

Introduction to Nanotechnology: An "Elementary" Education Program

Justin M. Bui
Greg S. Stutzman
David M. Beck
Dana Sharipova
Polina Kogay
Heather A. Budnik
Mark M. Budnik

1.0 ABSTRACT

Instructors at all levels of education are asked to introduce leading-edge concepts to their students. As part of our on-going outreach program, Valparaiso University's College of Engineering developed twelve hours of training material on nanotechnology for approximately 120 fourth and fifth grade students. To make such material accessible to young children, we developed a series of analogy-based lessons that focused on our state's fourth and fifth grade Science and Mathematics Standards. Our local school system offered the program in a series of two-hour sessions for three Saturday mornings. The curriculum for the program was developed by a professor in our College of Engineering who has research and pedagogical interests in the field of nanotechnology. The professor recruited nine undergraduate engineering students who were motivated to learn about nanotechnology and interested in sharing this knowledge with young students. The assistant superintendent of our community schools arranged the program's logistics, such as publicizing the program, reserving classroom space, and registering students. Our teaching techniques varied and included movies, stories, demonstrations, and projects. We provided a tangible macroscopic analogy for every nanotechnology topic we covered. In this paper, we introduce five of the lessons. Each was intended to be taught over a fifty minute

period. The lesson topics are nano-scale properties; Ohm's Law; one-dimensional conductors; scanning, tunneling electron microscopes; and digital logic. While these topics do not totally encompass the field of nanotechnology, they do represent a good mixture of theory and application. The students met approximately 90% of the objectives we set for the course. 67% of the students and parents returned a feedback form. On a scale of one (worst) to five (best), the students rated the course at 4.79. When asked if they would refer the program to a friend, all of the parents responded with a five.

2.0 INTRODUCTION

The technological world today is constantly evolving. Every year, new discoveries and improvements to previous technologies change the way we live. Nanotechnology is one field that is quickly advancing and impacting our daily lives. School systems often do not have the lesson plans or the funding necessary to teach students about these new technologies. Valparaiso University's undergraduate College of Engineering has developed simple, inexpensive, and efficient lesson plans to educate young students about the world of nanotechnology.

We structured our lesson plans around three main goals. The first and most important goal for the students was to learn and retain the information presented to them. Our next goal was to design lessons that were hands-on, active, and challenging. Our third and final goal was to observe the students' reactions and experiences with the lesson so that we may improve it for future classes. With these goals in mind, we were able to design five simple lessons that explain how nanotechnology affects the technological world.

The five lessons we developed were designed to take simple concepts and explain how they work at the nano-level. Since we choose to focus on the electrical/digital world, we covered basic topics such as Ohm's Law, conductors, and digital logic. We explained how we are able to visually see nano-scale devices and gave a basic introduction to their properties.

To test our lesson plans, we presented them to approximately 120 fourth and fifth grade students, equally distributed across six groups. The students all attend a local school district, and all had shown a strong aptitude and interest in science and math. We taught each of the lessons over three consecutive Saturday mornings and continually observed their reactions to the material.

The lessons were outlined by a professor of electrical and computer engineering. The details and analogies to explain the lessons were developed by the professor and the nine undergraduate electrical engineering students responsible for delivering the lessons. This gave all of the undergraduate students an opportunity to learn about nanotechnology and practice what they learned by teaching the material to younger children.

3.0 METHODS AND TECHNIQUES USED

In this section, we will provide the details of the five introductory lessons we developed. The five lessons included three dedicated to nano-scale devices and their properties: Properties of Nano-Scale Devices, Ohm's Law, and One-Dimensional Conductors. The last two lessons

introduced two applications for nanotechnology: Scanning, Tunneling Electron Microscopes and Digital Logic Circuits.

3.1 Properties of Nano-Scale Devices

Let's consider an object such as an orange. This orange has various physical properties, including shape, size, weight, and color. While we may be concerned with any of these properties, the two that make nanotechnology fascinating are shape and size. These two categories are analogous to surface area and volume. At the nano-scale, an object's surface area to volume ratio increases dramatically. This means that as objects get smaller, their surface area increases with respect to their volume; this property allows nanotechnology to have a potentially unlimited number of applications.

We started the lesson by briefly reviewing the concepts of surface area and volume. As the students gained confidence with these ideas, we divided the students into groups and gave them packages of cubic, wooden building blocks. We gave each group three tasks. First, they built a four-by-four-by-four cube (with a total of 64 blocks). We asked the students to count the number of individual block faces and then the number of blocks in the cube. We repeated the process with a three-by-three-by-three cube (27 blocks), a two-by-two-by-two-cube (8 cubes), and a single cube. We asked the students to calculate the surface area to volume ratio and graph that value with respect to the number of blocks per dimension (see Figure 1).

