Nanoscience…What's the Big Deal?

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This curriculum unit is recommended for:
Middle Grade Science, Introductory Biomedical/Biotechnology
Grades 6th, 7th, and 8th

Keywords: (Nanoscience, nanotechnology, atom, molecule, surface area, light spectrum and color)

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: With the advent of the scanning tunneling microscope (1981) and the atomic force microscope (1986), the door to a new frontier, was thrown wide. Not only could scientist 'see" structures at the atomic and molecular level, they could also manipulate them. Building materials from the bottom up, one atom at a time, is the very premise of nanotechnology. In this unit, students will be introduced to the nanoscale. Materials at the nanoscale exhibit very different properties from those we are used to experiencing with bulk materials. Students will discover the science behind some of these seemingly bizarre behaviors. Hands-on activities, interactive websites, computer games and lab experiments will guide student understanding of "nano" concepts, such as scale, size, surface area, light, color and van der Waals forces. The culminating activity in this unit is nanoparticle synthesis. Students will make carbon nanoparticles that will fluoresce, when exposed to UV light.

I plan to teach this unit during the coming year to 180 students in an elective Introductory Biomedical course that includes 6th, 7th and 8th grade students in each class.

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Joyce Patton

Student and School Background

Coulwood STEM Academy is located in the northwest corner of Mecklenburg County. We serve approximately 700 students; 70% of our students are African-American, 13% are Caucasian, and 13% are Hispanic. Our Free and Reduced lunch students represent 75.3% of our student population, 5% of our students are certified as Gifted; 14% qualify for services through the Exceptional Children's Department and 4% are certified as Limited English Proficiency. We are a Title I school serving in the West Learning Community.[1] Coulwood STEM Academy has been a partial STEM (science, technology, engineering and math) magnet for the past 2 years, offering students STEM elective courses covering a broad range of topics, including computer science, alternative energy, architecture, biomedical science as well as several different engineering disciplines. These courses are project-based with many hands on activities designed to encourage inquiry learning.

I am currently certified, as a middle grade science teacher, however I chose to move to our elective team 2 years ago, to teach several, semester-long STEM courses. Electives are on a rotating A-day, B-day schedule. I teach four classes per day that are approximately 55 minutes in length. Each class includes students from all grade levels; 6^{th}-8^{th} and is limited to no more than 24 students. In my classroom, we utilize the Promethean Board, 25 laptop computers, 13 tablets, and age appropriate books, magazines and articles. We also utilize various tools and software packages to collect data, design prototypes and simulate processes. Science, technology, engineering and math are incorporated throughout the curriculum lessons, activities and projects. Another aspect of my courses is career exploration. This element helps students make connections between what we are doing in class and how it is used "in the real world" as well as the many ways in which STEM relates to almost anything they might find interesting such as music, sports or gaming.

Rational

Within my science classroom, I saw students unable to utilize skills learned in their Language Arts class such as using content clues to determine the meaning of an unknown word. Others could not "plug and chug" given information into know equations or graph collected data. I would often hear complaints of, "This is science, why do we have to map the text?" or "This is science, why are we doing math?" Compartmentalization of content learning limited my students' ability, to fully engage with new learning, in the science classroom. Additionally, students would become frustrated when I would not simply tell them the information, but rather attempt to guide them through the critical thinking necessary to solve the problem. This type frustration often leads to disengagement and apathy in the classroom. I was dismayed to hear other teachers say they were just lazy or they did not want to learn. That was not what I saw. What I saw were students who had been "taught to the test" for most, if not all of their school life and here I was asking them to do something they did not know how to do nor did they see a good reason to learn how to do…after all, teachers know the information and could just tell the students, so they would know what to study for the test.

> Science as Inquiry: Traditional laboratory experiences provide opportunities to demonstrate how science is constant, historic, probabilistic, and replicable. Although there are no fixed steps that all scientists follow, scientific investigations usually involve collections of relevant evidence, the use of logical reasoning, the application of imagination to devise hypotheses, and explanations to make sense of collected evidence. Student engagement in scientific investigation provides background for understanding the nature of scientific inquiry. In addition, the science process skills necessary for inquiry are acquired through active experience. The process skills support development of reasoning and problem-solving ability and are the core of scientific methodologies.[2]

These words are the opening statement of the North Carolina Standard Course of Study (NCSCOS), for each grade level, K-12, of the science curriculum. Teachers throughout North Carolina are expected, to use inquiry methods, to teach science. However, the NCSCOS does not align with this directive. The NCSCOS at each grade level is over packed, leaving little time for true inquiry teaching/learning.

The rationale for this curriculum unit is to decrease student apathy by allowing them to connect nanoscience to their own lives and/or interest. Students will be able to explore ways in which nanoscience connects to many branches of science, engineering disciplines and technology fields. The lessons will utilize guided inquiry, that require them to use prior learning from other content areas. This will help build confidence and skill in the use of inquiry learning. The curriculum will align with several NCSOS Essential Science Standards from the middle grade level, allowing it to be used in part or as a whole, within any middle grade science classroom.

Content Objectives

As mentioned before, this curriculum unit will push students to use language arts and math skills to examine nanoscience connections to their own lives as well as college and career paths involving nanoscience. Students will be exposed to activities that promote an understanding of what nanoscale means and the properties of nanoscale materials. They will participate in hands-on lab activities to gain an understanding of nanoparticle properties and the ways they differ from bulk properties. Students will use this new knowledge to synthesize and tune carbon nanoparticles in the classroom. They will know they have successfully made nanoparticles of a specific size, by the color at which they fluoresce.

Content Background

Nanoparticles in Pre-Modern Times

The prefix "nano" is defined as one billionth or 10^{-9}. With this in mind, one nanometer is equal to one billionth of a meter. Objects identified as nanoparticles have at least one dimension that measures between one and one hundred nanometers. Nanoparticles have a long history of human use. More than 17,000 years ago, our ancestors painted cave walls in what is now France. Carbon nanoparticles have been identified, in the dark pigments, used to create these beautiful pieces of art.[3] Because of their extremely small size and high volume/surface area ratio, nanoparticles exhibit properties, such as color, that differ from those of bulk materials. The Lycurgus Cup, made by the Romans at around the fourth century A.D. is one of the most famous examples. It contains a molar ratio of silver to gold that is 14:1, giving it the most unusual effect of appearing green unless illuminated from the inside. When illuminated from the inside it appears to change color to an opaque red and pink. The Lycurgus cup is the only complete artifact of this unique type of glass, called, dichroic glass. During the Middle Ages, artisans utilized other methods to make the magnificently colored, stained glass windows of medieval churches. The vivid colors found in these windows resulted from varying sizes of silver and gold nanoparticles infused during the glass making process.[4]

Sabers and swords made of Damascus steel were used, by Muslims, to fight against the invading crusaders during the 11th to 13th century C.E. Damascus steel blades are unusually strong and sharp. These characteristics have been attributed to carbon nanotubes as well as other nanoparticles found to be present in blades made of Damascus steel.[5]

As early as the 9th century A.D. glazed ceramics with metallic luster decorations were being made in Mesopotamia.[6] While later ceramics, called Deruta pottery, made in Italy during the Renaissance period (1450-1600A.D.) appear iridescent or metallic.[7] This metallic appearance was achieved, in both cases, by the use of glazes containing nanoparticles of copper and silver.

