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Case Report

The Use of an Electronic Cardiovascular Model, Case-Studies, and Transparency in Learning and Teaching Technique in Undergraduate Anatomy and Physiology

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Abstract

We built a hands-on 1 by .9-meter electronic teaching model that simulates cardiovascular physiology. We used case studies, transparency in learning and teaching (TILT) method and the electronic model to reinforce information taught in freshman and sophomore level undergraduate Human Anatomy and Physiology classes. This model allows students to adjust electric current output from a mock heart simulating changes in cardiac output. It also allows regulation of resistance at selected organs simulating vasodilation or constriction that influences blood flow. It maintains mean arterial blood pressure and flow during changes in physiologic conditions. Students have found it an effective method of learning cardiovascular anatomy and physiology.

Keywords: *Electronic Cardiovascular Model; Case-Study; Cardiovascular System; Transparency in Learning and Teaching; Electronic Model*

Purpose of the Study

The purpose of this study was to increase student understanding of undergraduate cardiovascular anatomy and physiology through the use of an electronic model, case studies, and transparency in learning and teaching method.

Introduction

Undergraduate cardiovascular physiology is a difficult subject for students, especially how it compensates for physiologic changes during redistribution of blood during volume/pressure changes [1-3]. We built a 1 by .9-meter electronic cardiovascular teaching model (Figure 1) for undergraduate freshman and sophomore students in health science or biology programs. The correlation between electricity and the cardiovascular system including voltage and blood pressure, current and blood flow, and electrical and blood resistance enables this model [1-5]. The electronics of the model is secured onto wood and is covered by a sheet of plexiglass. The wood is painted white and an outline of a human torso, which covers the frame, is drawn in black. There is an electric circuit to six mock organs on the model, which include the heart (cardiovascular system), brain (nervous system), stomach, intestines and liver (gastrointestinal system), kidneys (urinary system), skin (integumentary system) and skeletal muscle (muscular system). Inserted into a routed outline in the wood are red plastic replicas of the aorta and vessels serving each organ system, including right and left carotid arteries, right and left subclavian arteries, celiac artery, and left renal artery. The plastic replica vessels were made by computer aided design (CAD) and a Fused Deposition Modeling (FDM) 3D printer. Small red Light-Emitting Diodes (LED) are evenly spaced within the vessels to display direction (light tracks down the LEDs) and rate of blood flow (Figure 1). Two circuit boards are secured to the back of the wood for each organ. The heart is the source of the current on the model (Figure 3). In real life its contraction generates high pressure (systole) for blood flow into the aorta. Blood flows from high pressure in the aorta to separate arteries that supply separate organ systems. The current source is created using a Bipolar Junction Transistor (BJT) [6]. The heart has multiple knobs: heart rate is set by a potentiometer connected to a microcontroller that adjusts the speed of light tracking down the LEDs within the vessels (simulating blood pulse); another knob adjusts systolic pressure by adjusting the current supplied from a current source (high voltage) and similarly another controls diastolic pressure (lower voltage). After these pressures are manually set their output is controlled by a timer to alternate between systolic and diastolic pressures (See figure 4); another knob on the heart is a potentiometer to adjust resistance and subsequently current to the heart. The results of adjustments are directly displayed on the heart display board. The heart (LCD) flashes between the normal organ information and the cardiac output information. There is a 1 K ohm potentiometer connected to each circuit board with a knob that can adjust resistance in current to an organ, simulating vasoconstriction and vasodilation of arterioles that regulate blood flow to organs and adjust mean arterial pressure. The main circuit board for each organ also contains a microcontroller that takes in signals from a common data bus as well as the 1 K ohm potentiometer knob(s). The microcontroller interprets signals and provides feedback on 3 output devices (Liquid Crystal Display (LCD) monitor, LED array and LED lighting) that are part of each organ. The main circuit board has an LCD monitor and 35 LED array that is connected to the microcontroller. It provides information on change in current in the format of a numerical percent on the LCD and illumination of one to seven rows of LEDs depending on amount of current allowed into an organ (Figure 2). The other circuit board, equipped with small LEDs located below each organ, is connected to the microcontroller and provides changes in illumination as current is altered. The model can simulate the effect cardiac output and vascular resistance have on each organ. An increase or decrease of flow to one organ means less or more flow to the others. All of the organs are connected by a 2-line data bus. Line 1 communicates two-time multiplexed analog signals representing the systolic and diastolic blood pressures. Line 2 is a clock signal. The heart board creates two current sources, the levels of which are set by the systolic and diastolic knobs. This current simulates pressure output by the heart. As shown in figure 4, when the clock signal is high, the systolic current source is enabled, at this point, all organs take an analog-to-digital measurement and record this value as the systolic pressure. Similarly, when the clock signal is low, the diastolic current source is enabled, at this point all organs take an analog-to-digital measurement and record this value as the diastolic pressure. The individual organs respond to these readings and output the data by a feedback method. Figure 5 shows a block diagram of the system. Individual organs feedback to the other organs as amount of blood (current) they are using varies. Current diverted from one system affects flow to another system. In this way when a vessel to one organ permits high blood flow, less is available to serve other body systems. This configuration allows for varying flow to different systems as demands by individual systems change. The cardiovascular system has a limited volume of blood and must be creative during times of volume loss to maintain pressure and flow or increased demand by certain systems while maintaining adequate flow to other systems. An essential main function of the cardiovascular system is to maintain mean arterial pressure in the aorta through controlling cardiac output, stroke volume (not controlled by model) times heart rate into the aorta and peripheral resistance, vasodilation or constriction of arterioles [2,3]. Either mechanism controls pressure in the aorta which allows modulation of blood flow to systems. Students need to understand that homeostasis of physiologic conditions such as blood pressure, oxygen levels, carbon dioxide levels. pH etc., are the driving force behind adjusting blood pressure and flow. The mechanism includes receptors through-out the body monitoring these conditions and sending their findings to a processing center such as the brain, spinal cord or an endocrine gland for interpretation. If the physiologic condition is out of balance in an organ, the control center sends nervous or hormonal messages to the heart and/or arterioles to bring about an appropriate adjustment of pressure and flow [2,3]. Theoretical and computational models of the cardiovascular system have been developed as teaching tools for graduate level courses and research and medical applications [7,8]. The model can be adjusted to compensate for various physiologic situations including rest, exercise, and fluid volume changes. It allows students to analyze and interpret different human physiologic situations and make appropriate hands-on adjustments to the model to address the changes.

