
AC 2012-4572: SPY CODE: A LEARNING MODULE LINKING NANOTUBES RESEARCH EXPERIENCE TO

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The Spy Code: A Learning Module Linking Carbon Nanotube Research to Teaching Algebra

Abstract

This paper focuses on presenting the experience of a mathematics teacher participating in a Research Experience for Teacher program at Texas A&M University-Kingsville. The research experience was focused on carbon nanotubes (CNTs) as suitable replacements for transistors. As transistors, they would be smaller, faster, less resistant, and cheaper to manufacture than anything currently in use. The greatest problem with studying CNTs and producing new electronics with CNTs as the chief component has been their size. Little experimental research has been conducted on actual CNTs to measure their output currents when voltages are applied to them. This research focused on collecting and presenting data on the electrical properties of bundles of CNTs, particularly in regards to how CNTs respond to the presence or absence of light.

Finding a link between this research experience based on sophisticated equipment and advanced electronics and teaching algebra has been a challenge. The paper describes a learning module that is based on simplified models of CNTs. It challenges the students to use simple electronic circuits to design and implement secret codes of blinking lights. The modules are based on the concept of the Legacy Cycle. It covers various topics in algebra including graphing lines, finding relations, solving equations, and manipulation of monomials.

Introduction

During the summer of 2011, the teacher participated in the Texas A&M University-Kingsville (TAMUK) Research Experience for Teachers (RET) project. This involved conducting research alongside graduate student, Divya Thummelapally, under the supervision of Dr. Reza Nekovei. The research focused on studying and recording various voltages as they pass through carbon nanotubes (CNTs). Since little experimental research had previously been done in this area, the teacher was literally a pioneer. As a mathematics teacher, she had never been a member of a research team nor worked long hours in a laboratory. She had no prior knowledge of electrical engineering going into the summer research program and experienced a steep learning curve. The teacher had a whole new set of terms and abbreviations to absorb, a new computer system to learn, and an adventure ahead of her wrapped up in the coils of CNTs that she could not even see under her microscope. The summer was stressful, but invigorating and renewed her confidence in her intelligence and her enthusiasm for teaching.

CNTs are coils of carbon atoms, similar in structure to graphite, on the nano scale². Their uses seem almost limitless, as CNTs with different diameters, lengths, and chirality (degree of twist) have different electrical properties ranging from insulating to conducting³. It is possible that our transistors of the future will be made almost entirely out of carbon, one of the most abundant and cheapest elements on the planet.

Since the discovery of CNTs the research community has been excited by the plausible uses of these tiny devices. CNTs may very well be the wonder material of the future; they are stronger than steel, more conductive than copper wire, and have various properties such as light emission, heat resistance, and water resistance¹. With so many varying capabilities, scientists and engineers in multiple fields have turned their attention and resources towards growing and studying these tiny structures. For this project, the possibility of replacing silicon transistors with these much smaller CNTs has been of prime focus. Most research on CNTs has been done thus far on computers, through the process of simulation and modeling. In this project, actual samples of carbon nanotube bundles (CNTBs) have been studied by running various voltages through them and recording the output currents.

However, one of the major problems with studying CNTs has been their size. CNTs are little more than carbon atoms, bound together into a hexagonal pattern and rolled up into the shape of a tube. Regular microscopes cannot magnify down to the level of atoms. In order to “see” things that are so tiny, researchers must turn to much stronger magnifying devices, such as the Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and Atomic Force Microscopy (AFM). Only then can calculations of their diameters and chirality (two of the most important physical properties in terms of calculating their electrical properties) be made. An SEM, which magnifies by shooting electrons at samples and recording the speeds at which these electrons return in order to form a picture, was available for this project. Unfortunately, the pictures captured by the SEM (see Figures 1 and 2) were not clear enough to calculate these measurements exactly; atomic resolution can only be observed with high resolution of a TEM. This means that all tests of these CNTBs were conducted without knowing the physical structures of the CNTs making up the bundle.