These are but a few of the pre-modern examples of human interactions with nanoparticle.

Nanoparticles in Modern Times

In December of 1959, Richard Feynman gave his now famous speech, "There's Plenty of Room at the Bottom",[8] to the American Physical Society at Caltech in Pasadena. Here he states, "The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom". He spoke of tiny machines, smaller computers and improvements to the electron microscopes to allow visual inspection of such technology.

His speech was published the following February, in the Caltech journal, Engineering and Science, Volume 23:5.

This idea of exploration, research and production by single atom manipulation did not have a name until 1974, when Dr. Norio Taniguchi, of the Tokyo Science University, coined the term nanotechnology. Nanotechnology saw several advances in the 1980's. For the first time in history, scientist were able to "see" individual atoms using the scanning tunneling microscope, invented, by Gerd Binnig and Heinrich Rohrer at IBM's Zurich lab, in 1981. By 1986, scientist had another tool to use in their quest to explore at the nanoscale. The atomic force microscope invented by Gerd Binnig, Calvin Quate, and Christoph Gerber, not only allowed viewing, but measurement and manipulation of materials only fractions of a nanometer in size. The 80's also saw the discovery of several nanoparticles. Alexei Ekimov, in 1981 discovered nanocrystalline, semi conducting quantum dots in a glass matrix and studied their electrical and optical properties in depth. Another type of quantum dot, the colloidal semiconducting nanocrystal, was discovered in 1985, by Louis Brus of Bell Labs. At Rice University, in 1985 researchers Harold Kroto, Sean O'Brien, Robert Curl, and Richard Smalley discovered a large molecule made of 60 carbon atoms and shaped like a soccer ball. It is named the Buckminsterfullerene, after architect Buckminster Fuller who used similar geometric shapes to design domed buildings. It is more commonly known as, the Bucky ball.
The 1990's saw the rise of many nanotechnology companies and the expansion of nano-scale research and development. By 1999 and on into the turn of the century consumer products that featured nanotechnology hit the market place. Industries, that included everything from make-up to car bumpers, where exploiting various nanoscale properties to improve their products.

The National Nanotechnology Initiative (NNI) was launched in 2000, by President Clinton. This initiative coordinated Federal research and development efforts and promoted U.S. competitiveness in nanotechnology. It was first funded by congress, in 2001. By 2003 Congress enacted the 21st Century Nanotechnology Research and Development Act. Now the NNI had legal standing and began to establish programs, assign agency responsibility, authorize funding levels and promote research that would address vital issues.[9]

Nanotechnology is multidisciplinary, touching nearly every branch and discipline of science, engineering and technology. Nanoscale properties are different from bulk properties; materials at the nanoscale exhibit unique properties and behaviors. As a material decreases in size, down to a few billionths of a meter surface area increases dramatically, which affects chemical reaction intensity and time. Another property that differs at the nanoscale is color. Nanoparticles are between 1 and 100 nanometers. At this size, materials are bound by the laws of quantum physics causing them to interact with light differently, producing unexpected colors or even fluorescence, not observed, in the same material, at the macro scale. For example, gold nanoparticles appear red or purple because electron motion is confined. Other properties, such as melting point, electrical conductivity and magnetic permeability, are also altered, at the nanoscale. These special properties make it possible to tailor material structures at the nanoscale, in order to make everyday products stronger, lighter, more durable, more reactive, more sieve-like, or better electrical conductors. For example, polymer composites containing nanoscale additives are used to produce baseball bats, tennis rackets, motorcycle helmets, automobile bumpers and luggage that is lightweight, rigid, durable and long-lasting. Nanomaterials are used in cosmetics to improve coverage and clarity, provide UV protection, as well as, act as antioxidant and antimicrobial agents. New TV's, laptop computers, cell phones, digital cameras, and other digital display devices include nanostructured polymer films and semi-conducting nanoparticles to make flat format images brighter, allow wider viewing angles, improve picture density, decrease power consumption, decrease weight and extend product life. These are but a few of the more than 800 commercial uses of nanotechnology.[10]

Nanotechnology is also having an impact on developing nations and society as a whole. Medicine, clean water and sustainable energy are key areas making major advances through nanotechnology research and development. These three key areas of nanotechnology focus along with the increasing number of commercial uses can move "nano" lessons beyond math and science classrooms and into every area of education.

Teaching Strategies

The 5Es

I will be using the 5E instructional model, designed by the Biological Science Curriculum Study (BSCS), a team led by Principal Investigator Roger Bybee. This model supports constructivism, whereby learning is constructed, from prior learnings. Within the 5E model, I will use additional teaching strategies such as heterogeneous groupings/jigsaw, hands-on/minds-on activities and labs, think-pair-share, and think aloud and modeling.

The 5Es, as designed by the BSCS team are as follows:

> Engagement- The teacher or a curriculum task accesses the learners' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organize students' thinking toward the learning outcomes of current activities.
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> Exploration- Exploration experiences provide students with a common base of activities within which current concepts (i.e., misconceptions), processes, and skills are identified and conceptual change is facilitated. Learners may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.
>
> Explanation- The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This

phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Learners explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase.
Elaboration- Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.
Evaluation- The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives. [11]

Game-Based Learning

I will also utilize aspects of game-based learning, during this unit. Students will be introduced to Geckoman, an educational computer game created at Northeastern University through the collaborative efforts of NEU's Center for High-rate Nanomanufacturing faculty, NEU game designers and education associates at the Museum of Science. Geckoman's target audience is children between 10-14 years old.[12] The game was designed to teach nanotechnology principles and guide student understanding of scale. One of the main characters, Harold, is shrunk to the nanoscale in a terrible explosion. Meanwhile, his lab partner, Nikki remains at the macroscale. She is able to help Harold navigate through three worlds starting at the nanoscale. Nikki's help comes in the form of her lab notes, which were scattered during the explosion. At each level, Harold will need to find Nikki's lost note pages, because they contains lessons and short tips that will help him avoid enemy attacks and return to normal scale.