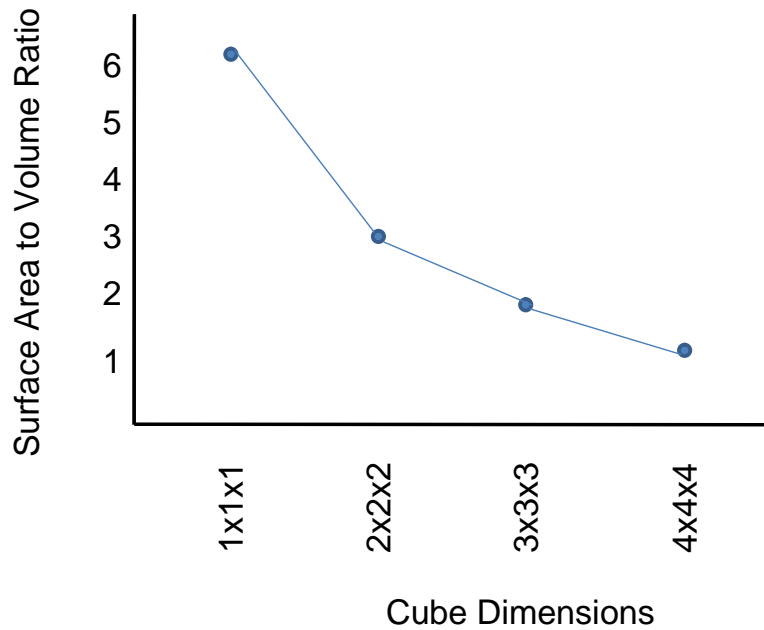
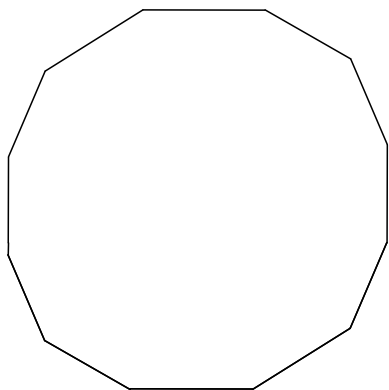
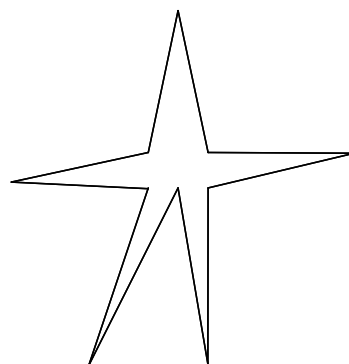


Figure 1. Ratio of surface area to volume of various size cubes

For our second lesson, we divided the students into groups of four and gave each group ten straws. We then asked them to lay out the straws to build a two-dimensional object with the largest possible area and smallest possible circumference. Many of the groups came close to the ideal decagon. We explained to the students that a circle is the ideal shape for minimizing circumference to surface area. We then asked the students to maximize the circumference/surface ratio. During the exercise, we were impressed that many of the groups built a single line with their ten straws. However, we had to explain that a line is not two-dimensional and asked them to try again. Eventually, many of the groups developed shapes similar to the star configuration in Figure 2.



Decagon
(minimizes
circumference/area)



Star
(maximizes
circumference/area)

Figure 2. Two-dimensional surface area to volume comparison.

After the lesson, we explained to the students why studying the surface area to volume and circumference to area ratios was important. We explained to them that having a large surface area to volume ratio impacts many nano-particle properties. They become more reactive and interact with their environment differently. We explained that medical researchers are using nano-particles to help improve the body's ability to absorb medicines [7]. After we had explained that nanotechnology is going to have huge impacts on our future, they took a greater interest in the material.

3.2 Ohm's Law

The German physicist, Georg Simon Ohm, is credited for realizing the relationship between potential difference and the flow of electricity. Published in 1827, his theory states that the “...

potential difference between any two fixed points on a given homogeneous conductor...is a direct measure of the current in the conductor...The ratio of that potential difference to that current...is a characteristic of the portion of the conductor in question, and is called the resistance” [1]. Today, this is known simply as Ohm’s Law. This definitive relationship serves as a fundamental tool in circuit analysis and a starting block for electricity newcomers.

A hands-on demonstration of the flow of water through varied diameter tubes provided a simple analogy to teach Ohm’s Law to the fourth and fifth graders. The flow of water represented current; the diameter of the tube represented the conductance (inverse of resistance); the height difference between tube ends was analogous to the potential difference. Students were able to understand the relationship between the three variables. Increasing the height, or voltage, of the system allowed the water, or current, to flow more freely. Similarly, they realized a higher water-flow rate would be achieved by increasing the tube diameter. This important concept was simplified through a basic, comprehensive demonstration (see Figure 3).