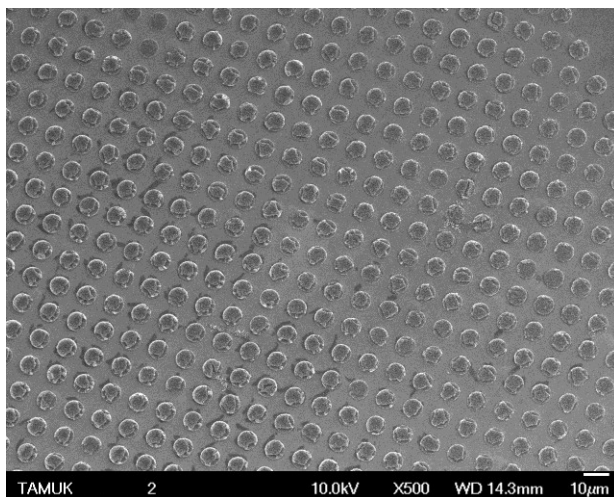


Figure 1: SEM image of CNTBs magnified 500 times

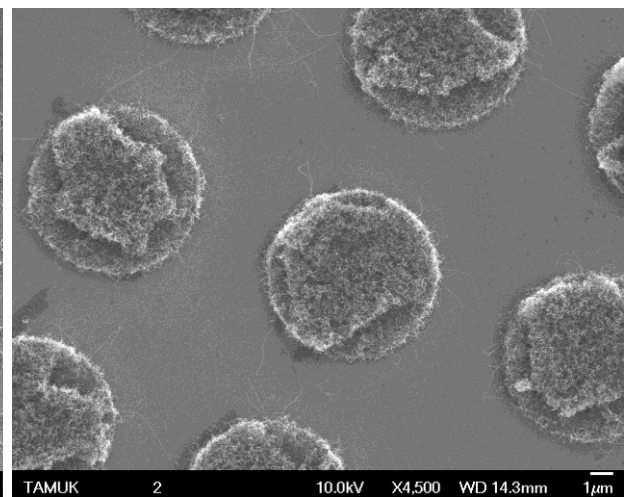


Figure 2: SEM image of CNTBs magnified 4500 times

After determining what a CNT “looks” like, researchers are still faced with the problem of separating one CNT from the next in order to study them individually. The samples used in this project came from Georgia Institute of Technology. The CNTBs were grown in etched pits on a silicon wafer. Even the strongest optical microscope and the scientist with the steadiest hand

could not take apart CNTBs without destroying their sample. “The isolation of individual nanotubes, is possible only by ultrasonic exfoliation of bundles in water surfactant dispersions”⁴. The researchers working on this project lacked access to the equipment needed to perform this procedure. For this reason, these tests have been conducted in such a way as to treat CNTBs as a single unit, resulting in data which should be the average of the CNTs studied.

Methodology

Prior to testing the CNTBs, the accuracy of machineries to be utilized was checked using known samples before the implantation of the required tests on CNTBs. Subsequently, all tests on the CNTBs were conducted using a Keithley Model 4200 – SCS Semiconductor Characterization System (SCS) and a Karl Suss PM5 Probe Station (a manual probe station). Only two probes were available so only two terminal devices could be studied.

The first tests of resistors resulted in noise until the wires connecting the probe station to the SCS were connected to the force outlets on the back of the SCS. Then, linear data was compiled which appropriately measured the rates of change of the resistors being tested. Further tests of diodes also returned expected data, so testing began on the nano samples.

In order to test the CNTBs, one probe station contact was placed on the silicon (to act as a ground) and the other at the top of a bundle of CNTs. Before running these tests, two “error” tests were conducted. For the first test, each probe station contact was placed on the silicon wafer, in case a test was later run in which the tester overshot the top of the CNTB and touched silicon with both probe station contacts. The second test was run with one probe station contact on the silicon wafer and the other in the air, in case the tester were to accidentally hover over the top of a CNTB without making contact. Each of these tests was of a voltage sweep from -0.5V to 0.5V and recording 201 points in a step of 0.005V. These tests were run so that these errors could be recognized and avoided during testing.

The first tests of CNTBs resulted in graphical representations that made evident a lot of noise (spikes) and were so chaotic that no conclusions could be made from them. Through experimentation, it was determined that much of the noise was created by unnecessary vibration on the table where the probe station rested and in the room, near the probe station. Spikes were recorded in the data whenever the slightest disturbance occurred, including the air conditioner turning on, the door opening or closing, and the person running the tests standing up or lifting an arm or a leg. In order to minimize these disturbances, tests were performed with one person in the room, sitting silent and still while the tests ran. The speed at which the test was conducted also had a huge effect on the validity of the graphs created. In order to determine the best speed, each test was run multiple times on the same site, varying the speed. Graphs compiled from data at normal and fast speeds (default speed options in the SCS) showed more consistent data than graphs of tests at the quiet speed. During the course of research, it was suggested that the presence of light may interfere with the validity of the data collected. In order to test this theory, tests were run with the lights on and again with the lights off (the room was never pitch black, as one light near the door could not be turned off, the window in the door let in light from the hallway, and the SCS screen gave off light, since it had to be on during the testing). Additional tests were also conducted in which the size of the probe station contacts were varied between T-

4-5 and T-4-22 or the placement of the wires connected to the SCS were switched between force and sense.