The main concept of World 1 is van der Waals forces, the forces that dominate at the nanoscale. Here, nano-sized Harold to "defy gravity" and walk on the ceiling.

In World 2, Harold is still at the nanoscale, but the effects of the shrinking machine have begun to wear off and he is just slightly larger. Since Harold has increased in size, he is no longer under the grip of van der Waals forces and falls from the ceiling to the floor. A puddle on the floor breaks his fall, but at this scale, the muddle appears to be a vast swamp. Harold finds that he can run across the top of the water as long as he does not become too heavy and break the surface tension.

In World 3, Harold has reached the microscale and can no longer stand on water, but he is small enough to be able to jump on floating dust particles. World 3 contains nine levels set in a microscale cloud world. The force of gravity is now a more dominant force because of Harold's increased size and weight. The player, however, must now contend with electrically charged particles causing Geckoman to "stick to" or "repel from" various objects and enemies, depending on his electrical charge. In this final world, the objective is to collect the missing pieces of the shrinking machine" along with notebook pages that explain how to reassemble it as a "growing machine".

Classroom Strategies

Throughout this unit, several different classroom strategies will be incorporated under the umbrella of the 5E Instructional Model. Most lessons involve intentional placement of students, into heterogeneous groups of 3- 4 students, where they will need to communicate and collaborate, to complete activities and labs. When one on one interactions are called for, students will be placed in pairs. Hands on labs and activities will be used throughout this unit to clarify and reinforce concepts. Finally, students will build an interactive journal, as they progress through the unit. The journal will be divided into three sections: Geckoman Discussion Questions and Nikki's Notes, Daily Activities and Labs and Double Entry Journaling. The interactive journal will act as a portfolio of the students work as well as an assessment tool to monitor student progress and content/concept understanding.

Day1-Observations and Inferences

Nanoscience and nanotechnology lend themselves well to many different types of teaching activities. However, the nanoscale is too small to see and most K-12 classrooms will not have access to equipment used to measure and "see" nanoscale objects. It is, therefore necessary for students to understand the difference between an observation and an inference. Students will also need to understand that often, scientist use indirect observation, when they cannot see the very thing they want to study. For example, a scientist may have to observe the behavior of a substance to gain information and make inferences. During this unit, students will keep an interactive journal to track progress and assess understanding of the material. Journals will be divided into three parts: Daily Activities and Labs, Geckoman Discussion Questions and Double Entry Journaling.

Engage-
Students will divide their journals into 3 sections- Geckoman Discussion Questions, Daily Activities and Labs and Double Entry Journaling. Use paper and tape to make divider tabs.

Students, as a class, will watch a 6 minute video at https://www.youtube.com/watch?v=CFmj_NY5tvg[13], outlining the differences between an observation and an inference. In their journals, students will define and give examples of the following words: observation, inference, qualitative observation and quantitative observation. The video will be played a second time, to give students the opportunity to see and hear the information again. To ensure students' understanding of the vocabulary, have a short class discussion to insure we all agree on the definitions and examples.

Explore-

We will then move to the activities for direct and indirect observations. Students will be work in heterogeneous groups of 4. First, groups will be given 1 minute to visually inspect objects that have been placed in a box. Each student will silently record direct observations in their journals. They will not be allowed, to share their notes, at this time. Upon returning to their seats, students will individually try to answer questions about the objects in the box, to see how well they made their observations. After answering as many questions as possible, they will then share their observations and question results, with the other people in their group. Next, each group will be given a sealed box with objects inside. They will have access to digital balances and will be able to hold and move the box around, for 1 minute. They will record their indirect observations in their journals.

Explain-

Students will remain in their groups, to discuss their indirect observations and make inferences. They will then report their observations and a conclusion to the rest of the class. Students will not be told the contents of the sealed box in order to reinforce the notion that indirect observations may be the only way to study some things. (See Appendix 2 for suggestions on box contents and questions for direct observation box)

Day2- Making Direct Observations and “Nano” Introduction

Elaborate-

Students will make direct observations of living geckos. They will draw a table, in their journals, to divide their observations into qualitative and quantitative observations. If the geckos are on the walls of the aquarium, they may be able to measure them and if I am feeling safe about taking them out, I will weigh them for the students. Other than that, students are on their own with the observations.

We will have a short class discussion to see what observations they made and if they placed their observations on the table correctly. I want to see if anyone notices that the geckos can “stick” to anything in the aquarium even if they are on glass or upside down. If students did not make this observation, then I will bring it up. I will ask students to think about what we could do with this ability and how it might be useful for us as humans.

Students will be given 3 minutes to respond in their journals. They will then pass their journals to the person on their right. That person will have 3 minutes to respond to what their classmate’s answer.

Engage-

Students will take the Geckoman Pre-assessment. (See Appendix 2)

Following the assessment I will write on the board- Nanotechnology

Students will draw a K-W-L chart in their journal with nanotechnology as the subject. They will fill in the Know (K) and Want to Know (W) sections. I will ask the class “Have you ever heard of nano or nanotechnology?” and “Could someone describe what they have heard about nanotechnology?” I will write their answers on the board. We will discuss the meaning of “nano” as one-billionth (10^{-9}) and a nanometer is one billionth of a meter and that although objects in nature can be measured in nanometers the term technology refers to things made by humans.

Day 3

The videogame “Geckoman” introduces students the idea that materials behave differently at the nano-scale than they do at the macro-scale. As students advance through the game, they will gain knowledge of the van der Waal adhesion forces, which dominate at the nanoscale, as well as other “nano” information found on the pages of Nikki’s Lab Book.

Engage-

Students will be introduced to the Geckoman video game by watching, as a class, the introductory splash video at http://www.coe.neu.edu/Research/geckoman/.[14] Start new player to hear the splash video backstory.

Each student will assemble a small version of Nikki’s Lab Book, to be filled in, as Harold finds the lost pages, throughout the game. Students will use I sheet of construction paper and 10 sheets of plain white paper. All paper is folded hamburger style with the construction paper acting as the cover. Staple at the fold to form the spine. Students will use cardstock paper and tape to make a pocket on the inside of their journal cover to store Nikki’s Lab Book.

Explore-

Students will then log in and play for 20 minutes. After 20 minutes, we will close the computer lids and have a class discussion about the game. We will answer World 1 Discussion Questions, about the characters, their abilities, the game environment and objects within the game. Discussion Questions are found at https://sites.google.com/site/geckomanproject/home[15]

Hint: Use any of Nikki’s Notes that Harold finds, to answer discussion questions.

