistance we used a formula based on Ohm's Law. Ohm's Law states that resistance equals voltage divided by current.⁶⁵

$$R=V \div I$$

We altered this formula to include the fact that we had a voltage drain and to account for our current drain coming from the number of LEDs per channel. The formula ended up being that resistance equaled the amount of voltage from the power source minus the voltage used by the LEDs divided by the number of LEDs in that channel times the amount of current used per LED (20 mA).

$$R= (V_S-V_L) \div (\# \text{ of lights} \times 20 \text{ mA})$$

From this formula, we were able to calculate the amount of ohms resistance needed for each channel.

Our formula for figuring out the power requirement of each resistor was a standard electrical power formula. We based our formula off the basic electrical power formula which states that power equals voltage multiplied by current.⁶⁶

$$P=V \times I$$

We changed the formula to include the voltage from our power source, the voltage drain from the LEDs, and the current from the LEDs. The formula for the power requirement was that power equaled voltage source minus voltage drain from LEDs times the number of LEDs times the current used per LED.

$$P= (V_S-V_L) \times (\# \text{ of lights} \times 20 \text{ mA})$$

⁶⁵ Ohm's Law. (n.d.). Retrieved February 24, 2015, from <http://www.rapidtables.com/electric/ohms-law.htm>

⁶⁶ Electrical Formulas. (n.d.). Retrieved February 24, 2015, from http://www.engineeringtoolbox.com/electrical-formulas-d_455.html

By knowing the power and ohms of resistance needed, our group was able to select the resistors needed per channel.

Section 4.5.8: Circuit Construction for Heart Models

To make sure we were understanding the circuit correctly and have a map of how the final circuit should be wired, we created an image of the final circuit that includes every aspect and numerical values. The images of our final circuit are shown below:

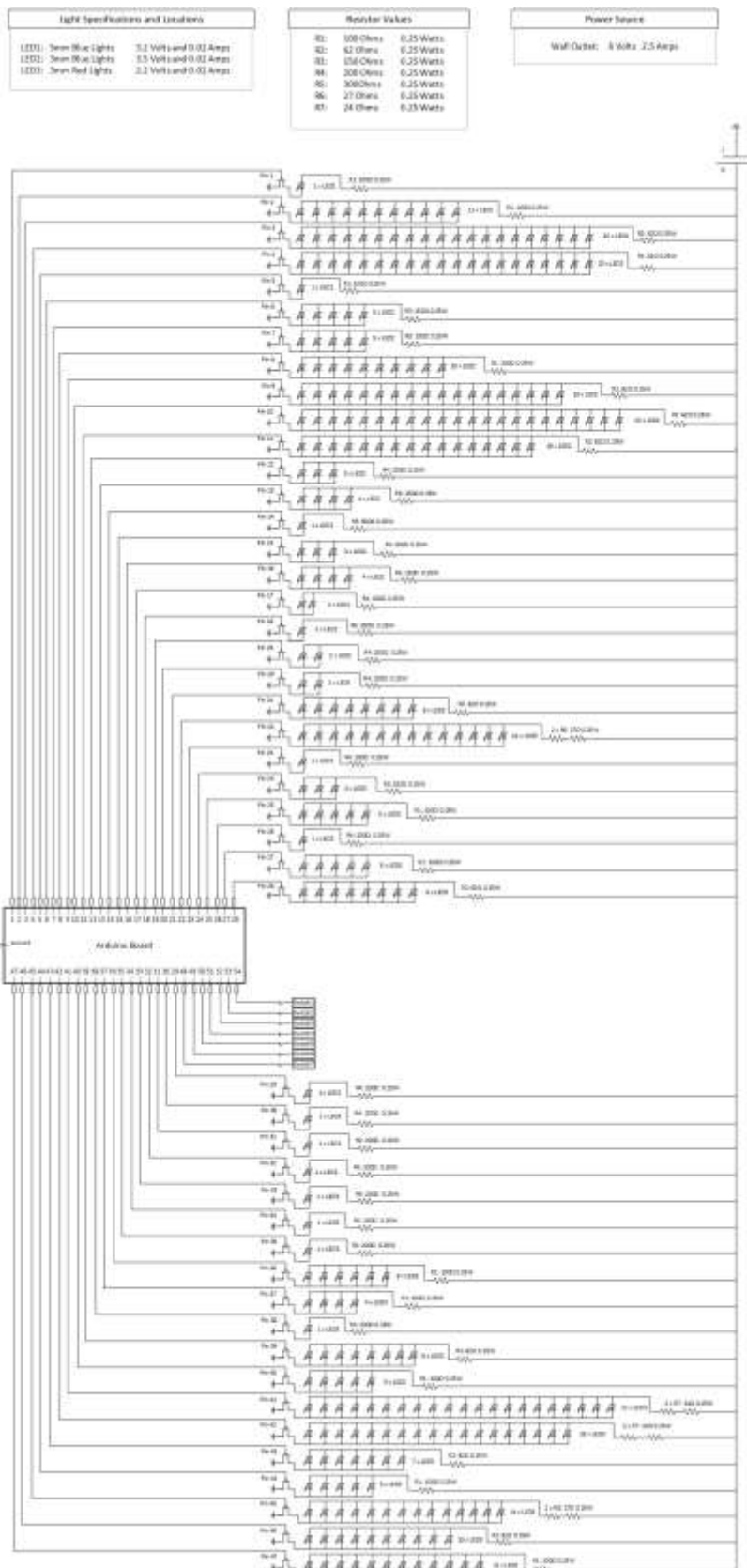


Figure 19: Complete Pin Diagram of Large Heart

Above is the complete pin diagram. Below, smaller sections are shown for reader convenience.

Light Specifications and Locations		Resistor Values		Power Source	
LED1:	5mm Blue Lights	3.2 Volts and 0.02 Amps	R1:	100 Ohms	0.25 Watts
LED2:	3mm Blue Lights	3.5 Volts and 0.02 Amps	R2:	62 Ohms	0.25 Watts
LED3:	3mm Red Lights	2.2 Volts and 0.02 Amps	R3:	150 Ohms	0.25 Watts
			R4:	200 Ohms	0.25 Watts
			R5:	300 Ohms	0.25 Watts
			R6:	27 Ohms	0.25 Watts
			R7:	24 Ohms	0.25 Watts
			Wall Outlet: 6 Volts 2.5 Amps		