Three tests were conducted on the CNTBs. The first was a voltage sweep from -0.5V to 0.5V and recording 21 points in a step of 0.05V. This test was conducted at all three speeds (quiet, normal, and fast). The second test run was a voltage list sweep from 0V to 1V and recording 11 points in a step of 0.1V. This test was conducted at two speeds (normal and fast). The first two tests resulted in data comparing voltage to current. The third test was a current bias with the voltage level set to 3e-12 amps and the compliance set to 30V. This test was conducted at two speeds (normal and fast) and resulted in data comparing voltage to time.

Results

Following are some of the results collected, selected due to their small amount of noise. Each test was conducted six times, three times with the lights on and three times with the lights off. In Figure 3, a consistent relationship which appears to be exponential was found between voltage and current while running a voltage list sweep, regardless of the amount of light present during testing. The T-4-5 probe station contacts were used during this test and the connecting wires were plugged into the force outlet on the SCS.

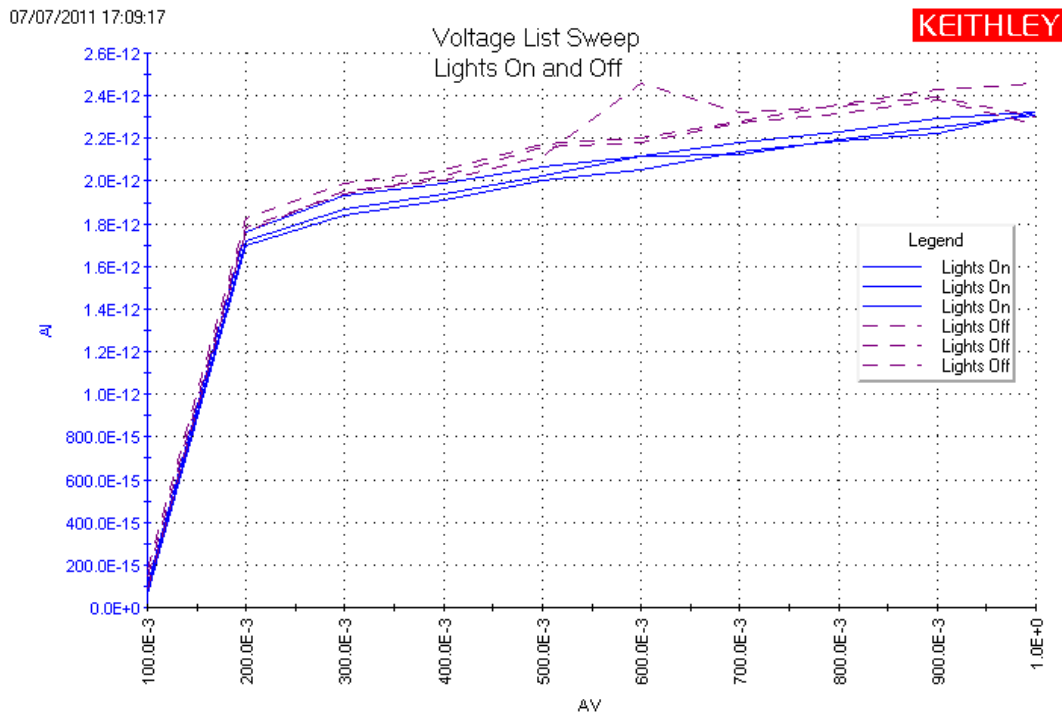


Figure 3: Voltage List Sweep Using small probe station contacts and the force outlet connection