Homework: Complete “World 1” and fill in any lost pages of Nikki’s Lab Book, found by Harold. Be ready for game discussion next class.

Day 4- Geckoman World 1 Discussion and Powers of Ten and Scale

Explain-

Students will be placed in heterogeneous groups of 4 to discuss World 1 and the information found in Nikki’s Lab Book (10 min)

Explore-

Following this discussion, I will turn the students back to the term “nano” and powers of ten. We will briefly discuss powers of ten, orders of magnitude, and metric prefixes, to gage prior knowledge. Students will log into computers in pairs (1 computer per pair). They use the following website: https://www.sophia.org/tutorials/measurements-and-prefixes--3[16] to find information concerning powers of ten, orders of magnitude and prefixes used in the metric system. They will also use the interactive site at: htwins.net/scale2/ [17] to view the scale of objects and find the appropriate examples for the following activity. Students will make a foldable using register tape. Each student will measure out 1 meter of register tape and cut it. They will fold it in half hamburger style and mark a line down the centerfold, dividing the left and right sides equally. Then, starting at the center fold, measure to the right, measure 7.5cm fold the left, again measure 7.5cm, this time fold to the left, continue to the end. Repeat this process to the left of the centerfold. Students should have 6 sections on either side of the center line. Each section will house metric measurements and examples, using powers of 10, from 10^{-18} through 10^{18}, increasing by 3 orders of magnitude in each section. Sections to the left of the centerfold will be used for powers of ten from 10^{-3} through 10^{-18}. Sections to the right of the centerfold will be used for powers of ten from 10^{3} through $10^{-}18$. For example, the first fold to the right of centerfold would contain- the prefix (kilo), it’s meaning (10^{3}), a sketched and labeled example with its measurement written both ways (Large Hadron Collider - 8.6 kilometers and 8.6×10^{3} meters).

Day 5- Surface Area Discussion and Practice

Engage-

Students will be placed in heterogeneous groups of 4. I will ask the class, “Can anyone can explain surface area?” After discussing their ideas with group members for 2 minutes, the reporter for each group will be asked to report out, to the rest of the class, their groups’ ideas about surface area. The group recorder will write or draw their group’s explanation of surface area on the board, while the reporter explains. We will review student ideas for correctness and misconceptions. If no one used a mathematical formula to explain surface area, I will ask, “Does anyone know a formula for surface area?” If so, I will place it on the board and show an example. If the example was not for a rectangular prism, I will place that formula ($2wl+2lh+2hw = units^{2}$) on the board and we will discuss what the formula is saying and what has to be measured, in order to capture all of the surface area of an object. Students will record correct surface area information and examples in their journals.

Check for understanding: Students will practice surface area problems on the board.

Explore-

Show the students a set of various sized blocks. Put the blocks together to build a cube or rectangular prism. Then, take them apart again. Ask students, “Does surface area increase or decrease as an object gets smaller?” Students will make a hypothesis and record it in their journals.

Groups will be given, similar sets of various sized blocks and rulers. Each group will measure the surface area of each block. They will draw a table in their journals to record the block shape and surface area. They will add all surface areas together to find the total and record it. Then each group, will use all of their blocks to build an object. Cubes and rectangular prisms are easiest to work with, but if students understand the concept of area they can build any shape they choose. They will measure and calculate the surface area of the object they built and record this calculation. They will review their data to determine how surface area is affected as size increases and decreases. Students will need to write a conclusion paragraph relating their hypothesis to their results. Conclusion questions to guide writing. Was your hypothesis correct? How do you know?
Ask each group to discuss why they think the amount of surface area, of an object, might be important. Brainstorm for 1 minute after which each group reporter will report out to the class why their group thinks surface area might be important. Explain that chemical reactions occur at the surface layer of materials so increasing surface area increases chemical reaction rates. Have them make this a note in their journals to refer to later.

Day 6- Surface Area Lab (Alka-Seltzer/water Lab Experiment)

Review surface area information from previous day. Remind students that chemical reactions typically involve the atoms or molecules at the surface of objects. For this reason, the amount of surface area is important when considering how a material will behave and/or interact with its' environment. Each student will get a procedure/activity sheet and glue it in their journals so they can fold it in half, hamburger style. (see Appendix 3)

Elaborate-

Students will be asked to make a hypothesis concerning which size Alka-Seltzer (whole tablet, broken tablet or crushed tablet) they believe will have the shortest reaction time when mixed with the water. They will record their hypothesis in their journals. Students will work in heterogeneous groups of 3 during this activity. Each group member will receive a procedure/activity sheet. After reading the procedure, one student from each group will gather the required materials. Groups will use Alka-Seltzer tablets of varying sizes (whole, broken, crushed) and water, to observe the reaction and record the amount of time required to dissolve each tablet. During their experiment, each group member will record their observations, in their journal. Reaction times will be recorded in the table provided on the activity sheet. Students will individually, complete the conclusion questions at the bottom of the activity sheet.

Explain-
Students will discuss their hypothesis, lab results and conclusion question answers with fellow group members.

Evaluate-
Students will write a conclusion paragraph, in their journals, relating their hypothesis to their results. Were students able to conclude that increased surface area equals increased rate of reaction?

Day 7- Geckoman World 2

Explore-
Students will log onto their computers and go to the Geckoman video game. They will navigate to World 2 and play for 20 minutes.

Explain-
After 20 minutes, we will close the computer lids and discuss World 2 Discussion Questions and Nikki's Lab Book.
Homework: Complete "World 2" and fill in any lost pages of Nikki's Lab Book.

Day 8- Electromagnetic Spectrum and Visible Light Activity

Engage-
Students will get headphones and computers. They will log onto computers and go to http://studyjams.scholastic.com/studyjams/jams/science/energy-light-sound/light.htm [18]
They will copy the key vocabulary words into their journals. The first time they watch the video they will listen only, pencils down. The next time they watch the video, they will define their key vocabulary terms. Students will then take the self-test and show me their results. Next, students will scroll to the bottom of the page and click on the next lesson called, "Light Absorption, Reflection and Refraction". Again, they will copy the key vocabulary terms and put their pencils down to view the video. Then as they watch the video a second time, they will define key terms. Students will take the self-test and show me their results.

Explore-
As students complete this first activity, they will be placed in groups of 3. Groups will be given a flashlight, a prism, colored pencils and lineless index cards.
The task is to prove that white light is made-up of all the visible colors. Students will need to record in their journals, the steps they took or procedures they used, to make this determination. Once the group has produced a "rainbow", each student should place their index card so that the colors project onto the card. Then use the colored pencils to color/sketch in the visible colors and label each one with the correct color name and wavelength in nanometers. The completed index card will be glued into their journals under the "steps" they just wrote for this activity.