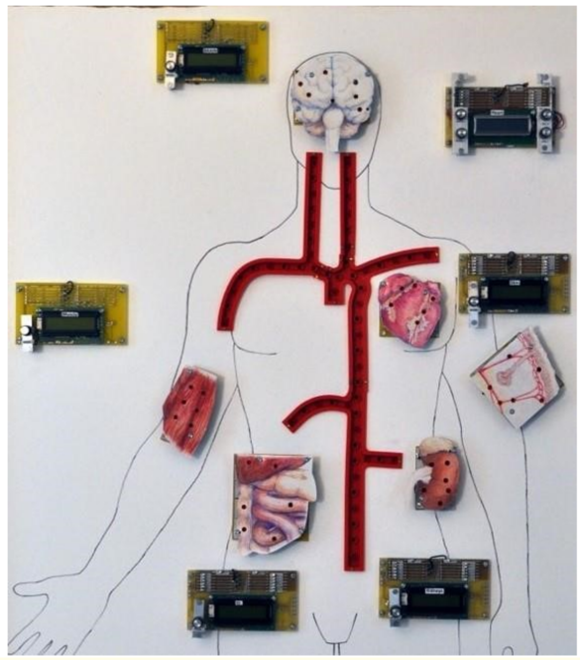

Figure 1: *Electronic cardiovascular model.*

Figure 1 shows cardiovascular system model including plastic tubes in red representing vessels, LED in the tubes as blood flow indictors, LEDs and circuit board with control knobs at each organ.