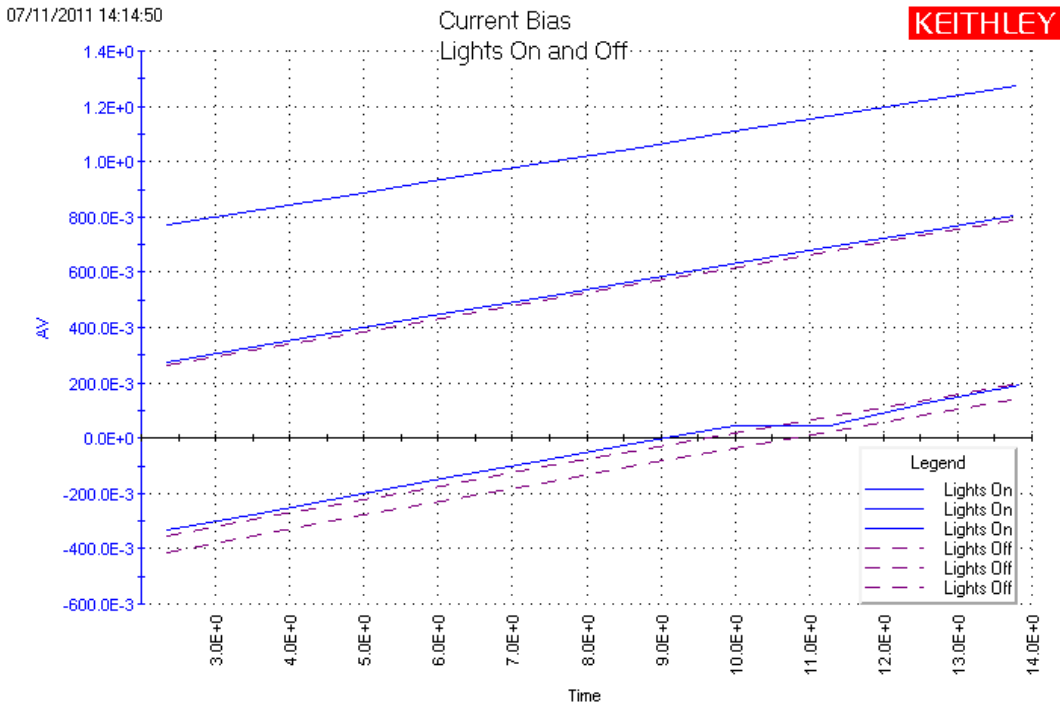


Figure 4: Current Bias Using small probe station contacts and the sense outlet connection

Figure 4 also presents a graph of data compiled using the smaller set of probe station contacts, though the wiring connecting the SCS and the probe station was connected to the sense outlet. Most current bias tests performed resulted in data similar to this graph, especially when run at the normal speed, as this graph was. It can be seen that the relationship between voltage and time is linear with a consistent rate of change throughout. Regardless of whether the CNTBs were tested with the lights on or the lights off, the same rate was recorded in each test, suggesting that voltage and time are directly proportional.

When using the T-4-22 probe station contacts, the current outputs during voltage sweep and voltage list sweep tests were not consistent with data collected while using the smaller probe station contacts. Instead of recording similar data throughout the six tests, vastly different ranges were recorded with the lights on versus the lights off. There was still consistency between the three tests conducted with the lights on (see Figure 5) and the three tests with the lights off (see Figure 6), but the range of current output jumped up considerably when the lights were turned off and the same stack of CNTs was tested. Figure 7 offers an average of the previous two graphs, which were graphs of the same test. The range is so different between the two sets of data that the line recording the output current with the lights on appears to be a flat line, even though it is actually increasing, as seen in Figure 5. These findings of differing current outputs based upon the amount of light present were unexpected and should be studied further.

