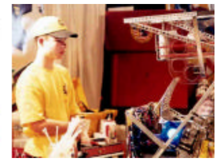

Honorable Mention

Using the Electrocardiogram to Teach Biomedical Engineering at the High School Level

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Learning Objectives:

This curriculum unit addresses many national standards set forth by AAAS, National Science Teachers Association, and the National Research Council's National Science Education Standards.

1. Students will be able to identify the critical characteristics of an ECG (also known as EKG from the German Electrokardiogram) trace and describe how these relate to the cycle of a beating heart.
2. Students will be able to explain how the heart generates electrical signals.
3. Students will learn about electric dipoles and electric fields in a unique and interesting context.
4. Students will be able to relate the parameters of a cardiac disease to its effect on the ECG.

Learning objectives 1 and 4 are particularly relevant to the AAAS's Benchmark for Physical Health: "Students should relate their knowledge of normal body functioning to situations, both hereditary and environmental, in which functioning is impaired. As they come across medical news in the media, students can identify new ways of detection, diagnosis, treatment, prevention, or monitoring. They should routinely try to find explanations for various disease conditions in physiological, molecular, or systems terms."

Learning objectives 1-4 are relevant to the NSTA's Content Core in that the topics of matter, energy, electricity and magnetism, properties of matter, nature of chemical change, and the properties of living things are addressed in the module.

Lastly, many of the National Science Education Standards are met through the learning objectives. Specifically, Content Standards A-G are met; Teaching Standards A-E are met; and Assessment Standards A &C are met. Particular highlights include the adaptivity of the curriculum to suit the students, the inquiry based learning, the self-assessment of learning that the students go through, the extended length of the investigations and the perseverance that students developed, as well as the authentic assessments.

Necessary Materials:

While no particular activity is essential to the success of this module, given the ideal conditions a classroom would require the following materials:

- ✓ an ECG machine or a set of TI graphing calculators with the Vernier ChemBio program, a set of Texas Instruments CBLs (Calculator Based Laboratories), and Vernier ECG sensors (strongly recommended)
- ✓ Interactive Physiology Software's cardiac module (entirely optional)
- ✓ Three-dimensional heart model (recommended)
- ✓ Galvanometer (0 to 25mV), 2 forty-cm strips of copper wire, 400mL beaker, 3M sodium chloride solution, 22-cm strip of dialysis tubing, 3M potassium chloride solution, rubber band for the "Constructing a Model of Nerve Cell Transmission" experiment published by Evan P. Silberstein in the January 1981 issue of The Science Teacher (recommended)
- ✓ Conductive paper, conductive ink pen, conductive tacks, corkboard, voltmeter or calculator, CBL, and voltage sensor for the electric field lab (recommended)

Project Phases:

The grand challenge introduces the curriculum unit. This grand challenge is then followed by three challenge questions that guide students to answer the grand challenge question. Each challenge question follows the Legacy Cycle (Schwartz, D. L., Lin, X., Brophy, S., & Bransford, J. D. (1999) Toward the development of flexibly adaptive instructional designs. In Reigeluth (Ed.), Instructional Design Theories and Models: Volume II. Hillsdale, NJ: Lawrence Erlbaum Associates. http://peabody.vanderbilt.edu/ctrs/ltc/brophys/legacy1.html).

The Legacy Cycle is composed of six different phases of learning, beginning with the aforementioned challenge question. The next stage is to "generate ideas" where students talk about what they already know about the challenge question. "Multiple perspectives" are introduced, allowing experts to point out ideas that students may not have considered and to guide their initial learning. The stage "Research and Revise" allows students to pursue the areas in which they identified as useful and relevant. This stage usually consists of teacher lectures, laboratories, demonstrations, homework, etc. "Test Your Mettle" is the stage where students begin to state their newly discovered information in a way that receives feedback from the instructor. Students may return to 'Research and Revise" after testing their mettle. Finally, students "Go Public" with their final answer to the challenge question.

It is important to note that this curriculum is specifically designed to be flexible. A teacher may decide to omit particular activities if the learning objectives of that particular activity do not meet the learning objectives of the class or if the material is too difficult.

The following paragraphs describe the learning cycles for this curriculum unit in more detail. A general timeline for implementation follows the legacy cycles.

Grand Challenge: Suppose one of your teachers visits his doctor and, as a part of a routine exam, he has his electrocardiogram (ECG) measured. The results are shown below. Should your teacher be concerned about these results?

Challenge 1: How does the heart beat and why?

Generate Ideas: Journal topics - What are your initial ideas about how this question can be answered? What background knowledge is needed? What do you know about the heart already?