Figure 20: Circuit Diagram Legend

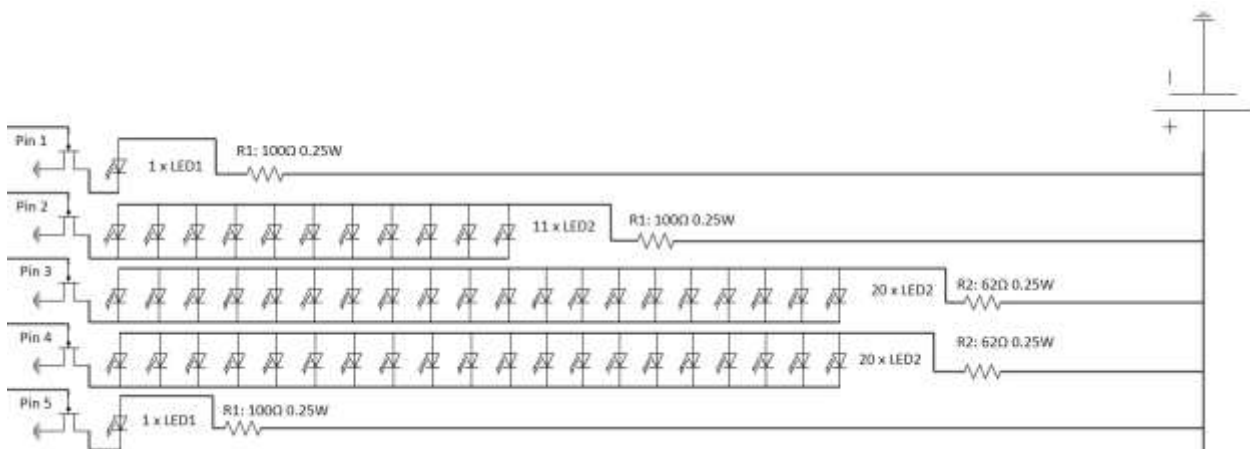


Figure 21: Circuit Diagram Channels 1-5

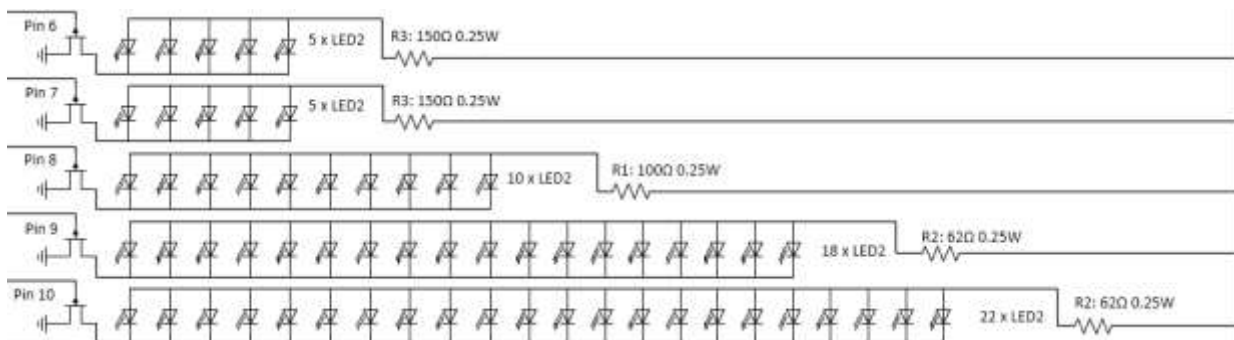


Figure 22: Circuit Diagram Channels 6-10

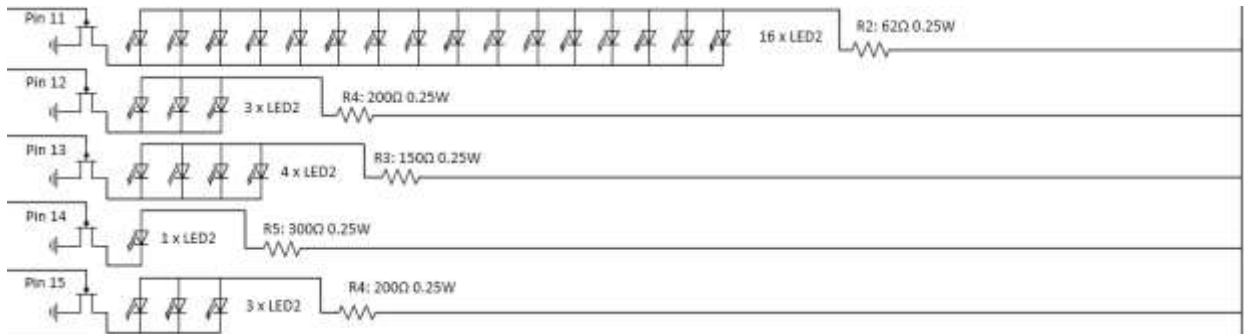


Figure 23: Circuit Diagram Channels 11-15

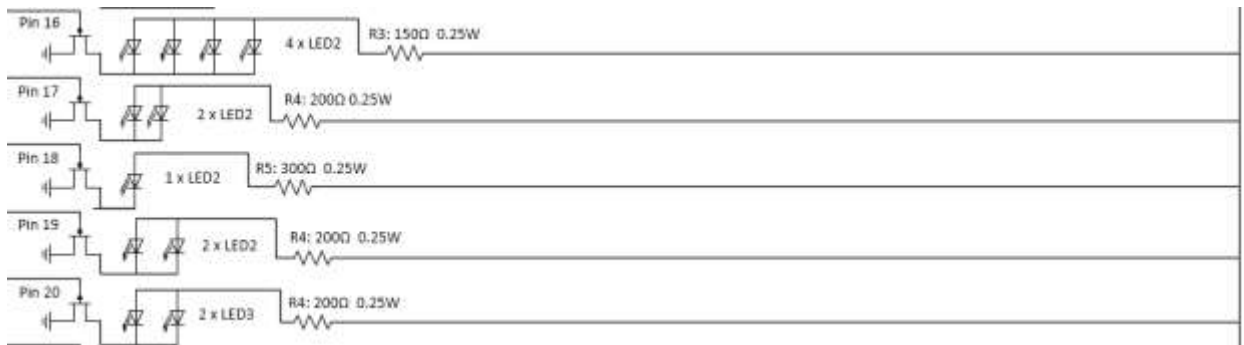


Figure 24: Circuit Diagram Channels 15-20

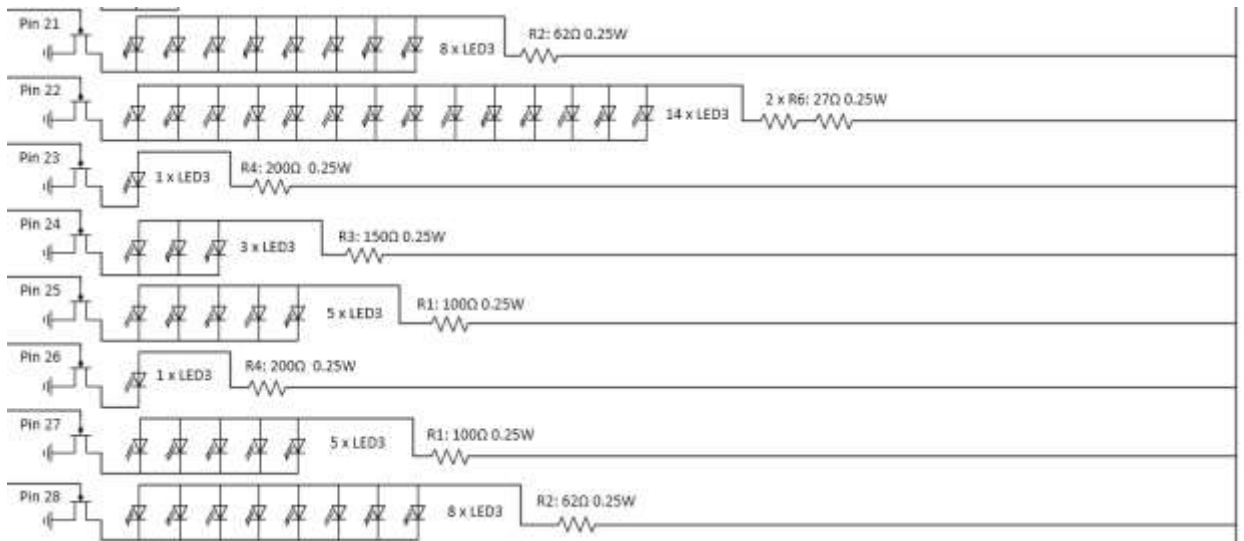


Figure 25: Circuit Diagram Channels 21-28



Figure 26: Circuit Diagram Channels 29-35

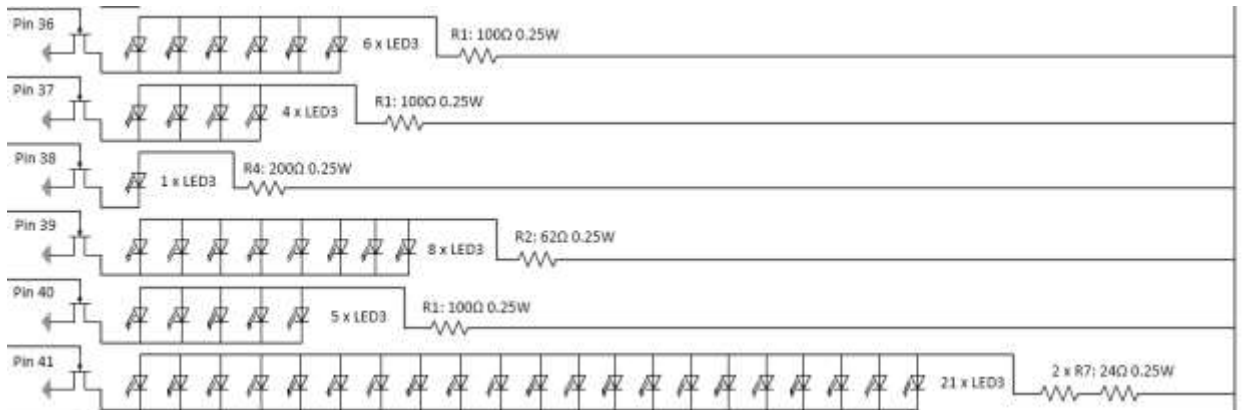


Figure 27: Circuit Diagram Channels 36-41

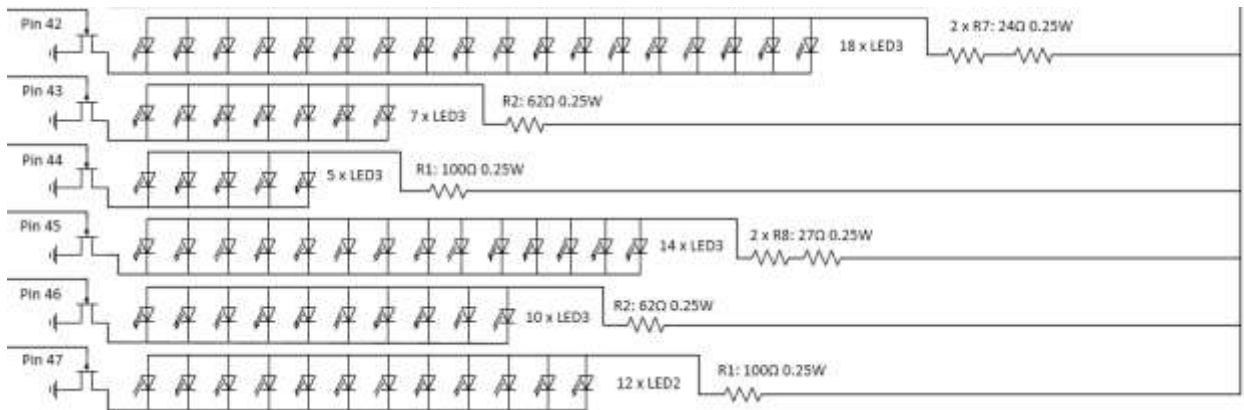


Figure 28: Circuit Diagram Channels 42-47

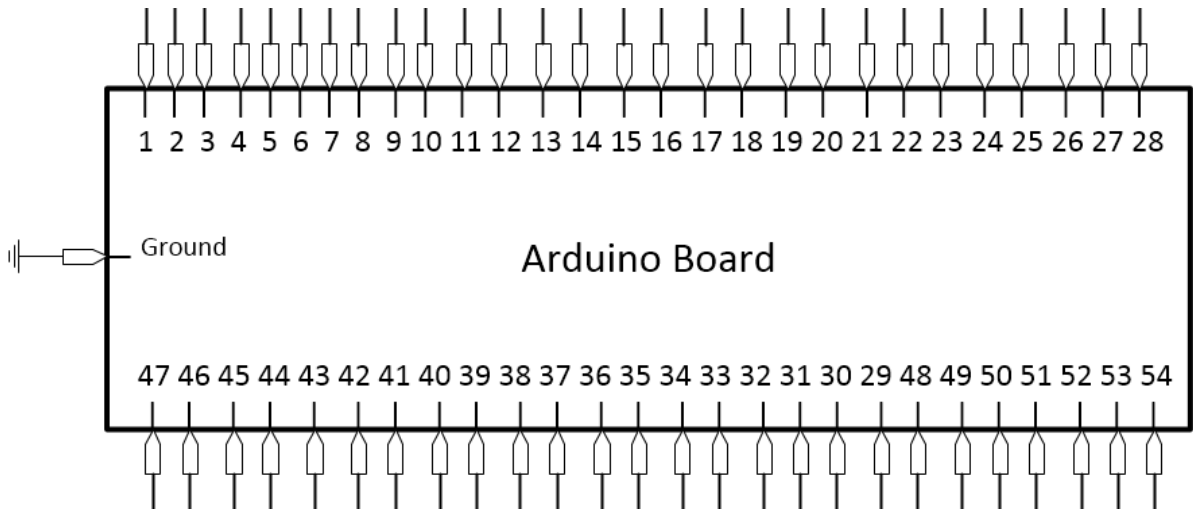


Figure 29: Circuit Diagram Arduino Board with Pin Connections

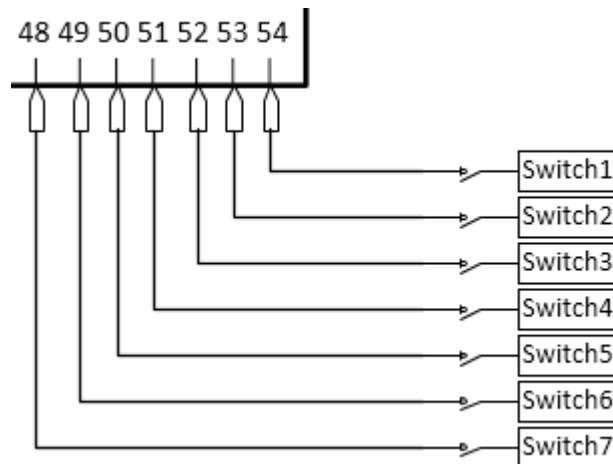


Figure 30: Circuit Diagram Channels 48-54 (Switch Channels)

Section 4.6: Prototyping

In order to prove the concept of our project, our group created a prototype. This prototype was a cardboard heart with LED lights connected to an Arduino Uno. The Arduino Uno had a limited number of channels (12) and could only light up two LEDs per channel. Based on these

limitations, our group created an outline for the LED light placement on the cardboard heart that represented the normal cardiac conduction.

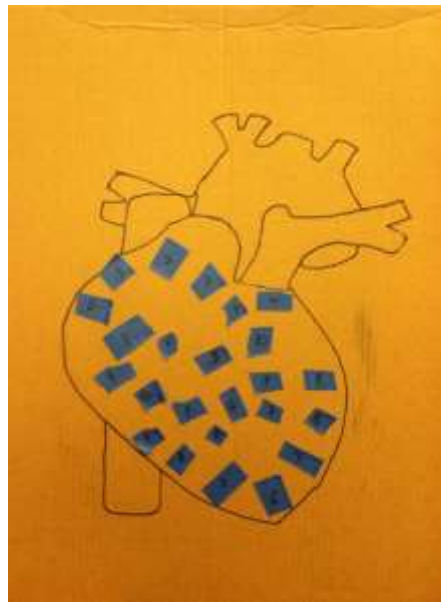


Figure 31: Cardboard Heart Layout

A code was created on Arduino Uno based on the light placement.



Figure 32: LED Placement in Cardboard Heart

Next we inserted the LED lights, wired the cardboard heart, and uploaded the code. We were able to successfully upload and demonstrate a normal cardiac rhythm on our cardboard heart meaning our design concept was correct. After proving that our cardboard prototype design was successful in turning on the right lights in the right order, the prototype was shown to Dr. Hawthorne for verification of medical accuracy.

