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The Size of Matter: Why Properties Change at the Nanoscale

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Overview

One basic idea that even Einstein started with is that our physical universe is made of matter and energy. [1] Matter and energy are therefore, studied in the area of chemistry and physics. The chemistry component addresses questions such as what is the composition of matter. The physics component is more concerned with the forces responsible for holding atoms together. To understand matter on tiny scales requires one to have a basic understanding of chemistry and physics. This basic understanding will help individuals understand why the properties and functions of matter change as materials go from bulk size substances to nanoparticles of the same materials.

We accept the idea that we live in both a macroscopic and microscopic world. The macroscopic world includes the objects we see objects with our naked eye. The microscopic world requires us to use special tools such as microscopes to view very tiny objects. The emergence of technology has afforded us an opportunity to discover more about our microscopic world and the overall importance of size in our lives. Small children are acutely aware of size differences in their world. Their world is full of large adults whom they are constantly looking up to in an effort to assess the world around them. The reference point for humans as it relates to size is generally our own size. Although we see and compare objects all around us by size, we seldom stop to think of the importance of size in our everyday life.

Bonner notes that there are five rules that correlate to size and the properties of matter. [2] Two of these rules will be the discussed in this unit. The first rule for review is strength varies with size. The second rule for review is surface area varies with size. One should be aware that size also affects the divisions of labor among organisms, and the rate at which living processes such as metabolism, generation time, longevity, and the speed of locomotion. [3] Size is also a determining factor in regards to the abundance of an organism in nature.

Rationale

The students participating in this unit will be in eighth grade physical science. Classes will consist of general, high achiever, and gifted students. The curriculum standards for the first six weeks focus on the structure and properties of matter. All classes meet on a modified block schedule; students attend all classes on Mondays and follow a block schedule for the remainder of the week. District and state standards change at six-week intervals. The modified block schedule allows me to preface the lessons for the week on Mondays, and incorporate hands on and other engaging activities during the block schedule. The units design fits within the required standards for matter, and incorporates required characteristics of science standards. The unit will afford me an opportunity to introduce a different perspective to scale, size, and properties of matter. Students will gain a better understanding of size and scale and its relationship to properties of matter. Many students at my school have difficulty understanding relative and absolute sizes. Introducing a unit on size will bring clarity to this issue. Students need to recognize that changes in size can affect how matter functions and behaves.

Objectives

The first objective of the unit is for students to be able to know an objects size as it compares to a known reference point. Students should recognize that an objects size is measureable by means of a scale or reference point. Students must also be able to arrange objects in order based on their size. Students need to be able to describe an object in multiple contexts. [4] Students must understand some objects are too tiny to view with the naked eye, which include micro, nano, molecular, and atomic size objects. These tiny divisions define different systems in the microscopic world. Many students have the misconception that objects in the microscopic world are the same size. Very often, their frame of reference for a tiny object relates to what they perceive as tiny. They may think an ant is very tiny and perceive that it is on the same scale as a cell or an atom, when in actuality all three of these objects are dramatically different in size. Another objective of the unit is to help students understand size can be comparisons between two known objects or an actual numeric measurement. Students will need to know the differences in value between 10, 100, 1000, and 1,000,000 and their inverses. [5] They need to understand the metric prefixes of kilo, centi, milli, micro, and nano and their relationship to each other.

A second set of objectives relate to properties of matter. Students should have an understanding of bulk materials and their properties. Students need to be aware that properties change at the nanoscale because of quantum mechanics. Students need to understand that some properties of nanoparticles are due to surface area. Students should be able to explain why properties of nanoscale objects can be different from larger particles of the same material at the macro scale. Finally, students need to understand the link between surface area, size of particles, and reactivity.

Background

The Structure of Matter

Atoms are the "building blocks" of all matter. Matter is anything that has mass and takes up space. As the sizes of various substances begin to move towards the nano-scale, their properties can become unique and dramatically different from the same substances in bulk form. To understand the affect size has on matter one must understand the structure of an atom.

Atoms are made of three smaller subatomic particles. Two subatomic particles are in the nucleus of an atom. The nucleus comprises the majority of the atom and is centrally located in an atom. The largest particles in the nucleus are protons. Protons have a positive electrical charge and the largest mass of the three subatomic particles. Neutrons are slightly smaller than the protons in the nucleus. Neutrons are neutral because they have no charge. Electrons are the last type subatomic particle. They possess a negative electrical charge, are very light and small in mass. Electrons are in constant motion and orbit around the nucleus at rapid speeds. Every element has a set number of protons, thus the protons determine each specific element on the periodic table. Electrons determine properties of materials such as conductivity, magnetism, and reactivity.