Multiple Perspectives: Evaluate journal entries. Did students see the need for a clear understanding of the normal heart's anatomy and physiology? Work with the students in a discussion format to create a plan of action and required knowledge.

Research and Revise: Students will learn about the heart's normal anatomy and physiology and the cardiac cycle. You may choose to use the Interactive Physiology program or traditional methods (texts, lecture, physical model of heart) to accomplish these tasks.

Test Your Mettle: You may give the Interactive Physiology's cardiac cycle quiz if this program has been used or a written quiz on the basics of heart's normal anatomy and physiology and the cardiac cycle.

Go Public: Students design (but do not actually build) an artificial heart that accomplishes the same things that the heart normally does. The students need not worry about the viability in the human body of the materials they choose. Instead, they are free to be creative and to focus on creating appropriate pressures, timing, and oxygenation in the heart. Each student should write or give an oral report relating the analogous structures and function between their heart and a real heart.

Challenge 2: What does an ECG measure? What information is reflected in the normal ECG?

Generate Ideas: Journal topics - What are your initial ideas about how this question can be accomplished? What background knowledge is needed? What do you know about the ECG already? If the doctor showed this trace to your teacher, how should he start to read this trace? How do you think the ECG relates to the cycles of a beating heart?

Multiple Perspectives: Evaluate journal entries. Consider asking a cardiologist to visit with the class or interview him/her on tape ahead of time. Did students see the need for a clear understanding of the normal ECG? Is understanding how an ECG is created and what it measures important? Work with the students in a discussion format to create a plan of action and required knowledge.

Research and Revise:

- What does an ECG measure? Discuss the action potentials in the heart's cells and the heart vector. Perform the lab measuring a membrane potential across dialysis tubing ("Constructing a Model of Nerve Cell Transmission" by Evan P. Silberstein. January 1981.The Science Teacher).

- Teach students about the heart's conduction system and how it normally works. Use the Interactive Physiology program or traditional methods (textbook, lecture, etc.) to do this.

- How does an ECG measure normal electrical activity? Look at Einthoven's triangle and how it measures the heart vector. Review the development and history of the ECG.

- What does a normal ECG look like and why? Learn about P, QRS, and T waves and how the heart creates these shapes.

- How is an ECG actually created? Learn about electrodes and the basic layout of an ECG machine. An article by Shawn Carlson in Scientific American (June 2000) article shows how to build your own crude ECG circuit if you are interested.

- What does my ECG look like? Do an ECG lab with students using the CBL, TI graphing calculator, and Vernier ECG sensor or an actual ECG machine.

Test Your Mettle: You may use the Interactive Physiology's Quiz on the Intrinsic Conduction System (optional) if you chose to use this software. Students may also turn in the ECG Lab for evaluation.

Go Public: Students design a tri-fold brochure for the purpose of instructing patients and relatives on what an ECG measures, how it is done, what a normal one looks like, how it helps in the assessment of the heart's conduction system, and any patient/safety concerns.

Challenge 3: How can the ECG reflect abnormalities of the heart structure and rhythm?

Generate Ideas: Journal topics - What are your initial ideas about how this question can be accomplished? What background knowledge is needed? What do you know about the ECG already? How could we monitor changes in the heart?

Multiple Perspectives: Evaluate journal entries. Possibly revisit the expert interview if available. Did students see the need for a clear understanding of the normal ECG before answering this question? Is understanding how an ECG is created and what it measures important? Work with the students in a discussion format to create a plan of action and required knowledge.

Research and Revise: If the heart's conduction system is altered, how will it affect the ECG readings? Introduce students to the topic with the list of famous people who have cardiac arrhythmias. Study various cardiac diseases. Learn about their basic changes in physiology and anatomy and how those changes are seen on the ECG.

Test your Mettle: Students will each present one abnormal ECG to the class. They should focus on what happens in this disease and how it affects the ECG. What happens physiologically and/or anatomically? How do these changes affect the ECG? What causes this disease? Specifically, what changes are seen in the ECG and why?

Go Public: Students answer the grand challenge question as to whether or not the teacher should be concerned about the ECG reading obtained at his last doctor's appointment. If there is cause for concern, why do they think so? What might be wrong?

Timeline:
Day 1 - Introduce the Grand Challenge and Challenge 1 questions. Have the students independently work in their journals to answer the Generate Ideas questions. If possible, have journal responses submitted electronically so that all entries can easily be pulled into one document.

Day 2 - As a class, review all journal entries. On the board, record the needed knowledge areas that students identified. Also record any specific ideas that were generated. Guide students to see that they must first understand the normal anatomy and physiology of the heart. If available, use the Interactive Physiology Program to learn about the heart's anatomy. Specifically, students should use the Anatomy Review in the Cardiovascular section. Students will learn the path of the blood and which chambers receive oxygen-rich blood and which chambers receive oxygen-poor blood. In lieu of the Interactive Physiology program, one may use traditional methods of teaching (texts, lecture, etc.) If possible, have a three-dimensional model of the heart available in the room as well for tactile and visual learners.