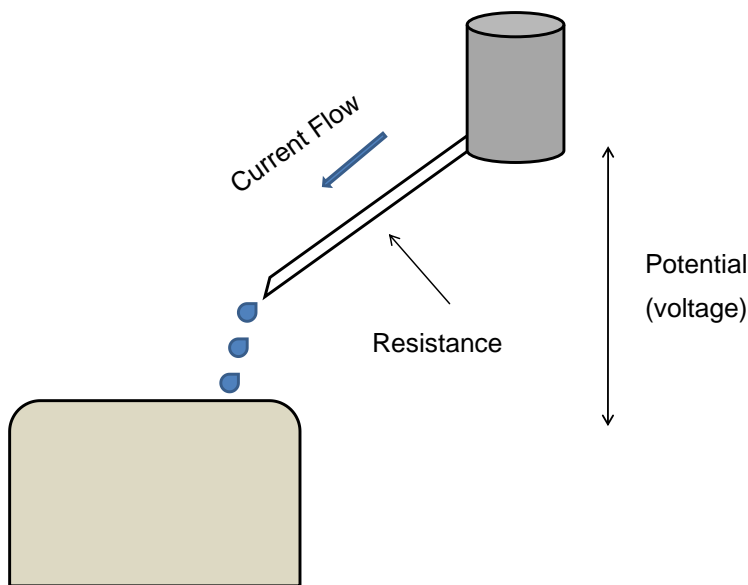


Figure 3. Water flow analogy for electrical current and Ohm's Law

A volunteer held one end of the tube at eye level while another filled a pitcher with water. This student poured the water into the tube, which emptied into a bucket. This process was repeated several times, each trial with a changed variable. Students would vary the height of one tube end and change tube sizes. Each of the iterations produced a different water-flow rate. Simple design questions were then presented to the students. For example, they were challenged with the task to design a system for water to flow most freely. They quickly devised the system, incorporating the largest diameter tube held high. They were also asked to optimize an objective given a set of parameters. For example, they were presented with the task to minimize water flow using a pre-selected tube. This water analogy was then revealed to the students as voltage, resistance, and current, with the relationship:

$$V = I R$$

where the voltage, V , is the product of the current, I , and the resistance, R (see Figure 4).

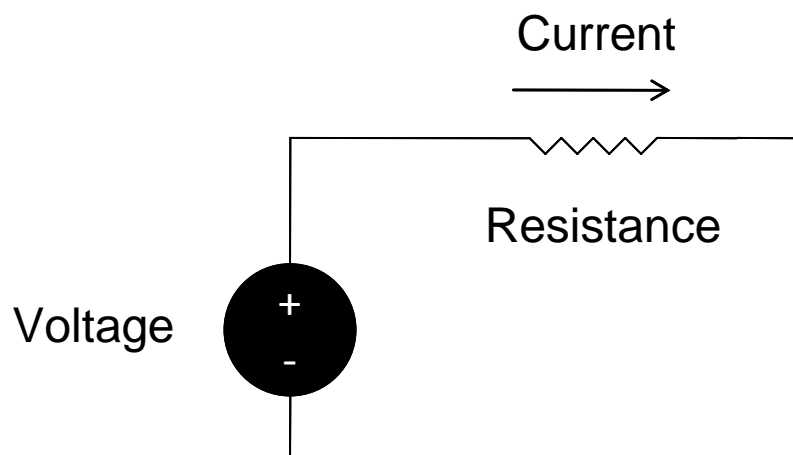


Figure 4. Simple electric circuit based upon water analogy in Figure 3.

3.3 One-Dimensional Conductors

The world today is filled with small electric devices, all of which contain thousands or millions of electrical connections. These connections are made by wires, and while they are often times extremely small (in length and diameter), they are considered physically three-dimensional. In these three-dimensional conductors, an electron is able to move in any direction (forward, backward, up, down, right or left). If we were able to shrink down these wires enough to decrease vertical and/or horizontal movement to the point where it is negligible, we would have what is known as a two-dimensional or a quasi-one dimensional conductor [2]. In these lesser dimensioned conductors, an electron's movement becomes more and more limited to fewer dimensions, allowing for any given electron to move more efficiently from high to low potential.

To better explain this concept, we have developed several different activity-based lessons. For our first lesson, we handed out a sheet and asked students to list as many three, two, and one-dimensional objects as they could. Many of the students were able to come up with multiple three-dimensional and two-dimensional objects, but the only one dimensional object they could come up with was a line. This demonstrated that the students had a strong understanding of what multi-dimensional objects were, and they were able to compare and contrast the differences between each.