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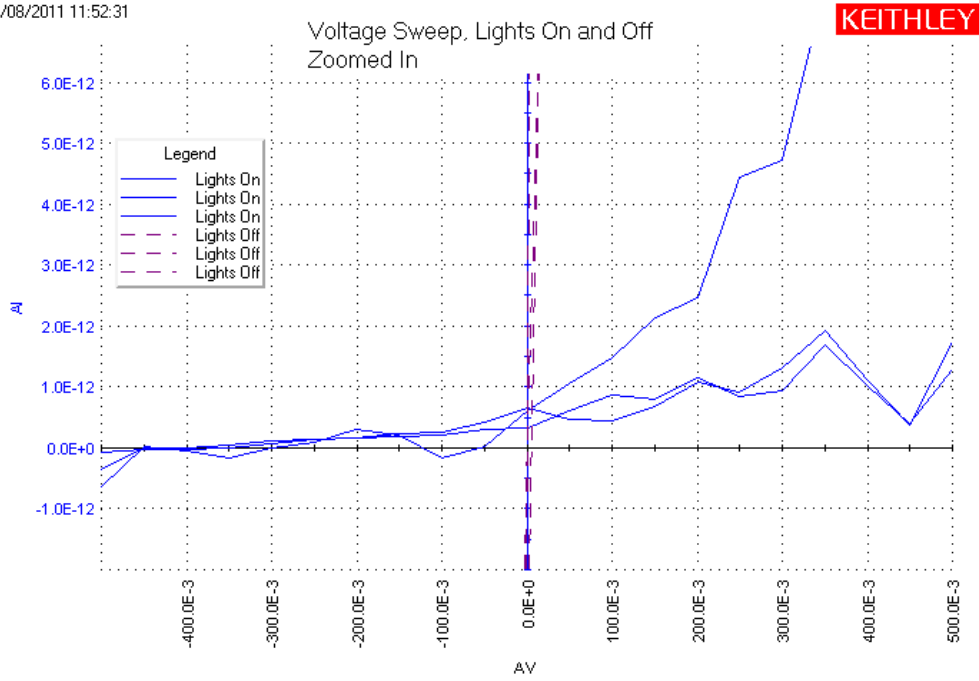


Figure 5: Voltage Sweep Zoomed in on the section of the graph showing the response with the lights on

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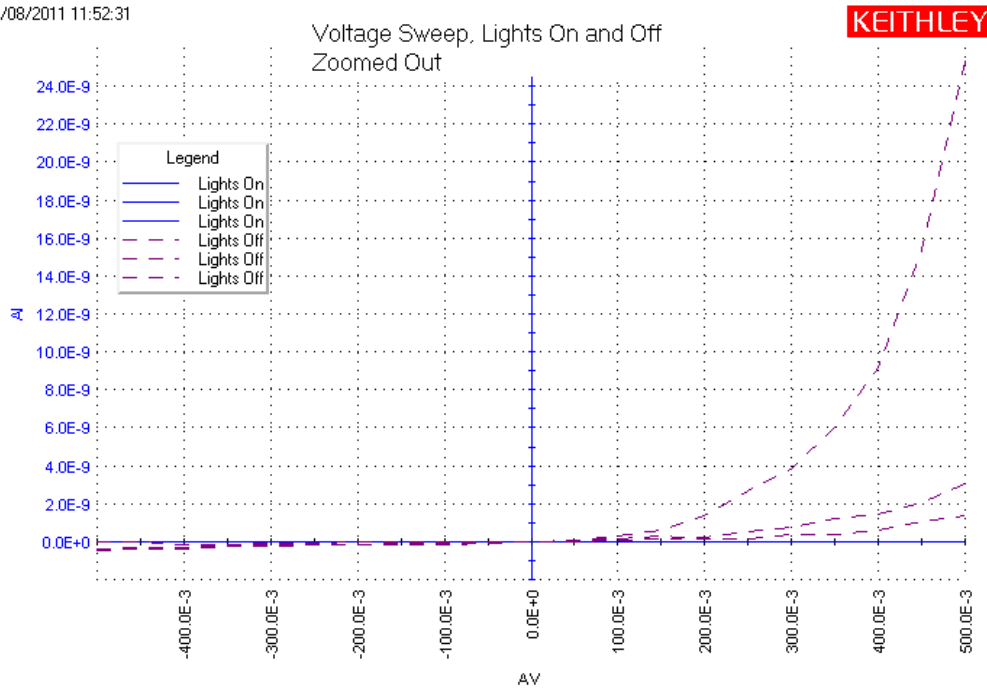