From the cardboard prototype, the group moved onto the final prototype. For the final prototype, the group inserted blue LEDs into certain channels of the large heart. These channels were specifically chosen so that the large heart could display the Normal Cardiac Rhythm. The wires chosen for this prototype were then temporarily wired together using alligator clips to create the circuit (see Figure 26). The heart was then turned on to demonstrate Normal Cardiac Conduction. This successful demonstration meant that the creation of the final models could begin.



Figure 33: Large Heart Prototype

Chapter 5: Design Verification

Section 5.1: Resistor Testing

Based on our current and power calculations per channel, our group determined the resistors needed per channel and tested that our calculations were accurate.

Section 5.1.1: Heat Testing of Resistors

The first test involved creating the circuit for each channel with the calculated resistors. Then we powered the current to determine the heat given off by the resistors. If the resistor heated too quickly or too much, we knew that we did not have the right resistor for that channel. Heat of the resistor was determined by holding the resistor in a team member's hand. Once the resistor was too hot to touch, it was determined too hot for the circuit. Below is a chart that shows whether each channel "Passed" or "Failed" our heat test.

Table 5: Heat Test for Large Heart LEDs

lights	Calculated			Heated
	Ohms	Watts	Current	
1 B 5mm	60	0.054	0.03	Passed
1 B 3mm	75	0.03	0.02	Passed
2 B 3mm	37.5	0.06	0.04	Passed
3 B 3mm	25	0.09	0.06	Passed
4 B 3mm	18.75	0.12	0.08	Passed
5 B 3mm	15	0.15	0.1	Passed
10 B 3mm	7.5	0.3	0.2	Passed
11 B 3mm	6.82	0.33	0.22	Passed
15 B 3mm	5	0.45	0.3	Passed
19 B 3mm	3.95	0.57	0.38	Passed
20 B 3mm	3.75	0.6	0.4	Passed
22 B 3mm	3.41	0.66	0.44	Passed
1 R 3mm	140	0.056	0.02	Passed
2 R 3mm	70	0.112	0.04	Passed
3 R 3mm	46.67	0.168	0.06	Passed
4 R 3mm	35	0.224	0.08	Passed
5 R 3mm	28	0.28	0.1	Passed
6 R 3mm	23.34	0.336	0.12	Passed
7 R 3mm	20	0.392	0.14	Passed
8 R 3mm	17.5	0.448	0.16	Passed
9 R 3mm	15.56	0.504	0.18	Passed
13 R 3mm	10.77	0.728	0.26	Passed
14 R 3mm	10	0.784	0.28	Passed
18 R 3mm	7.78	1.008	0.36	Passed
20 R 3mm	7	1.12	0.4	Passed

Section 5.1.2: Current Testing of Resistors

The second test we performed with resistors was current testing. We knew the calculated amount of current being drawn by the LEDs and the amount of current being drawn by the MOSFET and Arduino Mega Board from the specs of each product. However, we did not know the amount of current being drawn by the resistors as each type of resistor draws a different amount. We measured the amount of current used at each channel with a Triple Outlet DC Power Supply set at 6 V. Below are the results of our test with the calculated amount of current stated next to the amount of current drawn.

lights	Calculated			Tested			Tested			Tested			Tested						
	Ohms	Watts	Current	Ohms	Watts	Current	Ohms	Watts	Current	Ohms	Watts	Current	Ohms	Watts	Current	Ohms	Watts	Current	
1B 3mm	60	0.054	0.05	106	0.25	0.031	40	0.001	0.017	200	0.25	0.017	140	-0.013	500	0.25	0.008	440	-0.027
1B 3mm	75	0.03	0.02	100	0.25	0.031	25	0.011	0.017	200	0.25	0.017	125	-0.003	300	0.25	0.012	225	-0.008
2B 3mm	37.5	0.06	0.04	39	0.25	0.073	1.5	0.031	0.068	43	0.25	0.068	5.5	0.026	47	0.25	0.06	3.5	0.02
3B 3mm	25	0.09	0.06	27	0.25	0.105	2	0.045	0.095	30	0.25	0.095	5	0.035	33	0.25	0.088	8	0.038
4B 3mm	18.75	0.12	0.08	20	0.25	0.14	3.25	0.06	0.13	22	0.25	0.13	3.25	0.05	24	0.25	0.12	5.25	0.04
5B 3mm	15	0.15	0.1	15	0.25	0.182	0	0.082	0.141	20	0.5	0.141	5	0.041	25	0.5	0.116	10	0.016
10B 3mm	7.5	0.3	0.2	100	0.25	0.035	42.5	-0.365											
11B 3mm	6.82	0.33	0.22	100	0.25	0.035	93.88	-0.895											
15B 3mm	5	0.45	0.3	62	0.25	0.055	57	-0.245											
19B 3mm	3.95	0.57	0.38	62	0.25	0.056	58.05	-0.104											
20B 3mm	3.75	0.6	0.4	62	0.25	0.056	58.25	-0.348											
22B 3mm	3.41	0.66	0.44	62	0.25	0.056	58.59	-0.384											
1A 3mm	140	0.056	0.02	200	0.25	0.022	60	0.002											
2A 3mm	70	0.112	0.04	200	0.25	0.022	130	-0.018											
3A 3mm	46.67	0.168	0.06	150	0.25	0.029	101.31	-0.031											
4A 3mm	35	0.224	0.08	100	0.25	0.043	65	-0.032											
5A 3mm	28	0.28	0.1	100	0.25	0.043	72	-0.057											
6A 3mm	23.34	0.336	0.12	100	0.25	0.043	76.86	-0.077											
7A 3mm	20	0.392	0.14	62	0.25	0.068	42	-0.072											
8A 3mm	17.5	0.448	0.16	62	0.25	0.068	44.5	-0.092											
9A 3mm	15.56	0.504	0.18	62	0.25	0.068	46.44	-0.111											
13A 3mm	10.77	0.728	0.26	51	0.25	0.082	40.23	-0.178											
14A 3mm	10	0.784	0.28	55	0.5	0.077	46	-0.201											
18A 3mm	7.78	1.008	0.36	55	0.5	0.077	47.22	-0.293											
20A 3mm	7	1.12	0.4	49	0.5	0.086	42	-0.114											

Section 5.2: Testing Capabilities of Fading LEDs

This testing was simple, we wanted to test our ability to make the LEDs fade or dim so we could use this function in some of our programs. We set up a complete circuit with several blue LEDs. After creating the code, we uploaded it to the Arduino board and observed the LEDs. The LEDs notably dimmed with each pass of the code and then returned to their original brightness once the code was completed.

Section 5.3: Luminosity Testing

Through our current testing, we discovered that we could control the brightness of the LEDs by changing the amount of the resistors. Our group decided to test the effect of the resistance on the brightness of the LEDs. We set up three lights in a row and gathered several different resistors of varying resistance. Using one type of resistor at a time, we set up the circuit and turned on the LEDs. When the LEDs came on we measured their brightness by examining them from 25 feet in a brightly lit room. This was done for several sets of resistance. The results of our experiment are below.

Table 7: Luminosity Testing of LEDs

Lights	Calculated			Tested - Too Bright			Tested - Correct Brightness			Tested - Too Dim		
	Ohms	Watts	Current	Ohms	Watts	Current	Ohms	Watts	Current	Ohms	Watts	Current
1 Blue 5mm	60	0.054	0.03	62	0.25	0.045	100	0.25	0.031	200	0.25	0.017
3 Blue 3mm	25	0.09	0.06	27	0.25	0.105	200	0.25	0.018	510	0.25	0.008
3 Red 3mm	46.67	0.168	0.06	51	0.25	0.078	150	0.25	0.029	200	0.25	0.022

Chapter 6: Discussion

Section 6.1: Economics

Our project is designed for instructional use, specifically for Doctor Hawthorne's medical school class. If this project were to be mass-produced it would have a very small market as the everyday person has no reason to buy instructional models concerning the electrical pathway of the heart. Since our project would only corner a very small corner of the market, it would have no impact on the economy.

Section 6.2: Environmental Impact

If our project were to be mass produced, it would potentially have a negative impact on the environment. As our project is not made from any recycled materials and is mostly constructed from plastic and some metal, this could potentially cause an environmental problem. Plastic takes a long time to degrade which would cause landfill issues. Another potential environmental problem with our project is energy. At the moment, our project draws electrical energy to power it which would cause issues if the project were mass produced. To ensure our project did not cause environmental issues if mass produced would be use recyclable materials and a renewable energy source.

Section 6.3: Societal Influence

Since our project is designed specifically for medical students (with possible use by college professors in biology or biomedical engineering classes), it would not have an immediate effect on "ordinary people". However, since the purpose of this project is to better educate future doctors so that they could more accurately diagnose heart conditions and provide the correct medical treatment needed, this device could increase a person's life expectancy. If doctors are able to reliably diagnose and treat heart conditions then less people will die from misdiagnosed heart conditions and those people will be treated correctly and live longer lives. Therefore, our

project may not have an immediate effect on “ordinary people” but it will help everyone with a heart condition in the long run.

Section 6.4: Political Ramifications

Our project would only have an effect on the medical communities of various cultures across the globe. If our project becomes widespread, it could assist many medical professionals across the globe and develop a small global market. However, outside of the medical realm our project will have no effect on other country’s culture. Additionally, since the need for our design will be limited, the effect it will have on the global market will be almost zero.

Section 6.5: Ethical Concern

Our project will not increase the quality of one’s life, but it will increase the quantity of one’s life. While our heart model will not make a person’s life more satisfying it will increase the length of a person’s life by helping doctors accurately diagnose heart conditions. This way the person will live a longer life which they can make satisfying themselves.

Section 6.6: Health and Safety Issue

Both the large heart design and the small heart design in the torso will increase a person’s health by providing better education to medical professionals. The large heart displays the electrical pattern of various heart conditions while simultaneously displaying the selected heart condition’s output EKG wave. By viewing the EKG wave and the electrical pattern of a heart condition at the same time, doctors will gain a better understanding of what each portion of the EKG wave means and will be able to more accurately diagnose heart conditions. These more accurate diagnoses will lead to accurate medical treatments which will extend a person’s life. Additionally, the small heart inside the torso allows medical professionals to accurately associate EKG leads to views of the heart and will also allow them to practice the correct placement of the EKG leads. Correctly placing the EKG leads is vital to gaining an accurate EKG wave of the heart which allows for heart condition diagnosis. By increasing doctor’s ability to accurately

place EKG leads, our product will be increasing the quality of the EKG wave which will lead to more accurate diagnoses and treatment of a person ensuring that person's health.

Section 6.7: Manufacturability

The main issue with the design of our project is that it had to be created from scratch as there was nothing like it on the market, but now that the first design has been created with a few adjustments our product is manufacturable. The design will have to be altered slightly as it was intended for creating one product, not mass-producing. One such adjustment would be with the heart models and torso model. Since the models were ordered and then adjusted if a person wanted to manufacture our design they would either need to buy the rights to the model or create their own models. However, with the right adjustments the product could be mass produced and as there is nothing like it on the market it would have no competition.

Section 6.8: Sustainability

The project design was not created with sustainability in mind. It does not run off renewable energy such as wind or solar power. Additionally the design itself is not very sustainable. The LEDs will eventually burn out over time and, while the project was designed to have the LEDs be easily replaceable, they are not a renewable.