For our second lesson, we arranged desks into a large square, and we then asked for student volunteers. These students were asked to close their eyes and were spun around several times. After spinning them around, we asked them to keep their eyes closed and walk to the opposite corner of the square. While every student made it successfully to the other corner, their paths

were never linear or similar. Figure 5 show an example path that one student took. After a short break, during which we rearranged the desks, we asked the students to attempt the same task. This time however, the desks were lined up parallel to each other, with only about two feet in between them (see Figure 6). Even with their eyes closed, the students could simply walk through the “wire” with no problems, covering the same distance in a much faster time. We then asked them which of the "wires" were easier to move through, and they responded with the thinner, more tunnel-like wire.

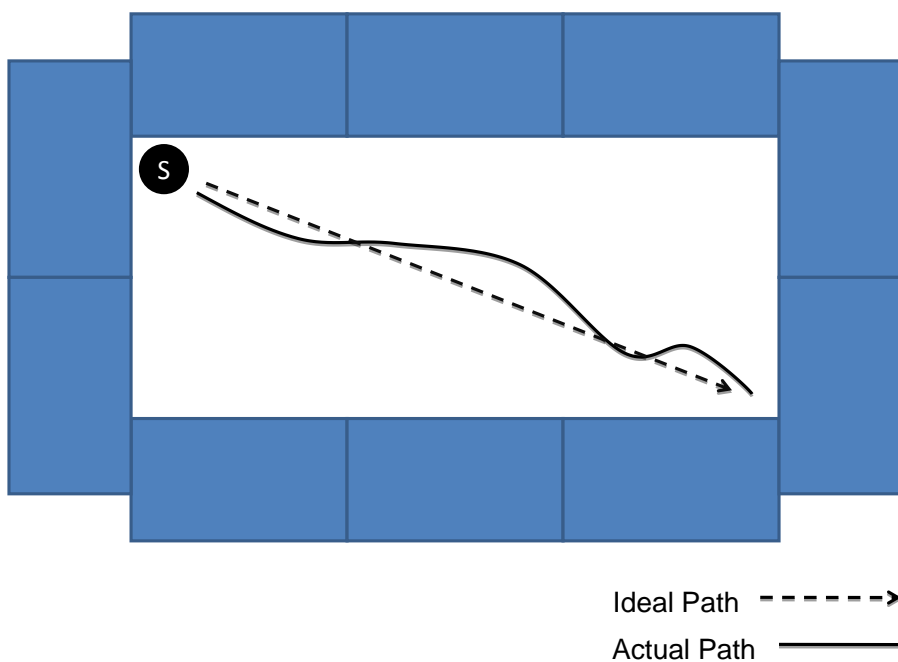


Figure 5. Student role playing an electron in a two/three-dimensional conductor.

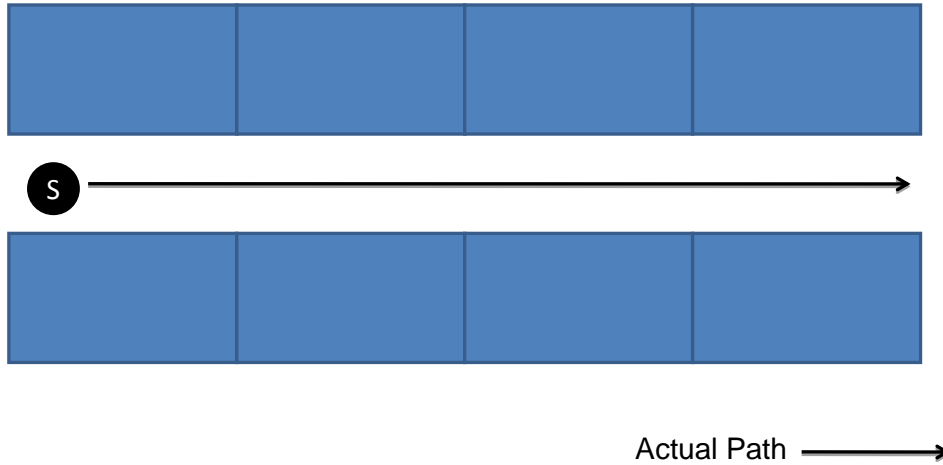


Figure 6. Student role playing an electron in a one-dimensional conductor.

To tie our two lessons together, we then sat the students down and explained that the students who walked through the large square space could be compared to electrons moving through a multi-dimensional wire, where they could move left, right, forward, backwards, up and down. When they were walking through the narrow tunnel, however, they were simulating an electron moving through a nano-wire, where the only directions they could move were forward and backward. Despite the simplicity of the lessons, the students responded positively and seemed to enjoy themselves.