Explain-

Discussion questions: Did you notice anything about the order of the colors? Was the order the same or different for each group? Why do the colors go in the same order each time? Hint: wavelength and refraction

Day 9- Chlorophyll Fluorescence Lab

Elaborate-
In this activity, students will observe fluorescence in chlorophyll, the green pigment found in plant leaves. Students will grind spinach leaves and add acetone to dissolve the chloroplasts and thylakoid membranes. The mixture will then be filtered, leaving behind the 'chlorophyll a' pigments and acetone. Students will observe that the green chlorophyll extract, under dimmed light, fluoresces red when a directed beam is shown through the test tube at a 90° angle.
Students will read the background information and follow the directions found on the Chlorophyll Fluorescence Activity Sheet. (see Appendix 4)

Students understand that light reacts with materials in many different ways and what we initially see (direct observation) may not tell the whole story. They will also understand that energy is transferred from the light photons in the beam to the chlorophyll extract and again, when the excited photon (with nowhere to go) releases its energy in the form of light and heat.

Day 10- Geckoman World 3

Explore-
Students will log onto their computers and go to the Geckoman video game. They will navigate to World 3 and play for 20 minutes.

Explain-
After 20 minutes, we will close the computer lids and discuss World 3 questions and Nikki's Lab Book with students at your table.
Homework: Complete "World 3" fill in any lost pages of Nikki's Lab Book.

Day 11

Explain-
Discuss World 3 and Nikki's lab sheets in heterogeneous groups of 4. (10 min)
Review what we have learned so far about nanoscale objects and materials. Class discussion (10 min)
Ask students to think about ideas and questions, such as "What can we do with nanotechnology?" or "How can nanotechnology be used to improve society?" also, "Do you think there might be risks associated with nanotechnology?" Students will record their ideas in their journals. (10 min)

Students will then pass their journals to students in another group to receive a response. Students will not make comments concerning grammar or spelling. They may respond to content only using positive feedback and sharing their own ideas concerning the questions posed. (5 min)
Homework: Read 2 *Nanooze*[19] articles. In their journal, students will summarize both articles and draw a Venn diagram to compare and contrast the articles.

Day 12-13 Carbon Nanoparticle Synthesis

Elaborate-

This activity is based on a thesis paper written by Bonnie Chen in partial fulfillment of the requirements for the degree of Master of Science from Texas A&M University.[20] Ms. Chen used a supersaturated glucose/water solution to synthesize carbon nanoparticles of varying fluorescence with respect to size. She used a Discover system microwave synthesizer to monitor pressure and control the time, temperature and wattage of the chemical reaction. The size of the carbon nanoparticles she synthesized, were found to be more dependent on time and wattage of the reaction, rather than other variables, such as temperature. As previously stated, the carbon nanoparticles produced, will fluoresce according to their size. In the absence of an electron microscope or atomic force microscopy, this property will be used to confirm that students have actually synthesized nanoparticles and the color of fluorescence will determine if their procedures were followed correctly.
Students become the scientists acting as Ms. Chen's scientific peers as they attempt to replicate parts of Ms. Chen's experiment and confirm or deny her findings. This part of the scientific process, is not often experienced in a middle grade science lab setting, making it seem to be of less importance. However, being able to replicate an experiment and produce the same results repeatedly, adds credibility to the experimental process and the scientist findings, as a result, of such an experiment. This is how discoveries are made and theories are established.

The first day of carbon nanoparticle synthesis-

Students will read parts of Ms. Chens thesis, including her hypothesis statement, background research, experiment design and procedures, and collected data as well as her results and findings. We will review and discuss the paper to answer questions and clarify students understanding of her experiment and results. Students will review Table 5.1 of Ms. Chen's thesis, outlining the synthesis procedures Ms. Chen used, to produce carbon nanoparticles of a specific fluorescent color and size. Here, students will see that Ms. Chen systematically changed only one variable at a time. With each variable change, she performed the experiment, gathered the data and recorded the results. While students read specified sections of Ms. Chen's thesis, I will prepare 100ml of super saturated glucose solution. Students will observe this solution under the UV light, to determine that it does not fluoresce prior to performing the experiment.

Students will be placed in random groups of 4, by having them choose a procedure, out of the hat, so to speak. Procedure strips will read like this for example: Microwave for 10 minutes at 300 watts. Students with identical procedure strips will form into groups. Students will review Table 5.1 described above, to discover, at what color their carbon nanoparticles should fluoresce, when viewed under UV light. Students will transfer their specific synthesis process information, as well as the expected outcome to their journals.

The second day of carbon nanoparticle synthesis-

Students will go to their groups from the day before to review the entire procedure. Each group will be given a tray containing their supplies except for the super saturated glucose solution and the synthesis microwave. Each group will need to come to me and measure the proper amount of glucose solution into their vials. Each group will then take turns using the microwave to synthesize their particles. One person in the group will need to load the sample into the microwave system, start a new procedure, set the temperature, time and wattage recorded on their procedure form, from the previous day. During this set-up, all group members must confirm that the input setting is correct according to their synthesis procedures, before moving to the next setting. If all group members agree that each input setting is correct, they may start the microwave synthesis.

Evaluate-

After cooling, each sample will be viewed under UV light to determine fluorescence. Students will discuss and record their results. If the results are unexpected we will attempt to discover reasons, by reviewing each step to determine if this might be an error on our part or truly a different result than was predicted. This boils down to research ethics. The researcher, has to be truthful and as unbiased as possible, when performing experiments and reporting results. Students need to realize that an unexpected result does not always mean they are wrong or will receive a poor grade, only that they will need to explain why they think they got the results that they got. Following the group discussions students will write a conclusion statement, in their journals, explaining their results.

Evaluate-

As groups wait their turn with the microwave they will complete the Geckoman post-assessment and complete the L-learned section of the KWL chart they started on Day 2.

Appendix 1

Implementing Teaching Standards

This curriculum unit will address the following North Carolina Essential Science Standards

6.P.1 Understand the properties of waves and the wavelike property of energy in earthquakes, light and sound waves.

> 6.P.1.1 Compare the properties of waves to the wavelike property of energy in earthquakes, light and sound.
>
> 6.P.1.2 Explain the relationship among visible light, the electromagnetic spectrum, and sight.

Day 8 lesson explores the electromagnetic spectrum, visible light and the relationship between wavelength and color.

6.P.2 Understand the structure, classifications and physical properties of matter.

> 6.P.2.1 Recognize that all matter is made up of atoms and atoms of the same element are all alike, but are different from the atoms of other elements.