Chapter 7: Final Design and Validation

Section 7.1: Meeting Goals

The goal of this project was to: “Design, develop, and test a physical interactive heart model that will help teach medical students to interpret electrocardiogram signals by including the best teaching tools of several types of models. It should also be designed so that the model can be viewed by a lecture hall of roughly 150 people. The model should demonstrate the electrical activity within different walls of the heart during various heart conditions and provide the subsequent electrocardiogram signals. The heart conditions that model will demonstrate are Ventricular Tachycardia, Myocardial Infarction, Ventricular Fibrillation, and Atrial Fibrillation.” In order to accomplish this goal our group came up with several design options. The option we decided to go with was the “Two Hearts Design”.

The two hearts design accomplishes our design objective because the large heart operates as the physical interactive model. The large heart will also help each medical student to interpret electrocardiogram signals and will demonstrate Ventricular Tachycardia, Myocardial Infarction, Ventricular Fibrillation, and Atrial Fibrillation. This task is accomplished by having the large heart model display the electrical conduction of the heart in the stated heart conditions and having the matching EKG wave to that heart condition display on a computer screen. Since the EKG wave and electrical conduction of the heart are in sync the model will enforce the understanding of the relationship of what it is going on in the heart to what is being shown on the EKG screen for medical students. Through this process the medical students will gain a greater understanding of what each portion of the EKG wave means in relation to the heart and will be able to read EKG screens of heart conditions not shown and understand them. Our group went above and beyond as our large heart model also displays electrical conduction for normal cardiac

rhythm and three different myocardial infarctions. Through our design process we also ensured that the heart model was large enough and the lights were bright enough to be seen in a lecture hall of 150 people.

While our large heart model accomplished most of our design objective, part of our goal was to help teach medical students to interpret electrocardiogram signals by including the best teaching tools of several types of models which we did through our small heart model placed inside a life-size torso. The large heart teaches medical students about electrical condition of the heart and the subsequent EKG signals, but the small heart teaches about the various views of the heart seen when placing EKG leads on a person. In order to correctly read an EKG, the EKG leads must be placed properly. Our torso accomplishes this by noting the correct sites to place the EKG leads. Additionally, the small heart is also covered with LEDs and these LEDs light up in certain areas to show what area of the heart the EKG leads are showing. Not only does each model in our project have a specific purpose that will help educate medical students further on EKG, but it employs several different styles of learning as well.

Our design met with every aspect of our project goal. In the following sections we discuss in detail how portion of our design meets with the intended functions and objectives of our project.



Figure 34: Final Models

Section 7.2: Large Heart Protocol

Since the large heart was essential to completing most of goal, our team approached it with set objectives and functions in mind. The first step to creating the large heart was to order a large heart model online, ours is four-times life-size. Following this, we decided on the heart conditions we wanted to display. We chose normal cardiac rhythm, Ventricular Tachycardia, Myocardial Infarction, Ventricular Fibrillation, and Atrial Fibrillation. After choosing the heart conditions, we conducted research on these heart conditions so that we could accurately portray the electrical conduction of these conditions and enhance medical students' knowledge. We then divided up the areas of the heart based on the heart conditions we had chosen. This portion of the project took a while as it involved intricate knowledge of the electrical conduction of the heart in each condition. By knowing where the electrical conduction has to travel, it allowed us to plan where we wanted the LEDs on the heart model and mark off those areas. This task was made

easier by creating a timing diagram for each heart condition. The timing diagram shows what channels turn on, the order they turn on, and how long each channel is on. All of this was done to ensure we could accurately model the heart conditions we had chosen in our goal.

Once we decided which areas of the heart belong to which channels, we needed to decide where to place individual LEDs within each channel. This was done by examining the model heart and the channel diagram we had created. Based on the number of channels, how we wanted the light to cascade, and the amount of room in each channel area we marked off the placement of each LED with a piece of tape with the number of the channel that LED would belong to written on it. Following this, we counted the number of lights in each channel and overall.

Now that we knew the number of lights in each channel, it was time to move onto circuit details. First we had to decide whether we wanted our circuit in parallel or series. Since parallel demands less voltage and more current (which is easier to supply) we chose to use this type of circuit. Next we figured out what kind of LEDs we wanted to use and ordered slightly more than the correct amount. For our project, we used two different sets of lights to illustrate when electrical conduction came from a node and when they did not. We did this to provide clarification for the medical students so they could understand the overall model better.

Additionally, when we were ordering the lights we made sure to buy the LEDs with the highest luminosity setting to ensure it could be seen by everyone in a 150 person lecture hall. Once the lights were ordered, we figured out the amount of voltage and current for each LED. Using this information and some mathematical formulas, we figured out the amount of current and voltage used by each channel. Now that we knew the power requirements, we used Ohm's Law and basic electrical power formulas to figure out the ohms and watts of the resistors per channel. This was important for ensuring our safety objective as we did not want to overheat any component of our

project and cause health risks. Since the resistors will change the current amount being drawn, we had to figure out the total current and voltage requirements for the entire circuit including resistors. To ensure the safeness and effectiveness of our project we performed resistor testing to check for the resistors overheating and to measure the amount of current being drawn by the circuit. Our group also did luminosity testing to make sure the LEDs followed our goal and could be seen in a lecture hall of 150 people.

Using this information, we selected a power source that could supply slightly more than the amount of current and voltage needed. Most circuit boards are incapable of providing the amount of voltage and current needed so an outside power source that can be wired to the circuit board as needed. Since the secondary power source is greater than what the board can provide, a transistor must be used. Our group chose to use an N-channel MOSFET because it can handle the amount of voltage and current of any of the channels.

Now that all the pieces of the circuit were figured out, we ordered them and then assembled them. One power source, one transistor per channel, and the various types of resistors needed were ordered. Additionally, we determined the size gauge wire needed and were able to find it in the lab. The size of the gauge wire depends on the amount of current going through it, so we selected the gauge wire that could handle the largest amount of current going through the circuit. Next our group had to decide whether we wanted to use multi-strand or solid conductor gauge wire. Our group chose multi-strand wire because it is more flexible and less prone to breakage. Choosing the correct wiring was important several of our design objectives as it promoted conduction accuracy and safety.

While we were waiting for parts to come on, we started on the mechanical aspect of the project. Since we marked the locations we would like to place the LEDs on the heart and we

knew the size of the lights, we selected the correct size drill bit and begin drilling holes into the heart for the LEDs. After all the holes were drilled into the heart, we began to place the LED mounts into the holes, making sure they were secure with glue. The heart was then mounted onto a microphone stand through a hole on the back of the heart and secured in place with a washer. The microphone stand was mounted on a cabinet by placing a hole in the cabinet for the microphone stand shaft and having the base rest on a shelf. From there, the correct color LEDs were be placed in their specific location and the wiring could begin. All the wires for each channel of the large heart was wired into parallel inside the large heart and then the wires for each channel were labeled and trailed out a hole in the artery of the heart. This process was done with a map of the LED light locations nearby for reference.

Once all of the parts were in one location, we began assembling the circuit using basic circuitry knowledge. All circuiting was done on a circuit board which was placed in an enclosure to ensure maximum safety. The circuit board was placed inside the cabinet the large heart was mounted on. On the circuit, the negative of the power source went to the source of the MOSFET of each channel, the positive of the power source went to the resistor of each channel, the ground of the Arduino Board went to the ground of the power source, the pin of the Arduino connected to the gate of the MOSFET, the drain of the MOSFET went to the negative of the parallel configuration of the LED lights, the resistor went to the positive configuration of the parallel LED channels, and the Arduino plugged into a computer through a USB drive. The channel wires on the circuit were trailed out the back of the cabinet and soldered to the same channel wire coming from the large heart. The wires on the circuit board connected each channel to the power source, Arduino board, resistors, and ground.

As the LED placement, number of channels, and LEDs per channel were being finalized we created the code for each heart condition. Code for the Arduino boards were written in C++ and translated over. In order to accurately create the code, we referred to their timing diagrams created earlier. Each heart condition had its own individual code, but for the code to work on the Arduino board all of the codes had to be uploaded together. Uploading to the Arduino board was simple as the board comes with a USB connection cable. Once the code was uploaded to the board it began to display the electrical conduction of the heart conditions immediately and displayed the heart conditions in the order uploaded. We let the entire code run through all the heart conditions to check that all of the LEDs were functioning properly.



Figure 35: Normal Cardiac Condition

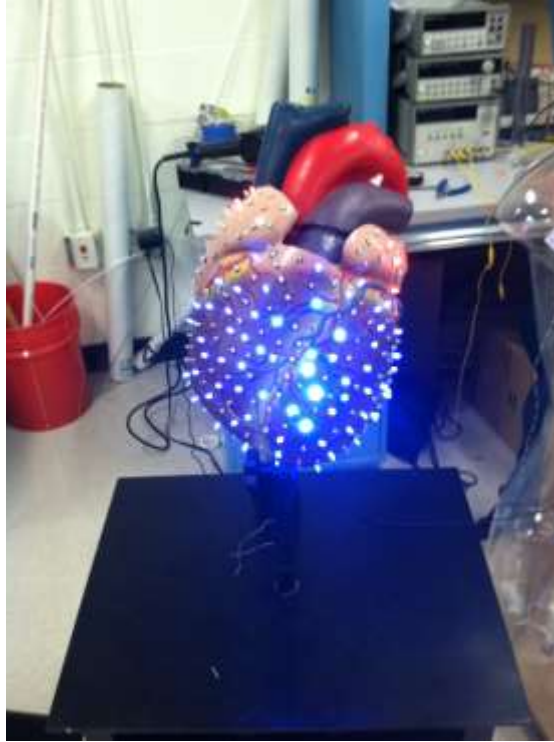


Figure 36: Atrial Fibrillation

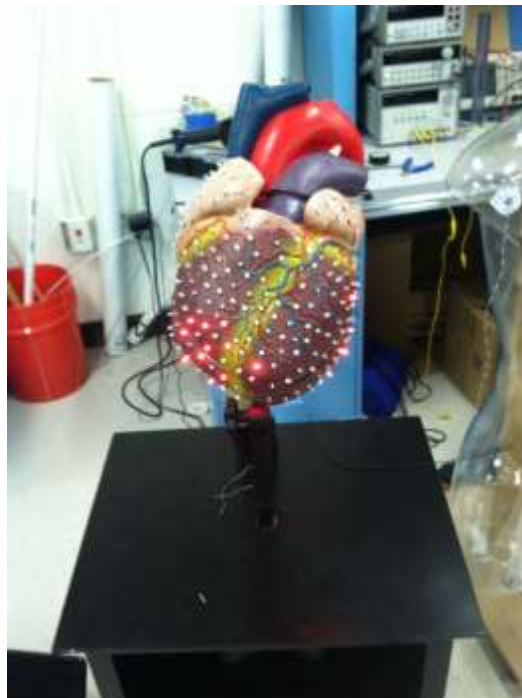


Figure 37: Ventricular Fibrillation



Figure 38: Ventricular Tachycardia

Section 7.3: Small Heart Protocol

While the small heart model is not specifically stated in our goal, it does satisfy many of objectives and our team and Dr. Hawthorne thought it was vital to the project. The small heart increases the understandable content and conveys important information. The purpose of the small heart is to show the various views of the heart. When EKG leads are placed on the body, each lead gets a read of a certain area of the heart. Several leads together creates a view. All the leads at once create the EKG wave, most people are familiar with. Understanding of how the EKG wave is formed and which parts of the EKG wave correlate to which sections of the heart is vital for a doctor to perform a good EKG analysis.