3.4 Scanning, Tunneling Electron Microscopes

Nanotechnology is starting to become very prevalent in the world of electronics and medicine. In order to test and research nano-sized circuits or objects, devices are required to create an image of these microscopic objects. For this purpose, scanning, tunneling electron microscopes were invented. Before 1939, the technology for microscopes was limited; a microscope that

could create a picture of an atom or nano-sized object was just hypothesized and not physically developed [4]. The predecessor to the scanning, tunneling electron microscope was the scanning transmission electron microscope invented in the early 1930's by Max Knoll and Ernst Ruska at the Technological University in Berlin [5]. In 1981, Gerd Binnig and Heinrich Rohrer, employees at IBM in Zurich, invented the first scanning, tunneling electron microscope [6]. Due to the fact that the scanning, tunneling electron microscope is a very accurate way to create a picture of a nano-sized object, this particular microscope is important in the world of nanotechnology. The scanning, tunneling electron microscope was also a great basis for future advancement in electron microscopy.

In order for the students to understand exactly how the microscopes could create a picture of a nano-sized object or particle without a lens, we had to explain a little of the theory and science behind the microscopes. Referring back to previous lessons, we explained that the microscope is based on Ohm's Law, which states that voltage is the product of current and resistance.

After a quick refresher lesson on Ohm's law, we explained to them how the scanning, tunneling electron microscopes worked. We first explained to the students that even though their desks' surfaces look smooth to the naked eye, they are actually very uneven on the atomic level (see Figure 7). Next, we had to explain to them the operation of the scanning, tunneling electron microscope. We explained to the students that a current tries to flow from the microscope's voltage source through the tip, but it runs into the air. We explained to the students that the air acts as a resistance, and a current will flow through the air. If the tip is closer to the surface, the air "resistance" is lower, and more current will flow; if the tip is farther away from the surface

less current will flow. In order to create the picture of the object, the tip of the microscope is scanned across the entire surface of the object, and all the different currents are recorded. All these current readings create the entire picture of the object. We explained that the result is analogous to how the terrain of the earth is mapped with topographic maps.

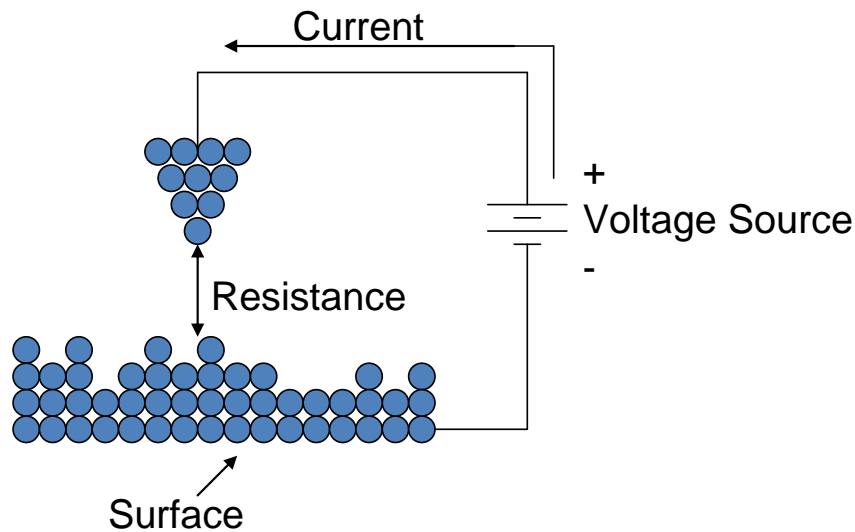


Figure 7. Scanning, Tunneling Electron Microscope

3.5 Digital Logic

Digital logic is becoming more and more significant in the world of engineering. Digital logic circuits operate with discrete values of amplitude instead of a continuous range of amplitudes. In a binary system, the values for digital logic circuits are represented by two values, 0 and 1. The 0 refers to 0V and the 1 is in reference to the source voltage. Digital logic is important in engineering and nanotechnology because of the high use of digital logic gates and circuits in computational hardware. Computers and other similar technology are made mostly from logic

gates and logic circuits. These gates are implemented on the transistor level, where the transistors are becoming smaller and smaller even reaching the nano-scale level.

Before we could explain to the students how digital logic works, we had to explain to them the basic logic functions: AND, OR, and NOT [3]. We explained that AND is a function that returns the value of TRUE (or logic 1) only if both of its operands are TRUE. If either operand is FALSE (logic 0), then the AND returning value will be FALSE. Logic OR is a function that returns the value of TRUE if either (or both) of its operands is TRUE. We taught the students that the logic function NOT is an inverter. If the input is TRUE the NOT output is FALSE and vice versa. After the students understood these concepts, we moved on to more in depth examples.

We first explained to the students how to read truth-tables for the functions AND, OR, and NOT. Some of the students understood them easily, but for most of them it was initially difficult to understand the idea of TRUE and FALSE arguments. To help them understand, we used simple statements as operands such as “I am ten.” Another statement could be “I have a dog.” For example, if we had “I am ten” (TRUE) AND “I have a dog” (TRUE) the returning value of the AND function would be TRUE. Then, we gave students more challenging exercises that had more functions connected together making the exercise more complex (see Figure 8). All the exercises were of this format so that students could understand the analogy. Using simple statements as inputs for functions helped the students to associate the concepts of logic TRUE and FALSE.