Nanotechnology is the human ability to manipulate a material at the atomic level by building nanostructures from the bottom up, one atom at a time. Students will come to understand, for example that a gold nanoparticle is made up of gold atoms just as a gold wedding band is made up of gold atoms.

6.P.3 Understand characteristics of energy transfer and interactions of matter and energy.

> 6.P.3.2 Explain the effects of electromagnetic waves on various materials to include absorption, scattering, and change in temperature.

This is also part of Day 8 and Day 9 activities. On Day 9 students will observe chlorophyll under normal lighting conditions and then in dim light with only a beam of light passing through the chlorophyll. They will see that under dim light the normally green, chlorophyll appears red. This is due to an excited electron that has nowhere to go, since it's normal path to photosynthesis has been disrupted. The excited photon releases its energy in the form of light and heat.

8.P.1 Understand the properties of matter and changes that occur when matter interacts in an open and closed container.

> 8.P.1.3 Compare physical changes such as size, shape and state to chemical changes that are the result of a chemical reaction to include changes in temperature, color, formation of a gas or precipitate.

Students will see chemical changes during the lab experiment on Day 6 as they observe the between water and Alka-Seltzer. On the final day of the unit, students will synthesize carbon nanoparticles using glucose and water. They will use a closed vessel microwave system to produce the reaction. By controlling the time and wattage of the reaction, students will synthesize particles of different sizes. These particles fluoresce at different colors based on their respective size.

Appendix 2

Geckoman Pre and Post Assessment Name _________________________

1. Have you heard of nanotechnology before?
    a) No, never.
    b) Yes, but not before this class.
    c) Yes, at home or in the news.
    d) Yes, at school.

For questions 2 to 6, use the Word Bank.

Rank the items in questions 1 through 6 from smallest (1) to largest (6).

2. ______ smallest
3. ______
4. ______
5. ______
6. ______ largest

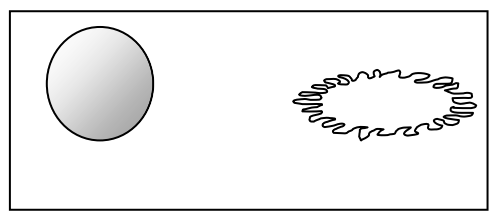
Word Bank:
(a) an atom
(b) thickness of a hair
(c) a bacterium (single cell)
(d) an ant
(e) a molecule

7. On the nanoscale, do you think a particle has **more** or **less** adhesion (stickiness) on a rough surface?

a) The paticle has **more adhesion** on a rough surface.
b) The particles will **adhere equally** on rough and smooth surfaces.
c) The particle has **less adhesion** on a rough surface.
d) Not enough information given.
e) Don't know.

8. Which of the following particles will have more adhesion at the nanoscale?

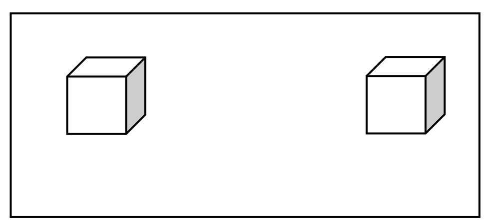
These particles have the same mass, but one has more contact area and one has less.



a) The paticle has **more adhesion** with more contact area.
b) The particles will **adhere equally** with more contact area.
c) The particle has **less adhesion** with more contact area.
d) Not enough information given.
e) Don't know.

9. Which of the following particles will have more adhesion at the nanoscale?

These particles have the same contact area, but one has greater mass than the other.

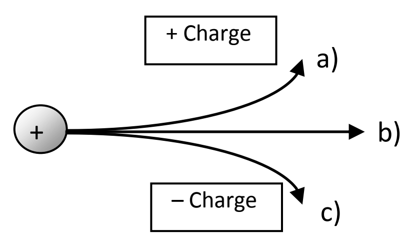


a) The paticle has **more adhesion** with greater mass.
b) The particles will **adhere equally.**
c) The particle has **less adhesion** on with greater mass.
d) Not enough information given.
e) Don't know.

10. A particle with a positive charge moves past two charged areas, as shown.

a) The positive particle will move to the positive charge.
b) The positive particle will not change its path.
c) The positive particle will move to the negative charge.
d) Not enough information given.
e) Don't know.

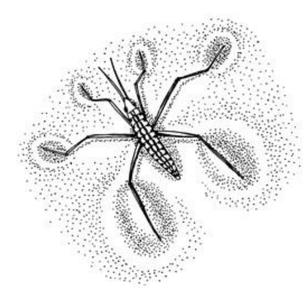
Image for question 16:



11. A water strider can travel across the surface of a pond because:

a) The surface tension of the water is greater than the force of the insect pushing down on the water.
b) The surface tension of the water is less than the force of the insect pushing down on the water.
c) The density of the insect is greater than the density of the water.
d) The density of the insect is less than the density of the water.
e) The surface tension of the water is greater than the density of the insect.

Water strider on a pond surface:



Appendix 3

Alka-Seltzer Surface Area Lab Experiment

Materials needed for each group:

Safety Googles	Graduated cylinder
6 Plastic cups	Mortar and pestle
3 Stop watches	3 Alka-Seltzer tablets
Sharpie	Water

Process:

1. Set out 3 cups. Place 100ml of water into each of these 3 cups.
2. Label the other 3 cups: Cup1-Whole, Cup 2-Broken, Cup 3-Crushed
3. Place a whole Alka-Seltzer tablet in Cup 1.
4. Gently break the second tablet into 3-5 fairly large pieces and place the pieces into Cup 2. Record the number of pieces.
5. Take the third tablet and grind it up into a fine powder using the mortar and pestle. Place the powder in Cup 3.
6. Pour one of the cups of water into Cup 1. As soon as you pour water into a cup, start a stopwatch and place in front of that cup.
7. Repeat step 6 with Cup 2 and Cup 3.
8. Observe the reactions and monitor the time. Stop the stop watch when the tablets have fully dissolved of fizzing has completely stopped. Record the time for each reaction in table below.