Since we wanted the heart to be represented as accurately as possible, the small heart model is the size of a real human heart. The small heart was also constructed after the large heart and in comparison its work was much simpler. We started off with ordering the small heart model. Then, using references, we labeled the areas of the heart in conjunction with the views

from the EKG. When we ordered the Arduino Mega for the large heart, we ordered an extra for the small heart. Additionally, we ordered 50 extra LEDs for the small heart when we were ordering LEDs for the large heart. However, unlike the large heart, the small heart only has blue LEDs. The team then mapped the specific locations on the heart for LED placement. The LEDs were only placed where the views were and we tried not to have LEDs of views overlap, as we feared it would cause confusion. After marking the spots for the LEDs, the team selected the correct size drill bit and drilled in holes for the LEDs. In these holes, the LED brackets were glued into place and then LEDs were inserted.

Unlike the large heart, we did not create a timing diagram ahead of time. Therefore, after placing the LEDs, the team created a timing diagram for the small heart and assigned each cluster of LEDs to a channel. From this timing diagram we also created a C++ code which stated what channels would be turned on, when they would turn on, and for how long.

Since we already knew the calculations of power and current from the large heart, we determined the amount of resistors needed and performed resistor testing. We selected the correct resistors and collected extra N-channel MOSFETs and wire that we had from the large heart project. We did the final calculations for voltage and current including the MOSFETs and resistors and came up with the voltage and current needed to be supplied. We brought a power supply that fit those requirements and began to assemble the circuits for the small heart. We made sure to include extra-long wire connections since we knew the heart would be hanging inside the torso. Once the small heart's circuits were established and connected, we test ran the small heart to ensure it worked. This was done to complete our objective of effectiveness of the device.



Figure 39: Lateral View

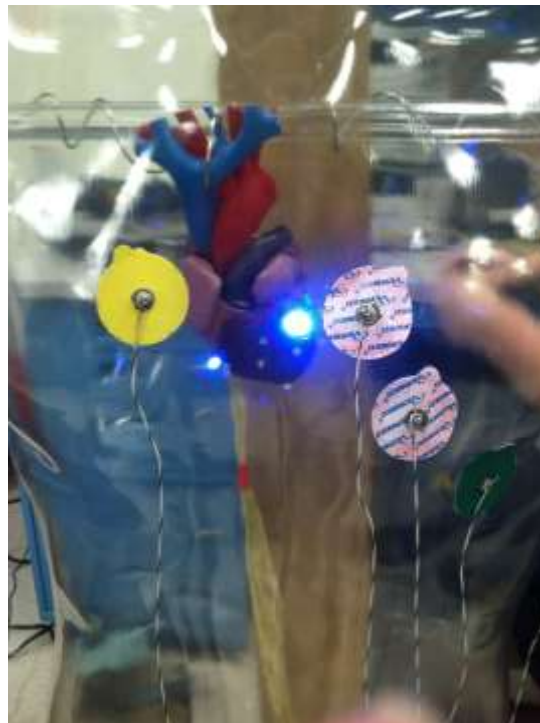


Figure 40: Inferior View



Figure 41: Anterior View

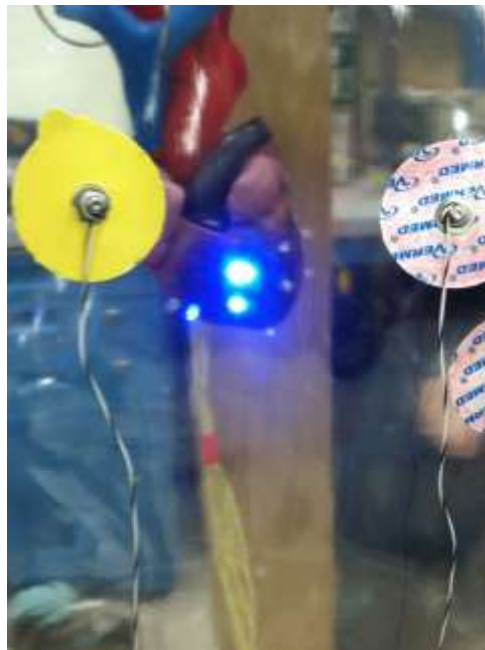


Figure 42: Septal View

Section 7.4: Torso Protocol

Part of our goal was to increase medical student's understanding of electrocardiograms by including the best teaching tools of several types of models. This is where our torso model

came in. The torso model also helped complete several objectives such as making the content more understandable and being user-friendly. The torso made the content more understandable by anatomically correct placement of the small heart and having places to practice putting EKG leads. Additionally, the torso was more user friendly because the places to put the EKG leads are labeled and the small heart lights up automatically in sections to show the various views which means users do not have to control the small heart.

In order to make the torso as understandable and user-friendly as possible it was vital that we obtain a clear torso that had arm and leg stumps because we needed to be able to see inside the torso and to properly place the EKG leads. The clearness was important because the small heart would be placed inside the torso and needed to be seen. The arm and leg stumps were needed because the 12-lead EKG has very specific placement points on the body (including on the arms and legs) and the torso is meant to practice placing EKG leads on. After ordering a mannequin torso that fits these specifications, the next step of the project was to label the placement points of 10 leads from the 12-lead EKG on the mannequin.

Following lead placement, we focused on placing the small heart inside the torso. At this point the protocol for the small heart was completed and just needed to be installed. Our torso was sealed entirely so the first step to heart placement was opening the torso up. We decided to cut off the bottom of the torso's left leg so that the heart could be inserted up through the leg and would be on the correct side of the body by using a soldering iron to melt the plastic off. We also created two holes in the torso's armpits with the soldering iron and placed a clear plastic tube, about .25 inches in diameter through the holes.

The top of the small heart model has several large tube-like structures which are meant to represent the arteries coming into and out of the heart. A hole was drilled through these and a

sturdy wire found in the lab space was placed through. This wire was then wrapped around these arteries and securely fastened into place. We left extra wire at the ends so it could be wrapped around the tube already placed in the torso. The small heart was then inserted into the torso through the left leg. The extra wire was wrapped around the tube and tied tightly. The small heart now hung in the correct place in the torso. The wires coming out of the small heart were allowed to hang through the torso and came out the left leg. The wires from the small heart were soldered to the matching wires on the circuit that connected to the Arduino Board for the small heart.

The torso we brought came with a wired loop on its head, so we found a mount to hang the torso from. In the lab we found what was essentially a coat rack made from plywood pieces. The coat rack also had wheels on the bottom for transport. We drilled a hole of the appropriate size through the vertical wood piece at the top. Then we placed a long screw through it. Finally, we hung the torso from the hook to test our mount. The torso stayed in place and did not tip the mount over so it was a success.

Chapter 8: Conclusions and Recommendations

While our project was originally intended to help one person, our work could have global reaches. After all every doctor in the world needs to learn to accurately read electrocardiograms. By creating a more effective teaching method that helps medical students understand EKGs instead of memorizing them, we will be creating more efficient doctors who will be able to provide medical treatments. Better medical treatment means that people all over the globe could live longer healthier lives.

While the work we have accomplished is a good start, there are ways to make our project provide even more content and further expand the knowledge that medical students can learn. The number one way to do this would be to add more heart conditions to the large heart model. This could be done relatively easily as long as the timing diagrams for future heart conditions use the channels and LEDs are already set up. Once a heart condition is picked and has a timing diagram, the person would only need to create a C++ code for it. The C++ code would then have to be uploaded to the Arduino board. If several new heart conditions are created, the data may exceed the amount the Arduino board can hold and a device to hold the codes will have to be created. Additionally, an EKG wave matching the heart condition will have to be created to display as a video. By creating more heart conditions and their matching EKG waves, the medical students will be exposed to more possibilities of the EKG wave and what is happening in the heart. This will increase the medical students' understanding of EKG waves and will allow for even better diagnosis of heart conditions.

A second improvement alternative that would involve minimal changes to our project, would be to have different versions of the same heart condition to show variability. We created timing diagrams and code for conditions like Ventricular Tachycardia but every person will not

experience Ventricular Tachycardia in the same way. Their EKGs will not look identical. To show this variability and to improve the understandable content, knowledge, and accuracy of our project the creation of several new timing diagrams and codes of the same heart conditions but slightly different would be needed. Additionally, several new EKG waves would have to be created as well.

Another way to improve our project would be to include a companion model to the large heart model that shows the interior of the heart. On our model we show the left and right bundle branch as one line (when it should be two) and we placed the LEDs on the outside of the heart walls when those particular electrical conductions would be on the inside of the heart wall. In order to improve the accuracy of our project, a companion heart model to the large heart that would show the electrical conduction of the interior heart should be made. The large heart and the companion model would have to be synced up and the LEDs of the large heart would have to be changed to no longer show the bundle branches, but this change would improve the accuracy and understandable content of our project.

Increasing the density of the LEDs on the large heart model is another way to improve our project. Right now the LEDs are a bit spread out and only bunched together in vital spots. By increasing the density of the LEDs, the electrical conduction of the heart will be more visible to whomever is watching the model and it will improve their understanding of the content the model is teaching them. Of course increasing the density of LEDs will involve a lot of work as more LEDs will have to be added to each channel and the current and voltage requirements of the model will change as well.

All of these changes will only improve our project so that will it be a more efficient teaching tool in the future for medical students.

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Appendices

Appendix 1: Bill of Materials

Bill of Materials:

LED Mounting Hardware LED Clip and Ring 5mm Nylon Black	4	\$0.60
Standard LEDs - Through Hole Blue Round LED	4	\$0.84
LED Mounting Hardware LED Mount Self Ret 3mm Black .325 inch	400	\$19.60
Standard LEDs - Through Hole SOLID STATE LAMP T-1 (3mm) HYPER RED	150	\$37.05
Standard LEDs - Through Hole Blue/ Water Clear 464476nm1500mcd	250	\$40.00
MOSFET N-CH 60V 55A TO-220AB	50	\$50.30
Budget Life-Size Heart Model	1	\$20.36
Budget Jumbo Heart Model	1	\$56.06
Proform 6-Volt AC Power Adapter	1	\$14.59
Nightstand with Door	1	\$40
Copal Electronics Inc ATE1D-2M3-10-Z	11	\$31.57
Pyle PMKS7 Microphone Stand	1	\$20.00
Various Circuit Supplies		\$20.00
Life-Size Clear Torso	1	\$200.00
Final Cost		\$550.97

Appendix 2: Complete Small Heart

```
const int led1 = 1;
const int led2 = 2;
const int led3 = 3;
const int led4 = 4;
const int led5 = 5;
const int led6 = 6;
const int led7 = 7;
const int led8 = 8;
const int led9 = 9;
const int led10 = 10;
const int led11 = 11;
const int led12 = 12;
const int led13 = 13;
const int switch1 = 14;
const int switch2 = 15;
const int switch3 = 16;
const int switch4 = 17;
```

```
int switchstate1 = 0;
int switchstate2 = 0;
int switchstate3 = 0;
int switchstate4 = 0;
```

```
void setup(){
  pinMode(led1, OUTPUT);
  pinMode(led2, OUTPUT);
  pinMode(led3, OUTPUT);
  pinMode(led4, OUTPUT);
  pinMode(led5, OUTPUT);
  pinMode(led6, OUTPUT);
  pinMode(led7, OUTPUT);
  pinMode(led8, OUTPUT);
  pinMode(led9, OUTPUT);
  pinMode(led10, OUTPUT);
  pinMode(led11, OUTPUT);
  pinMode(led12, OUTPUT);
  pinMode(led13, OUTPUT);
  pinMode(switch1, INPUT);
  pinMode(switch2, INPUT);
  pinMode(switch3, INPUT);
  pinMode(switch4, INPUT);
}
void loop() {
  switchstate1 = digitalRead(switch1);
  switchstate2 = digitalRead(switch2);
```

