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Physics Education Research

Pedagogical Goals for Teaching about Alexander Graham Bell's Metal Detector

The Modern Miracle Medical Machines (MMMM) project at Kansas State University aims to teach physics in the context of medical imaging. Curricular activities incorporating both hands-on activities and computer visualizations have been developed or are being developed to teach wave front aberrometry, positron emission tomography (PET) scans, computed tomography (CT) scans, and magnetic resonance imaging (MRI). Because of its novelty of being the first attempt at medical imaging, work has begun on an additional activity teaching about Alexander Graham Bell's attempt to find the bullet in President Garfield. In this activity, we recreated Bell's apparatus. We then developed a lesson plan for students to work through covering topics in electricity and magnetism, with the end goal of understanding Bell's apparatus. The intent of this research project is **t**o provide pedagogical strategies for teaching electricity and magnetism to students through this hands-on experiment.

Historical Background to the Project

When the president of United States wanted to travel in 1881, he took the train. While President James Garfield was standing alone on a train platform in Buffalo, New York, a person approached and shot him. President Garfield was a hefty guy and physicians could not determine if the bullet had hit a vital organ or not. In the 19^{th} century, physicians were ignorant to the use of gloves or sterilization and did not have knowledge of helpful modern surgical methods at that time. Physicians used tactics such as sticking their unsterilized fingers in President Garfield's wound in an attempt to find the bullet, causing infection in the process. [1]

Alexander Graham Bell had just invented the telephone and he insisted on trying to use his recent discovery on President Garfield, converting it into a metal detector to detect the bullet inside of him. Alexander Bell used a battery, two coils of insulated wire, a circuit breaker, and one telephone in his apparatus. Bell invented the induction balance to cancel out line interference on his telephone, and he noticed that they could easily be driven out of balance by a nearby piece of metal.[2] Bell's plan was to construct inductance coils to move around President Garfield's body. The coils were connected to the telephone. When the coil came close to the metal bullet,

the inductance would change and the frequency heard on the telephone would also change. This change was very small and difficult to hear. Bell used a bridge circuit to minimize that problem. The bridge circuit was balanced, meaning that no sound would come through the telephone until the inductance of one part of the circuit changed. When the inductance changed, sounds would easily be heard over the telephone. [3]

Bell's attempt failed to find the bullet because, unbeknownst to him, President Garfield was lying on a newly invented inner spring mattress. After President Garfield died from the lack of medical technology, Alexander Bell used a piece of meat and detected a flat bullet inside of it to assure that his metal detector was actually working.

Rebuilding Bell's Experiment

After studying all of Alexander Bell's papers we began to conduct the same experiment, but with up-to-date technology. The goal was to construct Bell's circuit and listen for changes in tone when one of the coils was passed over a piece of metal.

Bell's circuit is essentially a Wheatstone bridge circuit with inductors in place of the resistors and the DC voltage source replaced by an oscillating one, as shown in Figure 1. [4]

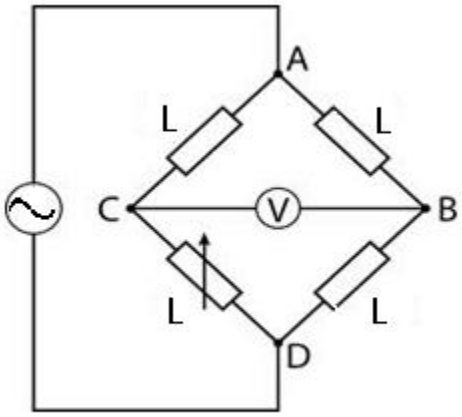

Figure 1: Wheatstone bridge circuit modified to replicate Bell's experiment.

Initially, an oscilloscope was used to monitor the circuit. We tried to see when the circuit was balanced no current, but we saw an increase or decrease when we inserted the metal inside each coil. Confused we disconnected the oscilloscope from the circuit and hooked up speakers. Doing so, we discovered that when the circuit is balanced there was no sound produced by the speakers. When metal was inserted inside the coil the circuit became unbalanced and produced a tone. After connecting the speakers to the circuit, we realized that the oscilloscope was either not reading correctly or it was showing the small imperfections of the circuit.

We used different approaches to detecting metal. We tested three different inductors: 200, 400, and 800 turns, to determine which will create a better, louder, and clearer sound for detecting the

metal. The 800 turn inductor proved to be the best because it has the greatest amount of coil. After figuring that out, we wanted to see if you could hear a difference based on how far away the coil was from the metal. We also tried putting a cardboard top over the coil to see if we could still hear a change.

Creating a Lesson Plan

Once we have found out how to use our circuit, we began to write a lesson plan for teaching this experiment to the students. As compared to or listening to a lecture we want the lesson we develop to be as hands-on as possible. Additionally, students learn better when they see the same thing multiple times in multiple contexts. Thus, we will attempt to approach the same concept in different ways. [5]

Bell's experiment is based upon a circuit. It therefore seems logical to begin the lesson by having students investigate circuit basics. We want students to begin with examples of how circuits work through two different activities: hands on and simulations. The goal of learning the properties of electric circuits is to help students understand the properties of electric circuits (like voltage, current, resistance, etc…), analyze the differences between real and simulated circuits, build circuits from schematic drawings, use a multi-meter, and provide reasoning to explain the measurements and relationships in circuits. Students should also acquire information on how to to apply Ohm's Law and the concept of electrical circuits to determine how a circuit puzzle is wired, measure and calculate the resistance of an object, and describe how energy output changes with resistance. Other goals students should meet in this experiment are determining how total resistance changes when the number of resistors change, transform at least two ways in which resistors or light bulbs may be connected in a circuit, study how the resistance of a circuit changes when the length of wire in the circuit changes, and learn how the power and energy of a circuit differs for different types of connections. Lastly students should attain knowledge on how to understand how inductance is formed and how to build inductance in a circuit, to describe the operation of telegraph using the idea of an electromagnet and describe how an electric current may be produced using only a magnet and a coil of wire and know what things the magnitude of the current depends on.

After the students have completed the lessons, they can begin to learn about some more applications that will apply to Bell's metal detector. Bell used a bridge circuit so that no sound would come through the phone, but in order for that to happen the bridge circuit has to be balanced. Introducing Kirchhoff's Law to students will provide students with the reason how and why things work the way they do in a Wheatstone bridge circuit.

Kirchhoff's Laws are the sum of the currents entering any junction must equal the sum of the currents leaving that junction and the algebraic sum of the changes in potential across all of the elements around any closed circuit loop must be zero. [6]

Students' knowledge of Kirchhoff's Laws will help them more easily become comfortable with bridge circuits. The Wheatstone bridge circuit is ideal for this. With it, students can find the unknown current flowing through the circuit using Kirchhoff's Laws. After students develop an understanding about this, then the next step is to replace the resistors in the circuit with

inductors, creating a circuit similar to the one that Bell used when attempting to find the bullet in President Garfield.

We can recreate Bell's attempt with the Teddy Bear Experiment. Students will attempt to detect a piece of metal that has been misplaced in the teddy bear by the factory. Our summarizing question for the lesson could be: "How did you determine where the metal is located in the teddy bear?"

Future Work

Further work will be needed on this experiment. First, we need to write-up a worksheet based activity that students can work through. Then, we need to have students work through the activity. We want to know if the experiment was helpful for learning the material, which parts they enjoyed or were confused by, and if they have any thoughts on ways to improve the activity their feedback is essential and could help physics teachers to better instruct students. Based on their performance and feedback, we would iteratively improve the lesson.

References

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