Day 3 - Use Interactive Physiology to study the cardiac cycle. Have students take the Quiz at the end of the section. In lieu of the Interactive Physiology program, one may use traditional methods of teaching (texts, lecture, etc.) to cover the cardiac cycle.

Day 4 - Review normal anatomy, physiology, and the cardiac cycle. You may also wish to read and review two articles from Natural History (April 2000) on the evolution of the heart here. These articles are entitled, “The Hidden Unity of Hearts” by Carl Zimmer and “As the Beat Goes On” by Warren Burggren.

Day 5 - Students take a written quiz on basic heart anatomy, the path of the blood through the heart, and the cardiac cycle. For homework, have students do the Go Public exercise for Challenge 1. Introduce Challenge 2. Have the students independently work in their journals to answer the Generate Ideas questions. If possible, have journal responses submitted electronically so that all entries can easily be pulled into one document.

Day 6 - As a class, review all journal entries. On the board, record the needed knowledge areas that students identified. Also record any specific ideas that were generated. Conduct a cardiologist interview if possible and add to ideas. Develop a plan of study. Use the Interactive Physiology (IP) program to study the Intrinsic Conduction System of the heart and the ECG. Have students take the IP Quiz at the end of the section. In lieu of the Interactive Physiology program, one may use traditional methods of teaching (texts, lecture, etc.) to study the conduction system of the heart and the ECG.

Day 7 - Discuss the term electrocardiogram. What does each part of the word imply? Does the heart contain or conduct electricity? How? Why? Perform the lab or do as a demonstration the “Constructing a model of nerve cell transmission” lab from The Science Teacher, January 1981.

Day 8 – Students do a lab illustrating basic electric fields. Pasco produces such a lab.

Day 9 - Lead students in a lesson on action potentials and how they work on a cellular level so that they understand the electrical basis of the ECG.

Day 10 - Have students complete/repeat the IP Quiz on the Intrinsic Conduction System to see that they have retained the information. If you have not already, give students a hard copy of the figure (p.154) from Guyton and Hall’s Textbook of Medical Physiology. (WB Saunders: Philadelphia, 2000) that ties together the ECG with the pressures and volumes found in the heart's chambers through time.

Day 11 - Students should now have a basic idea of what the normal ECG looks like, yet they may not know why it looks that way or how the ECG actually measures the electrical activity of the heart. Discuss the fact that many cardiac cells are depolarized at once as the electricity passes from chamber to chamber. This process creates a single heart dipole or heart vector, whose tail is at the center of the heart, which is simply the sum of all the electrical activity in the heart at that moment in time and whose vector head moves from chamber to chamber. It is this heart dipole that the ECG measures and records. Discuss Einthoven's triangle and what the leads record. Review the development and history of the ECG.

Day 12 - How do electrodes actually measure voltage? How does the ECG only measure the electrical activity of the heart and not get readings/interference from the muscles, nerves, eyes, brain, etc.? Discuss these questions by teaching students how an electrode converts ionic current to electronic current and comparing the frequencies of different biomedical signals. The article by Shawn Carlson in Scientific American (June 2000) describes a circuit that can allow you to measure your own ECG. You may wish to take the time to read this article and/or do this project.

Day 13 - Further look at the ECG. Study the normal timing and voltages of the P, QRS, and T waves.

Day 14 - Students do their own ECG either with a real ECG machine or Vernier's ECG sensor. The isoelectric (zero) line tends to wander with the Vernier probe. You may try experimenting with having students sit or lie down or perhaps holding their breath, although sitting has been found to work well.

Day 15 - Students analyze their own ECG timing and voltages.

Day 16&17 - Students turn in the ECG Lab. Introduce Challenge 3. Have the students independently work in their journals to answer the Generate Ideas questions. If possible, have journal responses submitted electronically so that all entries can easily be pulled into one document. As a class, review all journal entries. On the board, record the needed knowledge areas that students identified. Also record any specific ideas that were generated. Re-read the expert interview and add to ideas. Develop a plan of study. Review the list of famous people with cardiac arrhythmias to foster more interest in the topic. Assign abnormal ECG project.

Day 17&18 - Students present their abnormal ECG assignments. Discuss major diseases and conditions that alter the ECG. What is wrong anatomically and how does that relate to electrical activity and what the ECG reads?

Day 19 - Students work on essay response to Grand Challenge Question.

Day 21 - Grand Challenge Question response due.