Figure 6: Voltage Sweep Zoomed out to show the response with the lights off

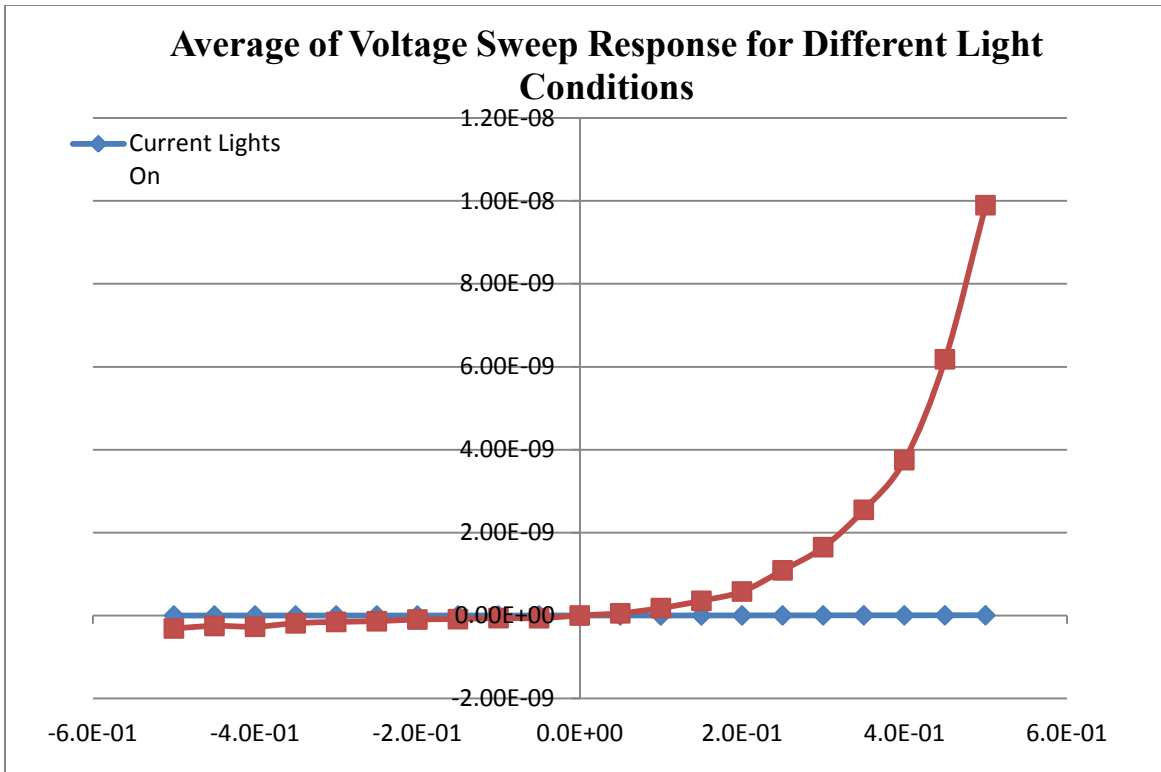


Figure 7: Average of Voltage Sweeps Showing the change in response when the lights are on or off

Research Conclusions

These conclusions are based upon a small data set and may be disproved through further study and research. In an effort to experiment with light, interesting data was recorded which seems to propose that CNTs are very responsive to light. By using the same voltage, but testing both with the lights on and the lights off, significantly different current outputs can be seen. These results happened most frequently when using probe station contacts T-4-22 (the larger set). It can be assumed that the larger probe station contacts were averaging a greater number of CNTs, resulting in more accurate data.

While using probe station contacts T-4-5 (the smaller set), the range of data collected with the lights on verses the lights off was not as great. The data consistently suggests that a current bias test will result in linear graphs with the same rates of change. A voltage list sweep test consistently results in a graph with a steep initial rate of change before leveling out, suggesting an exponential relationship.

Learning Module: The Spy Code

As part of the RET experience, the teacher was introduced to a new style of lesson planning called the Legacy Cycle. The cycle is based upon student-centered learning. Students are presented with a challenge question meant to spark their interest in the upcoming unit and to motivate them to learn. They are given an opportunity to generate ideas on what topics they need

to study and/or research in order to answer the challenge question. The students are presented with multiple perspectives of the topics they are about to learn. The learning begins with research, teacher lectures, group discussions, and revisions to the original ideas of the unit. Next is a section of the Legacy Cycle called “test your mettle” in which students are required to show what they have learned. This can be accomplished in a tradition paper and pencil test format or can be explored through projects, papers, or presentations. To finish out the Legacy Cycle, the students must “go public” with what they have learned, presenting their findings in front of their school or community through the format of a newspaper article, poster, or presentation. This will force the students to be accountable for their learning to their peers and community. Knowing that they must make a public presentation at the end of the unit should inspire the students to work harder to learn what is being taught. This paper will focus on the Legacy Cycle developed (named The Spy Code) and implemented by the teacher in her Algebra I classes during the 2011-2012 school year.