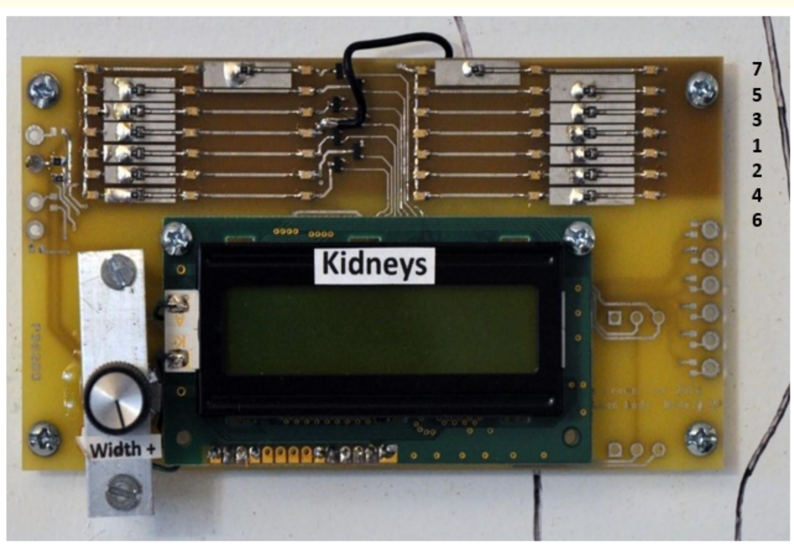

Figure 2: *LED array and LCD display for kidney.*

Figure 2 shows the LED and LCD displayed above is at each of the six organs of the model. Six column by seven row LED depicts intensity of electronic flow to organs. Frequency of LED flashes change as flow to the organ changes due to resistance. As resistances decreases and electric flow increases, more rows light up sequentially starting at row 1 to row 7. The LCD reveals flow rate to the organ as a percentage.

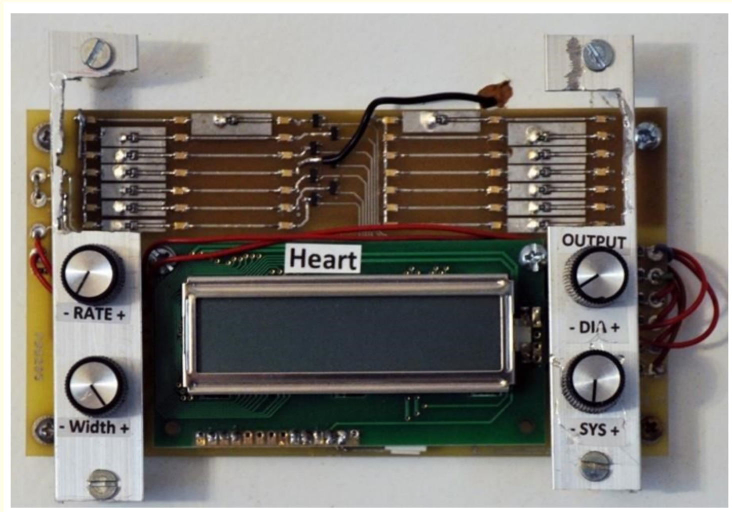

Figure 3: *The heart.*

The heart circuit board controls heart rate, diastolic pressure, systolic pressure. and resistance of flow to the heart. The heart controls the LEDs placed along the 3D printed artery to simulate blood flow. See figure 1 for the layout of the LEDs in the 3D printed artery.

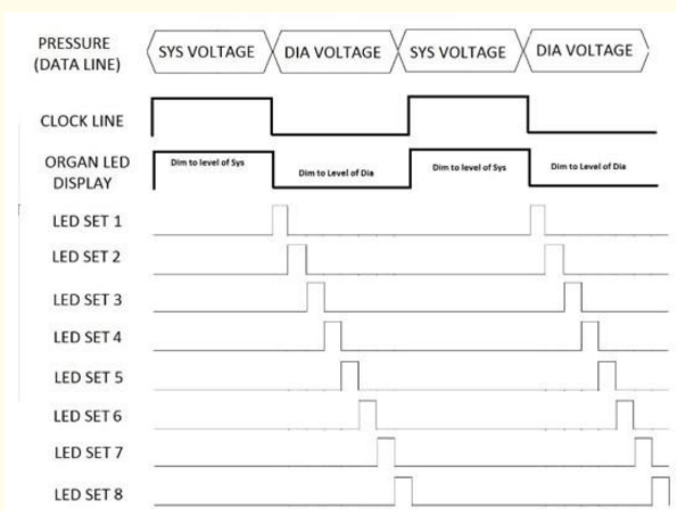

Figure 4: *System timing diagram.*

Figure 4 shows current flow from the heart alternates between systolic and diastolic pressures, representing pulse. As the heart rate changes, speed of pulsing current down the arterial tree changes directly. LEDs provide an intensity of illumination with changes in electric flow to an organ.