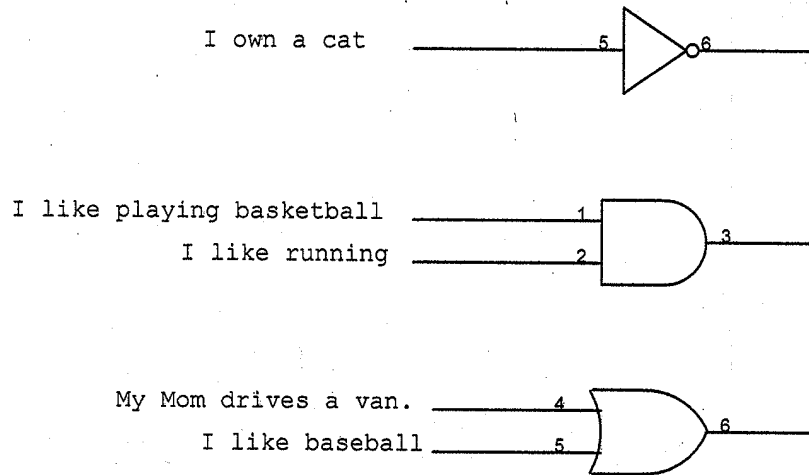


Figure 8. Example of digital logic worksheet.

Next, we wanted the students to explore how the logic gates could be used to interact with the outside world. For this, a number of electronic hobby kits were passed out (see Figure 9).

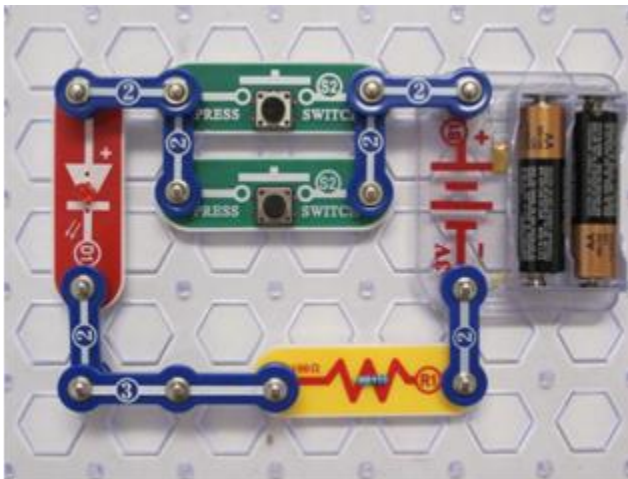


Figure 9. Electronic hobby kits used in digital logic lessons.

After explaining to the students how to use the kits, we gave them a task to build the digital logic gates that we had taught them. The first assignment was to try and implement a circuit that

would turn on a motor when two switches were pressed at the same time. To do so, the switches must be connected in series. When the students completed that task, we asked them how it was related to the concepts of logic functions we had just studied. Most of the students were able to see the connection that the circuit they built was actually an implementation of a two-input AND gate (see Figure 10). Next, we asked the students to build another circuit that would turn on a motor if either of the switches were on. That task seemed to be more challenging because a parallel connection of the switches was not as obvious for the students, but after few tries they got it working right. When that was done, we explained that they had just implemented a two-input OR function (see Figure 11).

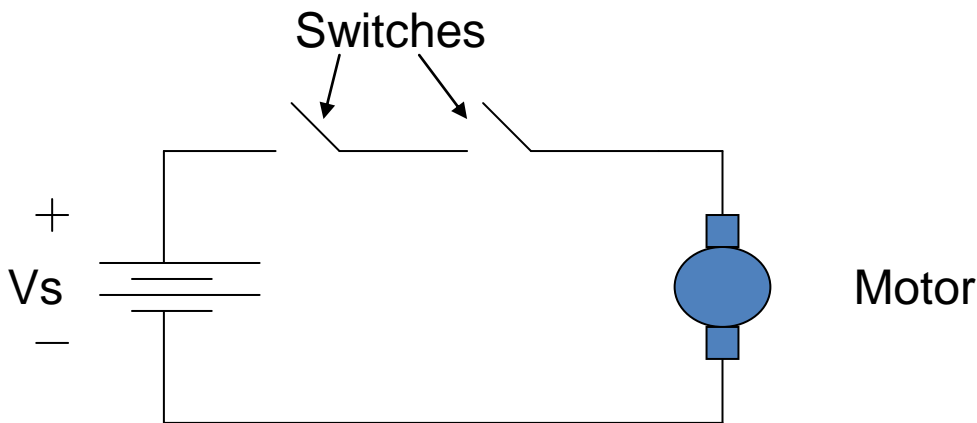


Figure 10. Circuit for implementing a logic AND function.