Tablet Size	whole	broken- number of pieces ( )	crushed
Reaction Time	_____min______sec	_____min______sec	_____min______sec

Conclusion Questions

1. Which size tablet had the fastest reaction time?
2. Why did this size tablet react more quickly?

Appendix 4

Chlorophyll Fluorescence Experiment

Background Chemistry

Grinding the spinach leaves disrupts the normal structure of the leaf cells and releases 'chlorophyll a'. Normally, chlorophyll absorbs light energy that excites an electron, which is then transferred to an acceptor molecule used during photosynthesis. However, in this experiment, the excited electron is not transferred anywhere because we disrupted the leaves' normal functions, so the energy is released again as light, i.e. **an electron gets excited to a higher energy level by a photon of light but then releases it again when the energy is not transferred anywhere else.** Under normal lighting conditions, the solution appears green because the chlorophyll is absorbing red light from all directions. Under darkened conditions, the chlorophyll is absorbing red light from the beam and then releasing it immediately, so we see the solution as red.[1]

MATERIALS Each group will need:	**PROCEDURE**
Safety goggles Fresh spinach leaves Mortar and pestle Acetone25-50mL Erlenmeyer flask Test tube Flashlight Filter paper Funnel	**1. Grind the spinach leaves using a mortar and pestle.** **2. Place leaves in Erlenmeyer flask.** **3. Add between 15 and 20 mL of acetone to the ground leaves.** **4. Place filter paper in the funnel. Place the funnel into the test tube.** **NOTE: Use a small amount of acetone to wet the filter paper, to hold it into place, instead of water.** **5. Filter the chlorophyll extract by pouring the liquid from the Erlenmeyer flask into the test tube.** **6. Shine a flashlight, or other similar light source, through the test tube and extract.** **7. Observe the fluorescence of the chlorophyll at a 90 degree angle to the flashlight.**

Conclusion questions

1. What made the electrons in the extract, get excited?
2. Since the excited electron had nowhere to go, how did it release or transfer its energy?

Student Recourses

National Nanotechnology Infrastructure Network. *Nanooze.* Carl Batt. Cornell University. Retrieved from http://www.nnin.org/education-training/nanooze-magazine
This is a nanotechnology magazine directed at 10-14 year olds. It is available online and in print free to educators.

Geckoman Computer Game. *Geckoman.* Northeastern University Center for High-rate Nanomanufacturing faculty, NEU game designers and education associates at the Museum of Science. http://www.coe.neu.edu/Research/geckoman/
Students will play Geckoman during several lessons to explore the nanoscale environment and discover why nanoscale objects behave differently than macroscale objects.

Scale of the Universe: Interactive size and scale. Haung, Cary and Michael. (2012). Retrieved from http://htwins.net/scale2/
This is an interactive site where students can zoom in and out to view objects smaller than sub-atomic particles and larger than galaxies. Useful in understanding size and scale, orders of magnitude and powers of ten.

Sophia Learning Website. *Measurements and Prefixes.* Retrieved from https://www.sophia.org/tutorials/measurements-and-prefixes--3
This is a useful website to learn about the metric system, prefixes and powers of ten.

Materials for Classroom Use

Each student will need a composition book to use as their interactive journal, access to a computer or Chromebook, construction paper, plain white paper, card stock or manila envelopes cut in half, markers, glue, tape, stapler, metric rulers.

Ball, Philip. “Renaissance nanotechnology.” Materials@nature.com (2003). http://www.nature.com/materials/nanozone/news/030626/portal/m030626-2.html
This article discusses the process used, in parts of Italy, to make ceramic luster glazes, during the Renaissance period. The metallic look of pottery from this area was caused by metal nanoparticles in the glazes.

Carl Batt. “Nanooze Magazine.” *National Nanotechnology Infrastructure Network.* 2016. Accessed March 21, 2015. http://www.nnin.org/education-training/nanooze-magazine
This is an excellent resource. *Nanooze* is a science magazine designed especially for kids. It contains the *Nanooze* magazine online as well as free print copies. It also has K-12 teacher nanotechnology curriculum lessons and activities and student resources.

Charlotte Mecklenburg Schools. *School improvement plan 2015-16 through 2016-17.* October 26, 2015. Retrieved from Charlotte Mecklenburg Schools web site: http://schools.cms.k12.nc.us/coulwoodMS/Pages/SchoolImprovementPlan.aspx
This website includes all departments within the CMS school system including individual School Improvement Plans.

Dictionary.com. definitions retreived from http://www.dictionary.com/ Accesed October 23, 2016

Feynman, R.P. (1960, February). *There's plenty of room at the bottom*. Retrieved from Zyvec Nanotechnology website: http://www.zyvex.com/nanotech/feynman.html Accessed Oct. 22, 2016.
This website has Feynman's lectures and a scanned copy of the original published speech, *There's Plenty of Room at the Bottom,* found in the Caltech journal, Engineering and Science, Volume 23:5. This speech is often pointed to as the foundation of nanotechnology.

Heiligtag, Florian J. and Neiderberger, Markus. The Fascinating World of Nano Research.” Materials Today16, no. 7-8 (2013). Accesed July 19, 2016. http://dx.doi.org/10.1016/j.mattod.2013.07.004
Describes ways that nanoparticles have been used in ancient times, nanoparticle synthesis, formation and applications.

Horikoshi, Satoshi and Serpone, Nick. Microwaves in Nanoparticle Synthesis: Fundamentals and Applications. Wiley-VCH Verlag GmbH & Co. KGaA, 2013. Accesed June 15, 2016 http://onlinelibrary.wiley.com/doi/10.1002/9783527648122.ch1/summary
The first chapter is a good introduction to nanoparticles. Gives a brief history, describes nanoparticle properties and outlines some current applications.

Huang, Cary and Huang, Michael. “Scale of the Universe 2.” htwins.net (2012). Accessed August 3, 2016 http://htwins.net/scale2/
This is an interactive website where students can view objects large and small. Helps to reinforce the difficult concepts of size and scale. Use with the Powers of Ten Foldable Activity.

mreppsclassroom. “Inferences and Observations”. Filmed [Aug 2013]. YouTube video, 06:00. Posted [Aug 2013]. https://www.youtube.com/watch?v=CFmj_NY5tvg
A short video explaining the difference between an inference and observations. There is also an explanation of the differences between qualitative and quantitative observations.

National Institutes of Health. Office of Science Education Report. *The BSCS 5E Instructional Model: Origins and Effectiveness*, by Rodger W. Bybee, Joseph A. Taylor, April Gardner, Pamela Van

Scotter, Janet Carlson Powell, Anne Westbrook, and Nancy Landes with research and preparation assistance from Samuel Spiegel, Molly McGarrigle Stuhlsatz, Amy Ellis, Barbara Resch, Heather Thomas, Mark Bloom, Renee Moran, Steve Getty, and Nicole Knapp. Office of Science Education Report. Colorado Springs, Colorado, 2006. Retrieved from https://bscs.org/sites/default/files/_media/about/downloads/BSCS_5E_Full_Report.pdf Accessed September 29, 2016.
This report gives a detailed account of the evolution and impact of the 5E instructional model.