The Legacy Cycle will be implemented with approximately 55 students. 18 of the students are Algebra I Pre-AP students of which 10 are 8th graders and eight are 9th graders. The remaining students participating are Algebra I students mostly 9th graders with a few 10th graders who are repeating Algebra I. The school characteristics include student demographics of 59.9% Hispanic, 39.8% White, and 0.3% Asian/Pacific Islander; 55.7% economically disadvantaged; 0.6% limited English proficiency; 29.1% students with disciplinary placements; and 40.1% classified as at-risk. The participating students consist of approximately equal numbers of males and females and including students with a variety of learning levels and challenges including special education students, at-risk students, and students who have performed poorly in mathematics in the past and believe themselves to be unable to learn mathematics. In addition, the Legacy Cycle was extended for the 18 Pre-AP students who are more gifted since more is expected from them (Texas Education Agency, 2010).

Challenge Question:

When starting The Spy Code Legacy Cycle, the students are presented with the following challenge question:

You are an international spy. While abroad, you must have a way of communicating with your informant. You and your informant have agreed upon a set of blinking lights as your secret code. How do you set up a device to give off your own secret code of blinking lights?

Generate Ideas:

Following the challenge question, the students are asked to come up with ideas. It is important for the teacher to stress to the students that they are not just trying to answer the challenge question itself. They should not be able to answer the question until they have done more question asking and research. They should consider and answer such as What do you know?, What do you need to know?, and What do you need a refresher on?

The teacher should not discount any ideas that the students come up with, but she may have to guide them toward ideas they miss. They should realize that the question deals with electricity, and therefore, they need to learn new definitions and how to measure and set up electric devices.

The math required for this Legacy Cycle (which may require the teacher to teach or review, depending on which part of the year it is implemented) are exponents, monomials, graphing lines, writing equations, and solving for variables.

Multiple Perspectives:

In order to lend credibility to the teacher, the perspectives of others will be brought into the classroom. Electrical engineers and electrical engineering graduate students will be invited into the classroom to explain how resistors and capacitors are connected in parallel and series and to help students with their project. The teacher should also use other available resources, such as the physics teacher and websites explaining how electricity works. With the addition of multiple perspectives, the students may feel the need to go back and add more ideas.

Research and Revise:

The “research and revise” section of the Legacy Cycle is the “learning” phase. The students will test resistors and capacitors, both in series and parallel. In small groups, the students will measure the output currents using an AVOMeter and gather the data into tables. They will also calculate the resistance of various resistors based on their color codes (which should be presented as an additional code for the spy’s arsenal of secret codes) and practice adding, subtracting, multiplying, and dividing monomials when setting those resistors in series and parallel.

Additional practice, either presented in the form of lectures or group work, will be conducted on using the tables of values to graph lines, write equations, and solve for variables. After coming up with equations separately, the whole class will come together to evaluate and discuss their finds. They will need to determine the relationships they have found. The teacher will use this time to introduce some of the simple electricity formulas they have uncovered.

The students will also practice using their new skills in matching games where they must match graphs to tables to equations to word problems. Since these skills are so important in mathematics, and the Legacy Cycle lends to strengthening these skills, it will be a good activity to be used near the end of the “research and revise” section of the Legacy Cycle.

Test Your Mettle:

After spending a few days learning about electricity and graphing and evaluating the results, the students and their partners (informant) will be able to come up with their own code of blinking lights. They will present their projects on poster boards and explain the equations and graphs used to create their signature code. The Pre-AP students will also be asked to “decode” other students’ signals, trying to find out which resistors and/or capacitors were used in the design.

Go Public:

The students’ posters will be put on display, either in the classroom or in the student center. The students will also assist the teacher in writing an article about the whole experience which will

appear in the school paper and will be submitted to the newspaper, where it will hopefully be printed for the wider community.

Conclusion

The teacher will implement the Legacy Cycle in her classroom during the spring semester. The teacher's objective is to spark the students' interest in mathematics, science, and engineering. By presenting mathematics in a hands-on engineering project, the students' questions of "when am I ever going to use this?" and "why is this important?" will be answered. The goal of the whole experience is to show high school students just how fun and cool math and engineering can be. The teacher plans on integrating other subjects (primarily science and engineering) into her math classrooms as time passes and she learns and gathers more ideas about how math is connected to and used in other subjects and the real world.

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