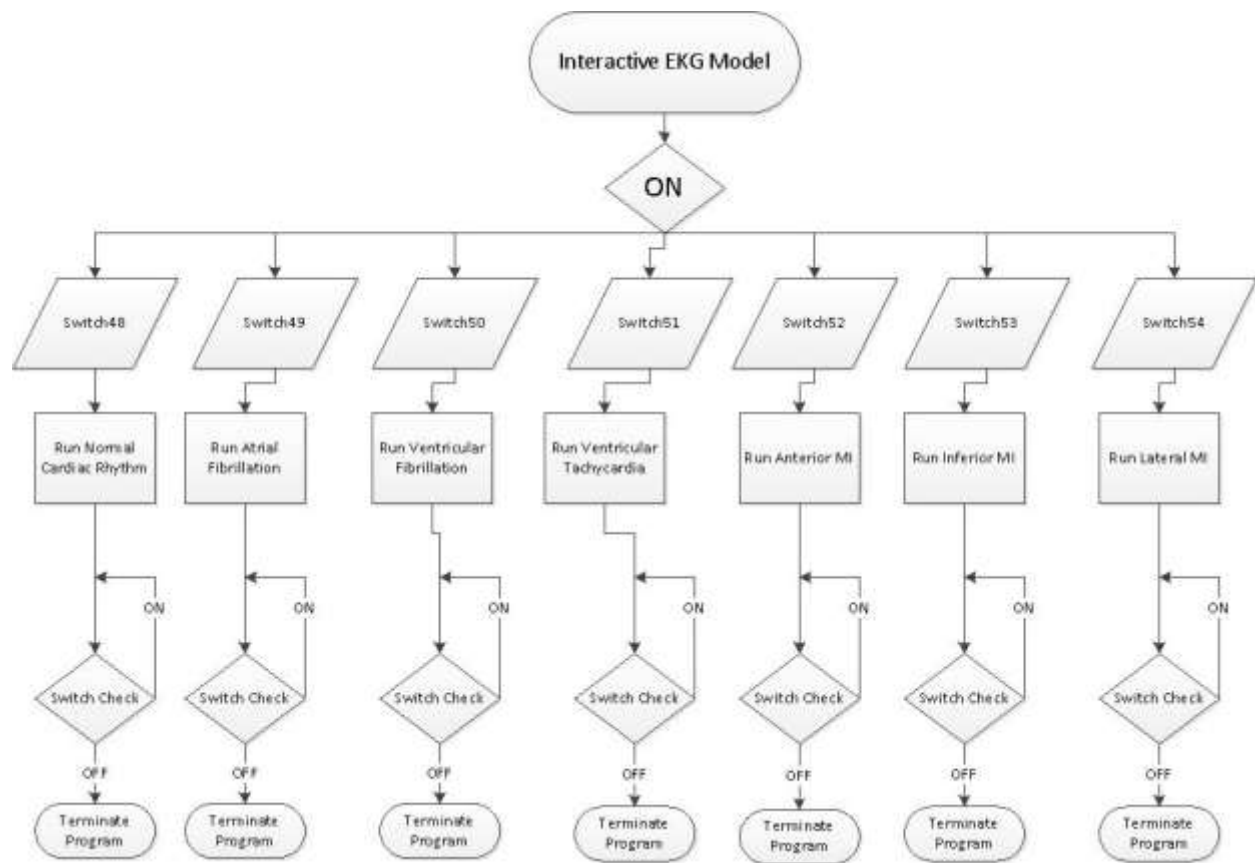
```

switchstate3 = digitalRead(switch3);
switchstate4 = digitalRead(switch4);

if (switchstate1 == HIGH) {
  digitalWrite(led1, HIGH);
  digitalWrite(led2, HIGH);
  digitalWrite(led3, HIGH);
  digitalWrite(led4, HIGH);
  digitalWrite(led5, HIGH);
}
if (switchstate2 == HIGH) {
  digitalWrite(led6, HIGH);
  digitalWrite(led7, HIGH);
  digitalWrite(led8, HIGH);
  digitalWrite(led9, HIGH);
}
if (switchstate3 == HIGH) {
  digitalWrite(led10, HIGH);
  digitalWrite(led11, HIGH);
}
if (switchstate4 == HIGH) {
  digitalWrite(led12, HIGH);
  digitalWrite(led13, HIGH);
}
else {
  digitalWrite(led1, LOW);
  digitalWrite(led2, LOW);
  digitalWrite(led3, LOW);
  digitalWrite(led4, LOW);
  digitalWrite(led5, LOW);
  digitalWrite(led6, LOW);
  digitalWrite(led7, LOW);
  digitalWrite(led8, LOW);
  digitalWrite(led9, LOW);
  digitalWrite(led10, LOW);
  digitalWrite(led11, LOW);
  digitalWrite(led12, LOW);
  digitalWrite(led13, LOW);
}
}
}

```

Appendix 3: Flow Chart for Large Heart Code



Appendix 4: Complete Large Heart

Complete Code for Large Heart

```
const int led1 = 1;
const int led2 = 2;
const int led3 = 3;
const int led4 = 4;
const int led5 = 5;
const int led6 = 6;
const int led7 = 7;
const int led8 = 8;
const int led9 = 9;
const int led10 = 10;
const int led11 = 11;
const int led12 = 12;
const int led13 = 13;
const int led14 = 14;
const int led15 = 15;
const int led16 = 16;
const int led17 = 17;
const int led18 = 18;
const int led19 = 19;
const int led20 = 20;
const int led21 = 21;
const int led22 = 22;
const int led23 = 23;
const int led24 = 24;
const int led25 = 25;
const int led26 = 26;
const int led27 = 27;
const int led28 = 28;
const int led29 = 29;
const int led30 = 30;
const int led31 = 31;
const int led32 = 32;
const int led33 = 33;
const int led34 = 34;
const int led35 = 35;
const int led36 = 36;
const int led37 = 37;
const int led38 = 38;
const int led39 = 39;
const int led40 = 40;
const int led41 = 41;
const int led42 = 42;
const int led43 = 43;
const int led44 = 44;
```

```

const int led45 = 45;
const int led46 = 46;
const int led47 = 47;

const int switch1 = 48; //Switch for Normal Cardiac Rhythm
const int switch2 = 49; //Switch for AFib Sequence
const int switch3 = 50; //Switch for VFib Sequence
const int switch4 = 51; //Switch for VTach Sequence
const int switch5 = 52; //Switch for Anterior Myocardial Infarction Sequence
const int switch6 = 53; //Switch for Inferior Myocardial Infarction Sequence
const int switch7 = 54; //Switch for Lateral Myocardial Infarction Sequence

int switchstate1 = 0; //Variable that will change. Variable that reads the switch status.
int switchstate2 = 0;
int switchstate3 = 0;
int switchstate4 = 0;
int switchstate5 = 0;
int switchstate6 = 0;
int switchstate7 = 0;

int brightness = 10; //brightness of LEDs (for fade during MIs)

void setup(){
pinMode(led1, OUTPUT); //Initializes LEDs as an output. (Arduino sends signal TO lights.)
pinMode(led2, OUTPUT);
pinMode(led3, OUTPUT);
  pinMode(led4, OUTPUT);
  pinMode(led5, OUTPUT);
  pinMode(led6, OUTPUT);
  pinMode(led7, OUTPUT);
  pinMode(led8, OUTPUT);
  pinMode(led9, OUTPUT);
  pinMode(led10, OUTPUT);
  pinMode(led11, OUTPUT);
  pinMode(led12, OUTPUT);
  pinMode(led13, OUTPUT);
  pinMode(led14, OUTPUT);
  pinMode(led15, OUTPUT);
  pinMode(led16, OUTPUT);
  pinMode(led17, OUTPUT);
  pinMode(led18, OUTPUT);
  pinMode(led19, OUTPUT);
  pinMode(led20, OUTPUT);
  pinMode(led21, OUTPUT);
  pinMode(led22, OUTPUT);
  pinMode(led23, OUTPUT);

```

```
pinMode(led24, OUTPUT);
pinMode(led25, OUTPUT);
pinMode(led26, OUTPUT);
pinMode(led27, OUTPUT);
pinMode(led28, OUTPUT);
pinMode(led29, OUTPUT);
pinMode(led30, OUTPUT);
pinMode(led31, OUTPUT);
pinMode(led32, OUTPUT);
pinMode(led33, OUTPUT);
pinMode(led34, OUTPUT);
pinMode(led35, OUTPUT);
pinMode(led36, OUTPUT);
pinMode(led37, OUTPUT);
pinMode(led38, OUTPUT);
pinMode(led39, OUTPUT);
pinMode(led40, OUTPUT);
pinMode(led41, OUTPUT);
pinMode(led42, OUTPUT);
pinMode(led43, OUTPUT);
pinMode(led44, OUTPUT);
pinMode(led45, OUTPUT);
pinMode(led46, OUTPUT);
pinMode(led47, OUTPUT);
```

```
pinMode(switch1, INPUT); //Initializes switches as an input. (Arduino RECIEVES signal
FROM switches.)
```

```
pinMode(switch2, INPUT);
pinMode(switch4, INPUT);
pinMode(switch5, INPUT);
pinMode(switch6, INPUT);
pinMode(switch7, INPUT);
}
```

```
void loop() {
  switchstate1 = digitalRead(switch1);
  switchstate2 = digitalRead(switch2);
  switchstate3 = digitalRead(switch3);
  switchstate4 = digitalRead(switch4);
  switchstate5 = digitalRead(switch5);
  switchstate6 = digitalRead(switch6);
  switchstate7 = digitalRead(switch7);
  if (switchstate1 == HIGH) { //Normal Cardiac Conduction Code Sequence
    delay(1000);
    digitalWrite(led1, HIGH);
    delay(250);
    digitalWrite(led2, HIGH);
```

```
delay(250);
digitalWrite(led3, HIGH);
delay(250);
digitalWrite(led4, HIGH);
digitalWrite(led5, HIGH);
delay(750);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
```



```

digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
}

if (switchstate2 == HIGH) { //AFib Code Sequence
digitalWrite(led20, HIGH);
digitalWrite(led26, HIGH);
digitalWrite(led27, HIGH);
digitalWrite(led28, HIGH);
delay(500);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
digitalWrite(led5, HIGH);
delay(250);
digitalWrite(led24, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
delay(250);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
}

```

```
delay(250);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
delay(250);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(250);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(250);
digitalWrite(led24, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
delay(500);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
delay(250);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(250);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
delay(500);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
digitalWrite(led9, LOW);
```

```
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
delay(250);
digitalWrite(led24, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(500);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(500);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
delay(500);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
delay(250);
digitalWrite(led24, HIGH);
digitalWrite(led5, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
delay(500);
digitalWrite(led25, HIGH);
```

```
digitalWrite(led27, HIGH);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
delay(250);
digitalWrite(led24, HIGH);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
delay(500);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
delay(250);
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digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
delay(500);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(500);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(250);
digitalWrite(led24, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
delay(250);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(250);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
delay(250);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(250);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
```