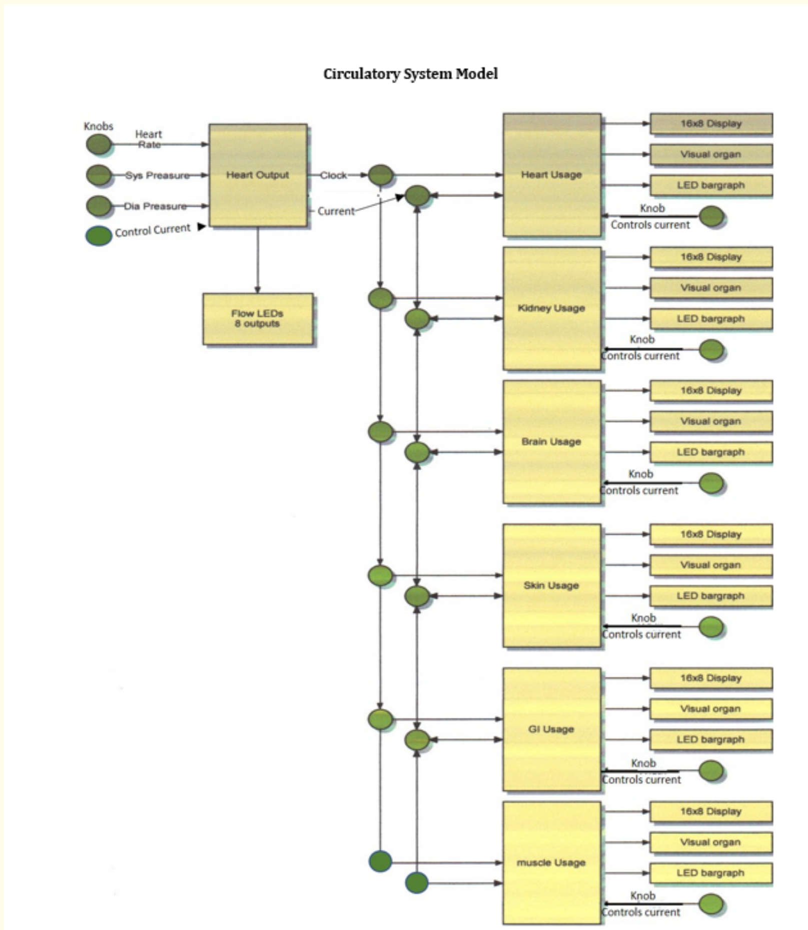

Figure 5: *System block diagram.*

Method

Monroe Community College's (MCC) Institutional Review Board reviewed and approved this educational study. It was considered minimal risk, with the only risk being disclosure of student names; however, the design of the study prevented this. It was placed in the exempt category by MCC's Institutional Review Board.

Case Reports

Case studies, an established teaching method [9], was used with this model. Anatomy and physiology of the cardiovascular system and handling of the electronic model is taught to students prior to assigning case study exercises. Transparency in learning and teaching (TILT) was also applied in this exercise. It is a technique that involves a collaboration among the teacher and students about the processes of learning and the rationale for required learning activities. It involves a precise overview of an assignment including its purpose, how it relates to objectives of the course, and if it provides resources related to the topic of an assignment. The case study exercise promotes teamwork, written expression of thoughts, and oral communication. This teaching approach helps level the understanding of assignments among students, making learning and achievement equitable among all students [10-13]. We provided clear instructions and criteria for success on the assignment including:

- A statement of the assignment goals which are to stimulate analytical, critical, and reflective thinking, and improve understanding of cardiovascular physiology
- Formatting guidelines for word processing, including font and margins
- Length of the submission (2 to 3 pages)
- Due date: One week
- Grade points for the assignment as an incentive
- Prompts of topics/issues to cover in the assignment.

In laboratory students were divided into groups with approximately four students per group. Each group was responsible to complete all case studies. Each case study covers a situation that brings about physiologic change in a hypothetical individual. Students in each group are asked to work together to complete questions in writing about the case studies including explanation of the physiologic changes that have occurred to the individual in the case study and how the cardiovascular system compensates for those changes. Students have one week to complete the assignment. Each group is also given one case assignment to summarize in front of the class the next week in laboratory and make appropriate adjustments to individual circuit boards on the model to compensate for the changing needs of the body.

Examples of three case studies

John, who is a member of his High School's cross-country team, prepares for a race by stretching and jogging in place. He is at the starting line and the starter gun is fired for the race to begin. Please explain the following in a written statement below: 1. How his cardiovascular system compensates from rest to running. 2. How blood flow speed and distribution to organs change during running. Each member of your group must contribute to the written answer. If this is your group's case study exercise to present at the next laboratory, each member of your group needs to explain to the class and make appropriate adjustments to the electronic model to simulate the changes to the cardiovascular system during running. Summary: During running, heart rate and pressure in the model are increased, and pulse away from the heart down the aorta and branches increases as illustrated by tracking lights. Potentiometer knob is adjusted to increase current to the muscles. This is illustrated as a percent increase on the LCD, an increase in the number of horizontal LED rows lit and brightness of LEDs under the muscle. Current to heart is increased, brain remains at baseline, GI system and kidneys decreased and integument first decreases, then increases, as blood is sent to integument to facilitate evaporative cooling.