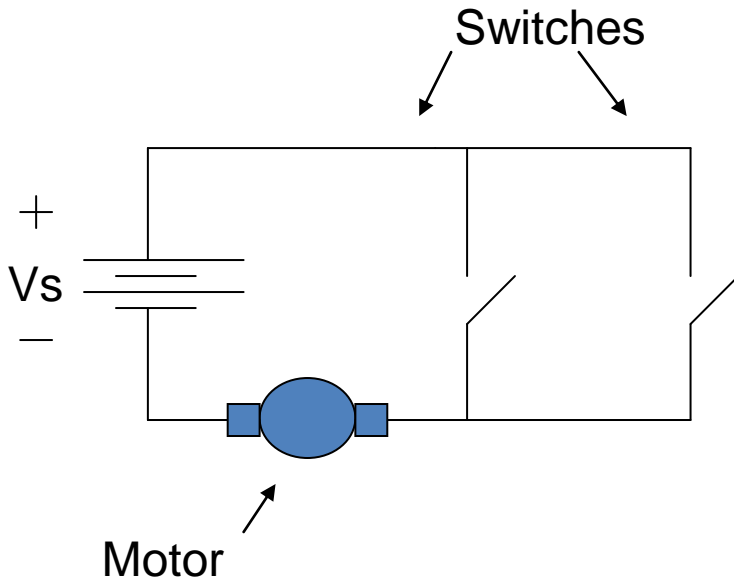


Figure 11. Circuit for implementing a logic OR function.

4.0 RESULTS AND DISCUSSION

For each of the five lessons, evaluation techniques were used to determine if they were successful. For this initial roll-out of our program, we were primarily interested in qualitative feedback. Specifically, the undergraduate instructors were tasked with determining if the fourth and fifth grade students enjoyed the lessons and if they were able to explain and convey their understanding. Finally, the undergraduate instructors look for ways to improve the lessons for future sessions. Overall, the students met approximately 90% of the objectives we set for the course. Following the course, 67% of the students and parents returned a feedback form. On a scale of one (worst) to five (best), the students rated the course at 4.79. The only negative comment received from the fourth and fifth grader students concerned the early (9am) start time on Saturday morning. When asked about the quality of their child's experience, all of the parents

responded with a five. Additionally, when asked if they would refer the program to a friend, all of the parents responded with a five.

4.1 Nano-Scale Properties

When we evaluated this lesson, we found that the students did not respond well immediately. It seemed that some of the students did not find the activities initially fun or challenging. When we quizzed the students, they were able to respond correctly, but were very eager to move on to the next lesson. After we had explained that nanotechnology is going to have huge impacts on our future, they took a greater interest in the material. It is apparent that children this age do not yet understand the significance nanotechnology will have on their lives. We took this to be of paramount importance for this and our future lessons. Tying the lesson to an eventual application really motivated the fourth and fifth grade students.

Our first step in re-planning the lesson was to communicate its importance. We felt that if we were better able to grab their attention early on, they would enjoy the lesson more. Secondly, we tried examining the examples used to teach this lesson. We felt that the block example, while not particularly challenging, was perfect for examining how the surface area/volume ratio changed with size. We decided that it was in the best interest of the lesson to keep the block example in the lesson plan. We then examined the straw shape challenge, and found that it provided the students with the opportunity to experience a hands-on challenge. Some groups of students responded well to the challenge and enjoyed trying to solve the problem presented. After some further discussion of any possible replacements for this experiment, we decided to continue using

the straw lesson, but reiterated the importance of motivating the students at the start of the activity.

Our concluding thoughts of this lesson were positive. The students were able to retain the information when quizzed, which was the most important goal to us. Our biggest concern with the lesson in the future will be to grab the attention of the students before proceeding with the lesson.

4.2 Ohm's Law

To verify their understanding of Ohm's Law, a worksheet was distributed displaying several incomplete Ohm's Law calculations. The students were responsible for determining an unknown variable, provided the other two parameters. They were thus able to practice a simple yet critical circuit analysis technique while sharpening their multiplication skills.

Student interaction was a critical tool in keeping interest during the lesson. Requesting volunteers with our water-based analogy sparked immediate interest in the topic from all students. The fourth and fifth graders especially enjoyed this demonstration because they partook in the teaching of this theory despite limited or no prior knowledge of electricity. They held a sense of pride when correctly designing systems to our specifications and completing the worksheets. Their interest for the task at-hand was noticed as enthusiastic remarks of ease were heard. They enjoyed applying their existing mathematical knowledge to a new and exciting

concept. Successful completion of the small design projects and worksheets verified that the objective was met.