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digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
delay(500);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
digitalWrite(led5, HIGH);
delay(500);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
delay(250);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(250);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
delay(250);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
```

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delay(250);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(250);
digitalWrite(led24, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
delay(500);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
delay(250);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(250);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
delay(500);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
delay(250);
digitalWrite(led24, HIGH);
delay(250);
digitalWrite(led22, HIGH);
```

```
digitalWrite(led26, HIGH);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(500);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(500);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
delay(500);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
delay(250);
digitalWrite(led24, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
digitalWrite(led5, HIGH);
delay(500);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led20, HIGH);
```



```
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(250);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(250);
digitalWrite(led24, HIGH);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(500);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
delay(500);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led28, HIGH);
delay(250);
```

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digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(250);
digitalWrite(led21, HIGH);
digitalWrite(led23, HIGH);
delay(250);
digitalWrite(led26, LOW);
digitalWrite(led27, LOW);
digitalWrite(led28, LOW);
delay(250);
digitalWrite(led24, HIGH);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(250);
digitalWrite(led22, HIGH);
digitalWrite(led26, HIGH);
delay(500);
digitalWrite(led25, HIGH);
digitalWrite(led27, HIGH);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(250);
digitalWrite(led20, LOW);
digitalWrite(led21, LOW);
digitalWrite(led22, LOW);
delay(500);
digitalWrite(led20, HIGH);
digitalWrite(led23, LOW);
digitalWrite(led24, LOW);
digitalWrite(led25, LOW);
digitalWrite(led47, LOW);
digitalWrite(led11, LOW);
}
if (switchstate3 == HIGH) { //VFib Code Sequence
digitalWrite(led29, HIGH);
digitalWrite(led32, HIGH);
digitalWrite(led35, HIGH);
delay(250);
digitalWrite(led31, HIGH);
digitalWrite(led33, HIGH);
delay(250);

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```
digitalWrite(led36, HIGH);
digitalWrite(led37, HIGH);
digitalWrite(led40, HIGH);
digitalWrite(led45, HIGH);
digitalWrite(led46, HIGH);
delay(250);
digitalWrite(led30, HIGH);
digitalWrite(led34, HIGH);
digitalWrite(led39, HIGH);
digitalWrite(led42, HIGH);
digitalWrite(led43, HIGH);
delay(250);
digitalWrite(led1, HIGH);
delay(250);
digitalWrite(led2, HIGH);
digitalWrite(led29, LOW);
digitalWrite(led32, LOW);
digitalWrite(led35, LOW);
digitalWrite(led36, LOW);
digitalWrite(led37, LOW);
digitalWrite(led38, HIGH);
digitalWrite(led40, LOW);
digitalWrite(led41, HIGH);
digitalWrite(led44, HIGH);
digitalWrite(led45, LOW);
digitalWrite(led46, LOW);
delay(250);
digitalWrite(led3, HIGH);
digitalWrite(led31, LOW);
digitalWrite(led33, LOW);
digitalWrite(led39, LOW);
digitalWrite(led42, LOW);
digitalWrite(led43, LOW);
delay(250);
digitalWrite(led4, HIGH);
delay(250);
digitalWrite(led29, HIGH);
digitalWrite(led30, LOW);
digitalWrite(led32, HIGH);
digitalWrite(led34, LOW);
digitalWrite(led35, HIGH);
digitalWrite(led38, LOW);
digitalWrite(led41, LOW);
digitalWrite(led44, LOW);
delay(250);
digitalWrite(led31, HIGH);
```

```
digitalWrite(led33, HIGH);
delay(250);
digitalWrite(led36, HIGH);
digitalWrite(led37, HIGH);
digitalWrite(led40, HIGH);
digitalWrite(led45, HIGH);
digitalWrite(led46, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led30, HIGH);
digitalWrite(led34, HIGH);
digitalWrite(led39, HIGH);
digitalWrite(led42, HIGH);
digitalWrite(led43, HIGH);
delay(250);
digitalWrite(led2, LOW);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led29, LOW);
digitalWrite(led32, LOW);
digitalWrite(led35, LOW);
digitalWrite(led36, LOW);
digitalWrite(led37, LOW);
digitalWrite(led38, HIGH);
digitalWrite(led40, LOW);
digitalWrite(led41, HIGH);
digitalWrite(led44, HIGH);
digitalWrite(led45, LOW);
digitalWrite(led46, LOW);
delay(250);
digitalWrite(led31, LOW);
digitalWrite(led33, LOW);
digitalWrite(led39, LOW);
digitalWrite(led42, LOW);
digitalWrite(led43, LOW);
delay(250);
digitalWrite(led4, LOW);
delay(250);
digitalWrite(led29, HIGH);
digitalWrite(led30, LOW);
digitalWrite(led32, HIGH);
digitalWrite(led34, LOW);
digitalWrite(led35, HIGH);
digitalWrite(led38, LOW);
digitalWrite(led41, LOW);
digitalWrite(led44, LOW);
```

```
delay(250);
digitalWrite(led31, HIGH);
digitalWrite(led33, HIGH);
delay(250);
digitalWrite(led36, HIGH);
digitalWrite(led37, HIGH);
digitalWrite(led40, HIGH);
digitalWrite(led45, HIGH);
digitalWrite(led46, HIGH);
delay(250);
digitalWrite(led30, HIGH);
digitalWrite(led34, HIGH);
digitalWrite(led39, HIGH);
digitalWrite(led42, HIGH);
digitalWrite(led43, HIGH);
delay(500);
digitalWrite(led29, LOW);
digitalWrite(led32, LOW);
digitalWrite(led35, LOW);
digitalWrite(led36, LOW);
digitalWrite(led37, LOW);
digitalWrite(led38, HIGH);
digitalWrite(led40, LOW);
digitalWrite(led41, HIGH);
digitalWrite(led44, HIGH);
digitalWrite(led45, LOW);
digitalWrite(led46, LOW);
delay(250);
digitalWrite(led31, LOW);
digitalWrite(led33, LOW);
digitalWrite(led39, LOW);
digitalWrite(led42, LOW);
digitalWrite(led43, LOW);
delay(500);
digitalWrite(led29, HIGH);
digitalWrite(led30, LOW);
digitalWrite(led32, HIGH);
digitalWrite(led34, LOW);
digitalWrite(led35, HIGH);
digitalWrite(led38, LOW);
digitalWrite(led41, LOW);
digitalWrite(led44, LOW);
delay(250);
digitalWrite(led31, HIGH);
digitalWrite(led33, HIGH);
delay(250);
```

```
digitalWrite(led36, HIGH);
digitalWrite(led37, HIGH);
digitalWrite(led40, HIGH);
digitalWrite(led45, HIGH);
digitalWrite(led46, HIGH);
delay(250);
digitalWrite(led30, HIGH);
digitalWrite(led34, HIGH);
digitalWrite(led39, HIGH);
digitalWrite(led42, HIGH);
digitalWrite(led43, HIGH);
delay(500);
digitalWrite(led29, LOW);
digitalWrite(led32, LOW);
digitalWrite(led35, LOW);
digitalWrite(led36, LOW);
digitalWrite(led37, LOW);
digitalWrite(led38, HIGH);
digitalWrite(led40, LOW);
digitalWrite(led41, HIGH);
digitalWrite(led44, HIGH);
digitalWrite(led45, LOW);
digitalWrite(led46, LOW);
delay(250);
digitalWrite(led31, LOW);
digitalWrite(led33, LOW);
digitalWrite(led39, LOW);
digitalWrite(led42, LOW);
digitalWrite(led43, LOW);
delay(500);
digitalWrite(led29, HIGH);
digitalWrite(led30, LOW);
digitalWrite(led32, HIGH);
digitalWrite(led34, LOW);
digitalWrite(led35, HIGH);
digitalWrite(led38, LOW);
digitalWrite(led41, LOW);
digitalWrite(led44, LOW);
delay(250);
digitalWrite(led31, HIGH);
digitalWrite(led33, HIGH);
delay(250);
digitalWrite(led36, HIGH);
digitalWrite(led37, HIGH);
digitalWrite(led40, HIGH);
digitalWrite(led45, HIGH);
```

```

digitalWrite(led46, HIGH);
delay(250);
digitalWrite(led30, HIGH);
digitalWrite(led34, HIGH);
digitalWrite(led39, HIGH);
digitalWrite(led42, HIGH);
digitalWrite(led43, HIGH);
delay(500);
digitalWrite(led29, LOW);
digitalWrite(led32, LOW);
digitalWrite(led35, LOW);
digitalWrite(led36, LOW);
digitalWrite(led37, LOW);
digitalWrite(led38, HIGH);
digitalWrite(led40, LOW);
digitalWrite(led41, HIGH);
digitalWrite(led44, HIGH);
digitalWrite(led45, LOW);
digitalWrite(led46, LOW);
delay(250);
digitalWrite(led31, LOW);
digitalWrite(led33, LOW);
digitalWrite(led39, LOW);
digitalWrite(led42, LOW);
digitalWrite(led43, LOW);
delay(500);
digitalWrite(led30, LOW);
digitalWrite(led34, LOW);
digitalWrite(led38, LOW);
digitalWrite(led41, LOW);
digitalWrite(led44, LOW);
}
if (switchstate4 == HIGH) { //VTach
digitalWrite(led29, HIGH);
delay(250);
digitalWrite(led36, HIGH);
delay(250);
digitalWrite(led37, HIGH);
digitalWrite(led38, HIGH);
digitalWrite(led39, HIGH);
delay(500);
digitalWrite(led30, HIGH);
digitalWrite(led31, HIGH);
digitalWrite(led32, HIGH);
digitalWrite(led33, HIGH);
digitalWrite(led34, HIGH);
}

```

```

digitalWrite(led40, HIGH);
digitalWrite(led41, HIGH);
digitalWrite(led42, HIGH);
delay(500);
digitalWrite(led43, HIGH);
digitalWrite(led44, HIGH);
digitalWrite(led45, HIGH);
delay(500);
digitalWrite(led35, HIGH);
digitalWrite(led46, HIGH);
delay(1000);
digitalWrite(led29, LOW);
delay(250);
digitalWrite(led36, LOW);
delay(250);
digitalWrite(led37, LOW);
digitalWrite(led38, LOW);
digitalWrite(led39, LOW);
delay(500);
digitalWrite(led30, LOW);
digitalWrite(led31, LOW);
digitalWrite(led32, LOW);
digitalWrite(led33, LOW);
digitalWrite(led34, LOW);
digitalWrite(led40, LOW);
digitalWrite(led41, LOW);
digitalWrite(led42, LOW);
delay(500);
digitalWrite(led43, LOW);
digitalWrite(led44, LOW);
digitalWrite(led45, LOW);
delay(500);
digitalWrite(led35, LOW);
digitalWrite(led46, LOW);
delay(1000);
}
if (switchstate5 == HIGH) { // Anterior Myocardial Infarction Code Sequence
//Beat 1
delay(1000);
digitalWrite(led1, HIGH);
delay(250);
digitalWrite(led2, HIGH);
delay(250);
digitalWrite(led3, HIGH);
delay(250);
digitalWrite(led4, HIGH);

```



```
digitalWrite(led5, HIGH);
delay(750);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
```