National Nanotechnology Initiative website. *Nanotechnology timeline*. Retrieved from http://www.nano.gov/timeline Accessed June 12, 2016.
The nano.gov website is extremely informative. Includes nanotechnology history, current nano news and resources for k-12 teachers and students.

National Nanotechnology Initiative. "Benefits and Application." Nano.gov. Retrieved from http://www.nano.gov/you/nanotechnology-benefits Accessed June 12, 2016.

North Carolina Department of Public Instruction. *Standard course of study; Middle grade science.* Retrieved from North Carolina Department of Public Instruction website: http://www.dpi.state.nc.us/docs/curriculum/science/scos/support-tools/new-standards/science/6-8.pdf Accessed September 15, 2016
North Carolina Standard Course of Study, Essential Standards, Common Core Crosswalks and additional teaching resources are housed, at this website.

Northeastern University. "Geckoman Computer Game." Geckoman. January 27, 2009. Accessed October 19, 2012. http://www.coe.neu.edu/Research/geckoman/
This web address will take you directly to the Geckoman computer game.

Northeastern University. "Geckoman Project." NEU Nonmanufacturing. Accessed October 19, 2012. https://sites.google.com/site/geckomanproject/home
This site introduces information about the Geckoman computer game and strategies for using the game to teach nanotechnology concepts. Also has connections to standards.

Penderson, Joel. "Nanotechnology Through History: Carbon-based Nanoparticles from Prehistory to Today," *Sustainable Nano* (blog), Center for Sustainable Nanotechnology, June 17, 2013. Accessed September 3, 2016. http://sustainable-nano.com/2013/06/17/nanotechnology-through-history-carbon-based-nanoparticles-from-prehistory-to-today/
Short history of carbon nano particles throughout history.

Scholastic. "Energy Light and Sounds." Studyjams.scholoastic.com. 2016. Accessed Oct 3, 2016. http://studyjams.scholastic.com/studyjams/jams/science/energy-light-sound/light.htm
Interactive site explaining the properties of light. Contains videos and self tests.

The Solar Spark. "Chlorophyll Fluorescence Teachers Notes." thesolarspark.co.uk. Accessed September 9, 2016. http://www.thesolarspark.co.uk/wp-content/uploads/2013/05/Chlorophyll-Fluorescence-Teachers-Notes.pdf
Useful background information about light energy, color and chlorophyll fluorescence.

Notes

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[1] Charlotte Mecklenburg Schools website.
http://schools.cms.k12.nc.us/coulwoodMS/Pages/SchoolImprovementPlan.aspx

[2] North Carolina Department of Public Instruction website.
http://www.dpi.state.nc.us/docs/curriculum/science/scos/support-tools/new-standards/science/6-8.pdf

[3] Penderson, Joel. "Nanotechnology Through History: Carbon-based Nanoparticles from Prehistory to Today," *Sustainable Nano* (blog), Center for Sustainable Nanotechnology, June 17, 2013, http://sustainable-nano.com/2013/06/17/nanotechnology-through-history-carbon-based-nanoparticles-from-prehistory-to-today/

[4] Horikoshi, Satoshi and Serpone, Nick. Introduction to Nanoparticles. Wiley-VCH Verlag GmbH & Co. KGaA, 2013 http://onlinelibrary.wiley.com/doi/10.1002/9783527648122.ch1/pdf

[5] Penderson, Joel

[6] Heiligtag, Florian J. and Neiderberger, Markus. The Fascinating World of Nano Research." Materials Today16, no. 7-8 (2013). http://dx.doi.org/10.1016/j.mattod.2013.07.004

[7] Ball, Philip. "Renaissance nanotechnology." Materials@nature.com (2003).
http://www.nature.com/materials/nanozone/news/030626/portal/m030626-2.html

[8] Feynman, R.P. (1960, February). *There's plenty of room at the bottom*.
Retrieved from Zyvec Nanotechnology website:
http://www.zyvex.com/nanotech/feynman.html

[9] National Nanotechnology Initiative. "Nanotechnology Timeline." Nano.gov.
http://www.nano.gov/timeline

[10] National Nanotechnology Initiative. "Benefits and Application." Nano.gov.
http://www.nano.gov/you/nanotechnology-benefits

[11] National Institutes of Health. Office of Science Education Report. *The BSCS 5E Instructional Model: Origins and Effectiveness*, by Rodger W. Bybee, Joseph A. Taylor, April Gardner, Pamela Van Scotter, Janet Carlson Powell, Anne Westbrook, and Nancy Landes with research and preparation assistance from Samuel Spiegel, Molly McGarrigle Stuhlsatz, Amy Ellis, Barbara Resch, Heather Thomas, Mark Bloom, Renee Moran, Steve Getty, and Nicole Knapp. Office of Science Education Report. Colorado Springs, Colorado, 2006.
https://bscs.org/sites/default/files/_media/about/downloads/BSCS_5E_Full_Report.pdf

[12] Northeastern University. "Geckoman Project." NEU Nonmanufacturing. January 27, 2009. Accessed October 19, 2012 https://sites.google.com/site/geckomanproject/home
This site introduces information about the Geckoman computer game and strategies for using the game to teach nanotechnology concepts. Also has connections to standards.

[13] mreppsclassroom. "Inferences and Observations". Filmed [Aug 2013]. YouTube video, 06:00. Posted [Aug 2013]. Accessed August 13, 2016. https://www.youtube.com/watch?v=CFmj_NY5tvg

[14] Northeastern University. "Geckoman Computer Game." Geckoman. January 27, 2009. Accessed October 19, 2012. http://www.coe.neu.edu/Research/geckoman/

[15] Northeastern University. "Geckoman Project."

[16] Lampson, Nathan. "Measurements and Prefixes." 2016. Accessed September 7, 2016. https://www.sophia.org/tutorials/measurements-and-prefixes--3

[17] Huang, Cary and Huang, Michael. "Scale of the Universe 2." htwins.net. 2012. Accessed August 3, 2016. http://htwins.net/scale2/

[18] Scholastic. "Energy Light and Sounds." Studyjams.scholoastic.com. 2016. Accessed Oct 3, 2016. http://studyjams.scholastic.com/studyjams/jams/science/energy-light-sound/light.htm

[19] Carl Batt. "Nanooze Magazine." *National Nanotechnology Infrastructure Network.* 2016. Accessed March 21, 2015. http://www.nnin.org/education-training/nanooze-magazine

[20] Bonnie Chen, "Microwave-assisted synthesis of fluorescent carbon nanoparticles." master's thesis. Texas A&M University. 2014. Retrieved from http://oaktrust.library.tamu.edu/bitstream/handle/1969.1/153578/CHEN-THESIS-2014.pdf?sequence=1