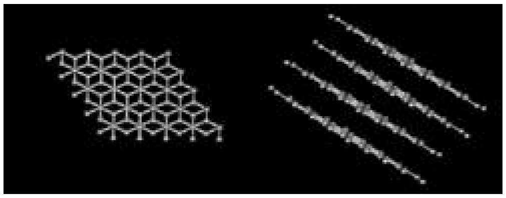
Forces and Matter

In nature, four forces affect atoms, gravitational forces, electromagnetic forces, strong nuclear forces, and weak forces. "Strong nuclear" forces hold protons and neutrons in the nucleus of an atom. This force is limited in range and has little influence beyond the range of the nucleus. Gravitational force is a function of mass and distance and is weak between nanosized particles. [6] Gravitational forces are negligible at the nanoscale because the mass of nanoscale objects is very small. Electromagnetic force is a function of charge and distance it is not affected by mass, so it can be very strong even when we have nanosized particles. [7] Electromagnetic forces occur between protons and electrons. The closer these charged particles are to each other the stronger the electromagnetic attraction. As the distance between these two charged particles increases, the electromagnetic attraction between them weakens. The forces that act on atoms can be attractive (unlike charges attract each other) or they can be repulsive (like charges repel each other). Electromagnetic forces act between the positively charged protons and negatively charged electrons. Electromagnetic forces help give an atom its shape and size. The size and shape of an atom depends upon the forces that attract electrons towards the nucleus and the repulsive forces that cause electrons to repel each other. An atom's ability to form chemical bonds depends upon the electromagnetic forces acting on the electrons found on the outermost energy level of an atom. When atoms do not have a complete outer energy level of electrons, they will transfer or share electrons with other atoms to become more stable. When atoms form chemical bonds with other atoms, they can form stable molecules.

Molecular Structure and Mechanical Properties of Matter

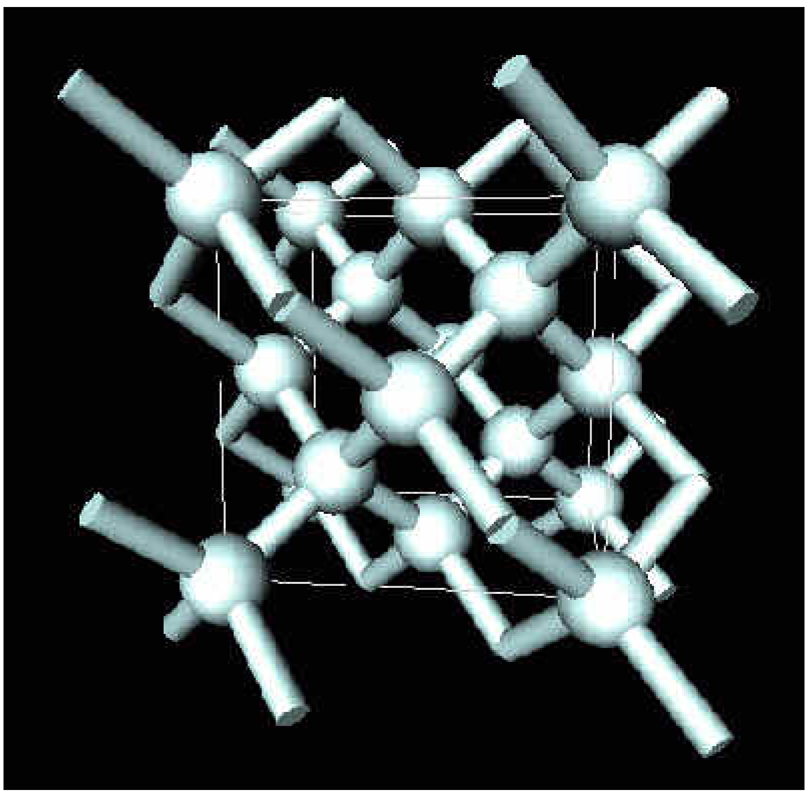
The atom carbon is a good example of how structural arrangements of atoms affect the properties of the resulting material. Carbon atoms have the ability to bond with many types of atoms, by means of covalent bonding (sharing of electrons to form chemical bonds). Carbon can form covalent bonds with four other atoms at the same time.

One common material formed when carbon combines with other carbon atoms is graphite. Graphite forms into sheets that are one carbon atom thick. These sheets can be large, with hydrogen atoms on their edge. The bonding that occurs between the sheets is due to weak forces called van der Waals' force. These weak bonds allow the graphite sheets to slide over each other. Therefore, when a pencil containing graphite moves across a piece of paper it leaves a trail of graphite. This property is the reason graphite is suitable as pencil lead and lubricants.