```
delay(2000);
//Beat 2
delay(1000);
  digitalWrite(led1, HIGH);
  delay(250);
  digitalWrite(led2, HIGH);
  delay(250);
  digitalWrite(led3, HIGH);
  delay(250);
  digitalWrite(led4, HIGH);
  digitalWrite(led5, HIGH);
  delay(750);
  digitalWrite(led5, LOW);
  digitalWrite(led6, HIGH);
  delay(250);
  digitalWrite(led1, LOW);
  digitalWrite(led7, HIGH);
  delay(250);
  digitalWrite(led2, LOW);
  digitalWrite(led6, LOW);
  digitalWrite(led8, HIGH);
  digitalWrite(led12, HIGH);
  digitalWrite(led13, HIGH);
  delay(250);
  digitalWrite(led3, LOW);
  digitalWrite(led7, LOW);
  digitalWrite(led9, HIGH);
  digitalWrite(led15, HIGH);
  digitalWrite(led16, HIGH);
  digitalWrite(led19, HIGH);
  delay(500);
  digitalWrite(led4, LOW);
  digitalWrite(led10, HIGH);
  analogWrite(led14, brightness);
  digitalWrite(led17, HIGH);
  digitalWrite(led18, HIGH);
  delay(500);
  digitalWrite(led11, HIGH);
  digitalWrite(led47, HIGH);
  delay(1500);
  digitalWrite(led8, LOW);
  digitalWrite(led12, LOW);
  digitalWrite(led13, LOW);
  delay(750);
  digitalWrite(led9, LOW);
  digitalWrite(led15, LOW);
```

```
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 3
delay(1000);
  digitalWrite(led1, HIGH);
  delay(250);
  digitalWrite(led2, HIGH);
  delay(250);
  digitalWrite(led3, HIGH);
  delay(250);
  digitalWrite(led4, HIGH);
  digitalWrite(led5, HIGH);
  delay(750);
  digitalWrite(led5, LOW);
  digitalWrite(led6, HIGH);
  delay(250);
  digitalWrite(led1, LOW);
  digitalWrite(led7, HIGH);
  delay(250);
  digitalWrite(led2, LOW);
  digitalWrite(led6, LOW);
  digitalWrite(led8, HIGH);
  digitalWrite(led12, HIGH);
  digitalWrite(led13, HIGH);
  delay(250);
  digitalWrite(led3, LOW);
  digitalWrite(led7, LOW);
  digitalWrite(led9, HIGH);
  analogWrite(led15, brightness);
  digitalWrite(led16, HIGH);
  digitalWrite(led19, HIGH);
  delay(500);
  digitalWrite(led4, LOW);
  digitalWrite(led10, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
```

```
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 4
delay(1000);
  digitalWrite(led1, HIGH);
  delay(250);
  digitalWrite(led2, HIGH);
  delay(250);
  digitalWrite(led3, HIGH);
  delay(250);
  digitalWrite(led4, HIGH);
  digitalWrite(led5, HIGH);
  delay(750);
  digitalWrite(led5, LOW);
  digitalWrite(led6, HIGH);
  delay(250);
  digitalWrite(led1, LOW);
  digitalWrite(led7, HIGH);
  delay(250);
  digitalWrite(led2, LOW);
  digitalWrite(led6, LOW);
  digitalWrite(led8, HIGH);
  digitalWrite(led12, HIGH);
  digitalWrite(led13, HIGH);
  delay(250);
  digitalWrite(led3, LOW);
  digitalWrite(led7, LOW);
  digitalWrite(led9, HIGH);
  analogWrite(led16, brightness);
```

```
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 5
delay(1000);
digitalWrite(led1, HIGH);
delay(250);
digitalWrite(led2, HIGH);
delay(250);
digitalWrite(led3, HIGH);
delay(250);
digitalWrite(led4, HIGH);
digitalWrite(led5, HIGH);
delay(750);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
```

```

digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000); }

```

```

if (switchstate6 == HIGH) { //Inferior Myocardial Infarction Code Sequence
  //Beat 1
  delay(1000);
  digitalWrite(led1, HIGH);
  delay(250);
  digitalWrite(led2, HIGH);
  delay(250);
  digitalWrite(led3, HIGH);
  delay(250);
  digitalWrite(led4, HIGH);
  digitalWrite(led5, HIGH);
  delay(750);
  digitalWrite(led5, LOW);
  digitalWrite(led6, HIGH);
  delay(250);
  digitalWrite(led1, LOW);

```

```
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 2
delay(1000);
digitalWrite(led1, HIGH);
delay(250);
digitalWrite(led2, HIGH);
```

```
delay(250);
digitalWrite(led3, HIGH);
delay(250);
digitalWrite(led4, HIGH);
digitalWrite(led5, HIGH);
delay(750);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
analogWrite(led12, brightness);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
```



```
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 3
delay(1000);
  digitalWrite(led1, HIGH);
  delay(250);
  digitalWrite(led2, HIGH);
  delay(250);
  digitalWrite(led3, HIGH);
  delay(250);
  digitalWrite(led4, HIGH);
  digitalWrite(led5, HIGH);
  delay(750);
  digitalWrite(led5, LOW);
  digitalWrite(led6, HIGH);
  delay(250);
  digitalWrite(led1, LOW);
  digitalWrite(led7, HIGH);
  delay(250);
  digitalWrite(led2, LOW);
  digitalWrite(led6, LOW);
  digitalWrite(led8, HIGH);
  analogWrite(led13, brightness);
  delay(250);
  digitalWrite(led3, LOW);
  digitalWrite(led7, LOW);
  digitalWrite(led9, HIGH);
  digitalWrite(led15, HIGH);
  digitalWrite(led16, HIGH);
  digitalWrite(led19, HIGH);
  delay(500);
  digitalWrite(led4, LOW);
  digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led13, LOW);
delay(750);
```

```
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 4
delay(1000);
  digitalWrite(led1, HIGH);
  delay(250);
  digitalWrite(led2, HIGH);
  delay(250);
  digitalWrite(led3, HIGH);
  delay(250);
  digitalWrite(led4, HIGH);
  digitalWrite(led5, HIGH);
  delay(750);
  digitalWrite(led5, LOW);
  digitalWrite(led6, HIGH);
  delay(250);
  digitalWrite(led1, LOW);
  digitalWrite(led7, HIGH);
  delay(250);
  digitalWrite(led2, LOW);
  digitalWrite(led6, LOW);
  digitalWrite(led8, HIGH);
  delay(250);
  digitalWrite(led3, LOW);
  digitalWrite(led7, LOW);
  digitalWrite(led9, HIGH);
  digitalWrite(led15, HIGH);
  digitalWrite(led16, HIGH);
  digitalWrite(led19, HIGH);
  delay(500);
  digitalWrite(led4, LOW);
  digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
```

```

delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
}
if (switchstate7 == HIGH) { //Lateral Myocardial Infarction Code Sequence
  digitalWrite(led1, HIGH);
  delay(250);
  digitalWrite(led2, HIGH);
  delay(250);
  digitalWrite(led3, HIGH);
  delay(250);
  digitalWrite(led4, HIGH);
  digitalWrite(led5, HIGH);
  delay(750);
  digitalWrite(led5, LOW);
  digitalWrite(led6, HIGH);
  delay(250);
  digitalWrite(led1, LOW);
  digitalWrite(led7, HIGH);
  delay(250);
  digitalWrite(led2, LOW);
  digitalWrite(led6, LOW);
  digitalWrite(led8, HIGH);
  digitalWrite(led12, HIGH);
  digitalWrite(led13, HIGH);
  delay(250);
  digitalWrite(led3, LOW);
  digitalWrite(led7, LOW);
  digitalWrite(led9, HIGH);
  digitalWrite(led15, HIGH);

```

```
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
digitalWrite(led17, HIGH);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 2
digitalWrite(led1, HIGH);
delay(250);
digitalWrite(led2, HIGH);
delay(250);
digitalWrite(led3, HIGH);
delay(250);
digitalWrite(led4, HIGH);
digitalWrite(led5, HIGH);
delay(750);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
```

```
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
analogWrite(led17, brightness);
digitalWrite(led18, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led17, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 3
digitalWrite(led1, HIGH);
delay(250);
digitalWrite(led2, HIGH);
delay(250);
digitalWrite(led3, HIGH);
delay(250);
digitalWrite(led4, HIGH);
```

```
digitalWrite(led5, HIGH);
delay(750);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
digitalWrite(led19, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
analogWrite(led18, brightness);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
digitalWrite(led18, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 4
```

```
digitalWrite(led1, HIGH);
delay(250);
digitalWrite(led2, HIGH);
delay(250);
digitalWrite(led3, HIGH);
delay(250);
digitalWrite(led4, HIGH);
digitalWrite(led5, HIGH);
delay(750);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
analogWrite(led19, brightness);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
digitalWrite(led19, LOW);
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
```

```
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);
//Beat 5
digitalWrite(led1, HIGH);
delay(250);
digitalWrite(led2, HIGH);
delay(250);
digitalWrite(led3, HIGH);
delay(250);
digitalWrite(led4, HIGH);
digitalWrite(led5, HIGH);
delay(750);
digitalWrite(led5, LOW);
digitalWrite(led6, HIGH);
delay(250);
digitalWrite(led1, LOW);
digitalWrite(led7, HIGH);
delay(250);
digitalWrite(led2, LOW);
digitalWrite(led6, LOW);
digitalWrite(led8, HIGH);
digitalWrite(led12, HIGH);
digitalWrite(led13, HIGH);
delay(250);
digitalWrite(led3, LOW);
digitalWrite(led7, LOW);
digitalWrite(led9, HIGH);
digitalWrite(led15, HIGH);
digitalWrite(led16, HIGH);
delay(500);
digitalWrite(led4, LOW);
digitalWrite(led10, HIGH);
digitalWrite(led14, HIGH);
delay(500);
digitalWrite(led11, HIGH);
digitalWrite(led47, HIGH);
delay(1500);
digitalWrite(led8, LOW);
digitalWrite(led12, LOW);
digitalWrite(led13, LOW);
delay(750);
digitalWrite(led9, LOW);
digitalWrite(led15, LOW);
digitalWrite(led16, LOW);
```



```
delay(750);
digitalWrite(led10, LOW);
digitalWrite(led14, LOW);
delay(750);
digitalWrite(led11, LOW);
digitalWrite(led47, LOW);
delay(2000);

//END
}
else {
  digitalWrite(led1, LOW);
  digitalWrite(led2, LOW);
  digitalWrite(led4, LOW);
  digitalWrite(led5, LOW);
  digitalWrite(led6, LOW);
  digitalWrite(led7, LOW);
  digitalWrite(led8, LOW);
  digitalWrite(led9, LOW);
  digitalWrite(led10, LOW);
  digitalWrite(led11, LOW);
  digitalWrite(led12, LOW);
  digitalWrite(led13, LOW);
  digitalWrite(led14, LOW);
  digitalWrite(led15, LOW);
  digitalWrite(led16, LOW);
  digitalWrite(led17, LOW);
  digitalWrite(led18, LOW);
  digitalWrite(led19, LOW);
  digitalWrite(led20, LOW);
  digitalWrite(led21, LOW);
  digitalWrite(led22, LOW);
  digitalWrite(led23, LOW);
  digitalWrite(led24, LOW);
  digitalWrite(led25, LOW);
  digitalWrite(led26, LOW);
  digitalWrite(led27, LOW);
  digitalWrite(led28, LOW);
  digitalWrite(led29, LOW);
  digitalWrite(led30, LOW);
  digitalWrite(led31, LOW);
  digitalWrite(led32, LOW);
  digitalWrite(led33, LOW);
  digitalWrite(led34, LOW);
  digitalWrite(led35, LOW);
  digitalWrite(led36, LOW);
```

```
digitalWrite(led37, LOW);  
digitalWrite(led38, LOW);  
digitalWrite(led39, LOW);  
digitalWrite(led40, LOW);  
digitalWrite(led41, LOW);  
digitalWrite(led42, LOW);  
digitalWrite(led43, LOW);  
digitalWrite(led44, LOW);  
digitalWrite(led45, LOW);  
digitalWrite(led46, LOW);  
digitalWrite(led47, LOW);  
}  
}
```