Assessment Criteria and Expectations:

The artificial heart design project should be evaluated for creativity, accuracy, and depth of explanation in the following manners: Does the heart have four chambers, or does it have some other means of having part of the heart fill with returned blood and part of the heart emptying new blood into the body at the same time? Does the heart have a means of controlling flow with varying pressures? Does the heart have a means of separating filling from emptying chambers? Does one side of the heart have oxygen-poor, carbon dioxide-rich blood that is pumped blood to the lungs? Does one side of the heart have oxygen-rich, carbon-dioxide poor blood that pumps blood to the body? Each of the main arteries, veins, and chambers should have an analogous structure within the artificial heart.

The ECG Patient Brochure should include what an ECG measures (explain basics of the heart's changing voltages, electrodes detect potential differences, ECG machine prints out the changing voltages during each heartbeat). It should also explain how an ECG is done, including where the leads are placed and what type of recording is produced. The brochure should explain what a normal ECG looks like including the shape of the P, QRS, and T waves and their relationship to the heartbeat, as well as a diagram with average timing, voltages, and shapes of the waves. How an ECG helps in the assessment of the heart's conduction system should be addressed including an example of how changes in timing and shape indicate disease. Any patient safety concerns should be addressed. Lastly, creativity, readability, and clarity should be assessed.

The Grand Challenge itself should be assessed primarily by stating whether or not the teacher should be concerned (they should be monitored, but their condition, atrial fibrillation, is not usually life threatening). The students will explain how they know that the teacher is not in grave danger and state what they think is wrong with the teacher with specific support from measurements off of the ECG. The student's work should also be assessed for clarity and style.

Expected Results:

The expected results are that the students will understand electric fields and cardiac anatomy and physiology in a much more meaningful and deep manner than a 'typical' physics or biology classroom would create. The students will also see the integration of the sciences and technology and learn how biomedical engineers work through and solve a problem. Lastly, students will learn perseverance for a problem through the extended study of this curriculum module.

Handouts - Electrocardiogram Lab:

- After wiping your skin dry with a paper towel, each student should place an electrode on the inside of his left wrist, right wrist, left ankle and right ankle. Each subject should be seated. He or she should remain very still, relaxed, and quiet, and should not change breathing patterns during data collection.
- Connect the CBL and the ECG sensor to your calculator. Run the CHEMBIO program on your graphing calculator. Set Up Probes by choosing one probe and selecting the ECG sensor. Follow additional instructions on the calculator screen. To obtain Lead I: Attach the negative wire to the subject's right wrist, positive wire to the left wrist, and reference to the right ankle. To obtain Lead II: Attach the negative wire to the subject's right wrist, positive wire to the left ankle, and reference wire to the right ankle. To obtain Lead III: Attach the negative wire to the left wrist, positive wire to the left ankle, and reference wire to the right ankle.
- Print a copy of each Lead, using Graphical Analysis if possible, and carefully attach your data to your lab report. Remember that every time you take data, you overwrite the last set of data. Be sure to either save your data in a program or print your data before recording more!

1. What is the horizontal (independent variable) axis's unit of measurement?

2. The vertical (dependent variable) axis is measure in volts (amplified). What is the mV/V ratio?

3. Where is the isoelectric line on your ECG tracing? In other words, is 'zero' really zero mV? How does the position of the isoelectric line affect any voltages you read off your graph?

4. For each lead that was done on you, identify the lead on the ECG tracing you turn in. Clearly label the P, QRS, and T waves in each lead on one heartbeat. Also, label the axes and their units on each graph.

5. Measure and tabulate the following durations and intervals. Record the shape and polarity when asked for a description. Heart rate can be calculated from the R-R interval by dividing 60 by the time in seconds of the R-R interval.

LEAD	I	II	III
P-wave Duration			
Description of P-wave			
P-R Interval			
QRS Duration			
Q-T Interval			
Description of T-wave			
R-R Interval			
Heart Rate			

6. Measure and tabulate the amplitude of P, Q, R, S, and T in the table below.

LEAD	I	II	III
P (mV)			
Q (mV)			
R (mV)			
S (mV)			
T (mV)			
PR Segment			
ST Segment			

7. How do your P-R and Q-T intervals compare with the average value? Does your heart rate fall in the normal range for adults?

Resources:

- Vernier – www.vernier.com or 503-277-2299 (ECG sensors, ChemBio calculator program)
- Texas Instruments – http://education.ti.com or 800-TICARES (graphing calculators and CBLs)
- Interactive Physiology – www.interactivephysiology.com or 800-456-0179 (software)
- Carolina Biological – www.carolina.com or 800-334-5551 (heart models)
- Pasco – www.pasco.com or 800-772-8700 (conductive ink pen and paper)

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