Louis, a 55 year old man, goes out with his family for a celebration dinner which includes pasta, sauce, meat balls, sausage and cake. Please explain in a written statement below how his cardiovascular system compensates and blood flow change during and after eating. Each member of your group must contribute to the written answer. If this is your group's case study exercise to present at the next laboratory, each member of your group needs to explain to the class and make appropriate adjustments to the electronic model to simulate the changes to the cardiovascular system during and after eating. Summary: During and after eating heart rate is increased modestly. Pulse away from the heart down the aorta and branches increases slightly. Potentiometer knob is adjusted to increase current to the GI system. This is illustrated as a percent increase on the LCD, an increase in the number of horizontal LED rows lit and brightness of LEDs under the GI system. Current to heart, muscles, brain, kidneys and integument remain at baseline. An increase of current to any of these other systems can occur if they start being used, such as the brain if a student is studying for a physiology test.

78-year-old Betty is out working in the garden, a favorite past time. It is 95 degrees and humid. She is sweating profusely, is feeling dizzy and her heart is racing. Her daughter Anne, a nurse, takes her blood pressure and it is low. She places her mother under a shade tree, gives her a couple of glasses of cold water, and places cold towel on her forehead. After a while she is no longer dizzy, pulse is back to normal, blood pressure is normal and she feels much better. Please explain in a written statement below what is happening to make Betty sweaty, dizzy, her blood pressure low and why her heart is racing. Also explain why her daughter would place her under a shade tree, gave her cold water and placed a cold cloth on her forehead. Each member of your group must contribute to the written answer. If this is your group's case study exercise to present at the next laboratory. each member of your group needs to explain to the class and make appropriate adjustments to the electronic model to simulate the changes to the cardiovascular system during sweatiness, low blood pressure, increased heart rate, and dizziness and recovery. Summary: In the hot humid weather Betty starts to sweat to cool down. As she sweats, she loses blood volume. Blood pressure decreases, systolic and diastolic pressure from the heart is reduced. Current to the brain is reduced. Not enough blood is getting to her brain so she feels dizzy. Baroreceptors in her carotid arteries and aorta notice low blood pressure and sends a signal to increase heart rate (heart rate on model is increased) in an attempt to compensate for low blood volume, pressure and flow. Placing Betty under the tree, giving her cool water and a cold cloth cools her body down and she stops sweating. The water also adds fluid to her cardiovascular system. Her blood volume increases and her systole, diastolic and heart rate normalizes.

Assessment

At the end of the course, to assess efficacy of the model, students completed the following multiple-choice question, "Did the model improve your understanding of the cardiovascular system?" Approximate 600 students completed a lab exercise using this electronic model. A compilation of data over the years reveals the following: 92% of students agreed or strongly agreed, 5.5% were neutral, 2.5% disagreed that the method helped them. Those who agreed that the activity was helpful indicated that group interaction, critical thinking, learning from peers, reflection, and oral presentation of the case study questions were the most helpful aspects. Those who were neutral felt they did not need the extra exercise and those who disagreed did not feel the exercise helped. The use of this model along with case studies during laboratory promoted small group discussion, critical thinking, problem-solving, presentation skills and group interaction. Other educators also support the efficacy of models in education [14]. We suggest the following research designs to further assess the efficacy of the model:

- Assess students in sections of A&P who received electronic model training with an equal number of sections not receiving electronic model training.
- Compare results of students in the two different sections on multiple choice and short answer unit lecture exam questions pertaining to the cardiovascular system and reassess on the comprehensive final using different questions. The later would help determine information retention.
- Compare grades of students in the different sections on a short, written assignment concerning the topic.

Discussion

Professors at Monroe Community College who teach Human Anatomy and Physiology attempt to use teaching techniques and laboratory exercises that promote and enhance student learning. They try to develop assignments that engage students, use instructions that are clear and easy to understand, prompt students to explore, research, and reflect on the concepts and activities, either by themselves or in groups. It is felt the electronic model along with Transparency in Learning and Teaching technique achieved those goals. This model was built in 2011 and is durable with no breakdowns even after being handled by 600 students over the years. It is heavy and we would use lighter materials if another one was built. Materials to build the electronic board cost approximately $300.00.

Conclusion

There are numerous laboratory resources for Human Anatomy and Physiology students including lab text and computer-based laboratories [15]. Hands-on models are a proven learning method and we in education are pairing assignments with techniques such as TILT that promotes student equity in learning.

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