The students were able to easily grasp this effective demonstration of Ohm's Law. Involving them directly allowed them to better understand changing variables and the consequent effects on the system. Varying our teaching techniques provided multiple opportunities for fourth and fifth graders to understand this fundamental law. Comprehending Ohm's Law prior to learning the related terminology was also beneficial. This prevented initial student confusion and minimizes intimidation when learning a new concept.

4.3 One-Dimensional Conductors

When we evaluated the success of this specific lesson, we found that we met our established goals. The most important goal was to ensure that the students would learn and understand the material we were presenting. After the small quiz we gave our students, we felt confident that the lesson was instructive and informative. Our next concern was to make sure that the lessons were fun, hands-on, and challenging. While we felt that these exercises were not particularly challenging, the students did enjoy participating in them. Our third and final goal was to observe the students reactions and experience with the lesson, so that we may improve upon it for future classes.

One thing that we all agreed on that could be improved is adding one more activity. We felt that while the two lessons included were sufficient, a third would be even more beneficial. A more

hands-on experiment with multi-dimensional objects would fit perfectly. One way that this may be achieved is through the use of models, such as a mobile. These cutaways could display perfectly how an electron could move through a given wire, and could be scaled down to simulate two and one-dimensional conductors as well. Another method may include asking the students to draw how they believe an electron moves through a wire. After asking students for their opinions, we could then move to the desk activity. The introduction of this activity may help the transition between the introduction/review of multi-dimensional objects, and the electron flow activities.

Our concluding thoughts on this lesson pointed towards a positive experience. We felt that the lesson plan was appropriate for the students and helped them to understand the concept of multi-dimensional conductors. While we understand that there is always room for improvement, our experience has led us to believe that this lesson plan was successful in achieving our determined goals.

4.4 Scanning, Tunneling Electron Microscopes

When we evaluated the success of this lesson, we came to the conclusion that the students understood the concept. To confirm, we asked the students certain questions about how the microscope could get a picture of such a small object. With the responses of the students, we felt confident that we had successfully informed and instructed the students.

To help prove to the students that these devices could create a picture of nano-scale objects, we handed out pictures taken by scanning, tunneling electron microscopes. Once the students saw these pictures, they asked deeper probing questions about how the different currents could create actual images of the objects. Since it was not possible to have a hands-on project to show them how the microscope worked, we had to explain that a computer system took the currents and analyzed them in terms of heights. The computer would print out the picture of the object. This explanation seemed to help them understand the concept well. Throughout this lesson, we tried to observe the students facial expressions and reactions to the lessons to try and understand if we met our goals of the lesson.

We all agreed that this lesson would be much more informative if we could incorporate some sort of hands-on experiment. One idea was to set up a circuit with a variable resistor (potentiometer) and display the current of the circuit when the resistance is varied. This could help them to visualize the idea of how the changing current and resistance are related. If we started with this activity, it might help give the students a more visual grasp on the function of the microscope.

In our final discussion, we came to the conclusion that the lesson was an overall success. We believe that the lessons taught and the analogy used helped the students to understand the function and use of the scanning, tunneling, electron microscope. After teaching the lessons to the students, we are confident that we achieved our goals.

4.5 Digital Logic

When we evaluated how the lessons went, we decided that the goals of the lessons were achieved. As mentioned above, at first some of the students were a little confused by truth-tables. After going through several problems with the help of the instructors and their classmates, all of the students were able to demonstrate that they understood how the truth-tables functioned. The students also liked the idea that they can create stories using statements as logic operands. We noticed that as the activities became more challenging, the students' interest increased. They liked the fact that they were learning material that college students learn. However, the students' favorite part of the lesson was when they got to work with electronic hobby kits because they had fun with all the motors, switches, and lights. They even asked us for additional tasks to complete. We came to the conclusion that this lesson was the most enjoyable for the students because of the hands on interaction with the electronic kits.

Overall, the lesson was very successful and easy to follow. However, sometimes we felt that students needed more time on understanding some of the ideas. Being limited in time did not always allow us to work one-on-one with a student that was struggling. When going through the logic circuits worksheets, we needed a lot of time to work through them, and then make sure all the students had the correct answers. We also think that there should be more interaction between students because interaction helps the students to understand the topics better. We know there is always room for improvement, but we thought that between the worksheets and the hands on exercises, this lesson was very successful in teaching the students the basic logic functions, AND, OR, and NOT.

5.0 CONCLUSIONS

At the end of our pilot session, we sat down to evaluate our impressions and opinions of the overall lesson plan. When we compared our individual lesson results to our overall goals, we were very pleased with the outcomes. The students were able to retain the information over the course of the three weeks, as we had hoped. In addition to their improvement in understanding, their interest in the material itself increased greatly as well. Often times, students would stay after to ask us additional questions about the individual lessons. The students' overall response demonstrated an appropriate and well-planned set of lessons. Overall, we were very pleased with the outcome, and our observations have allowed us to improve the lessons for future classes.

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