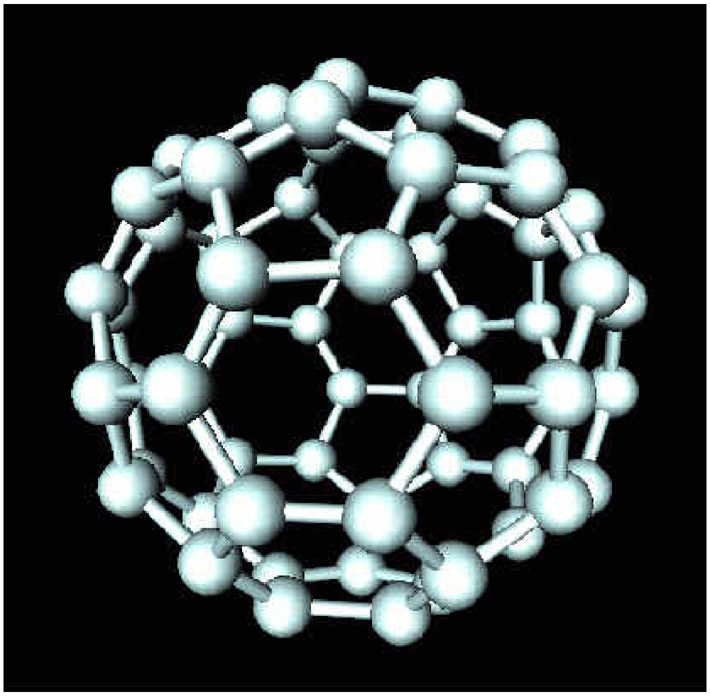
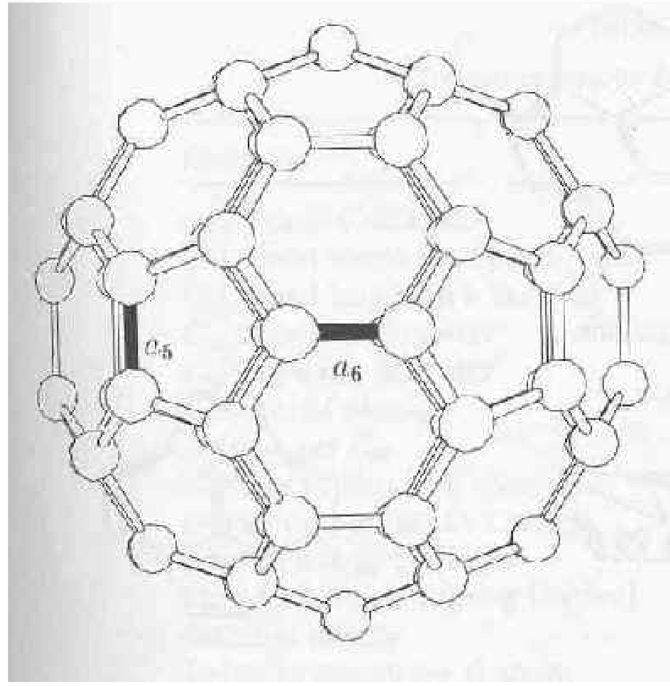
(Graphite)

Diamonds also form when carbon atoms bond together. However, when diamonds form the atoms arrange in neat stacks to form a three dimensional lattice type structure. In these three dimensional lattices, carbon atoms form bonds with each atoms immediately surrounding it in the lattice. A diamond's three-dimensional structural arrangement makes it stable and hard. Diamonds are the hardest known substance in nature.



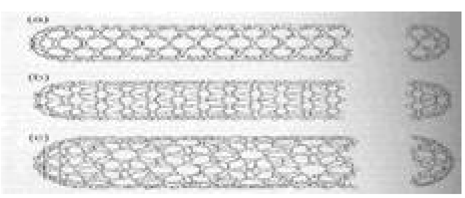
(Diamond)

When carbon atoms bond together at the nanoscale, they can form different structures, which are spherical or cylindrical in shape. Fullerenes, better known as "buckyballs," contain 60 carbon atoms arranged into a spherical lattice containing 12 hexagons and 30 pentagons. These tiny spheres are strong and are good conductors of electricity.

(Fullerene "Buckyball")

Carbon also forms structures called nanotubes. Nanotubes are tiny structures that have a chicken-wire type appearance when rolled up at different angles forming open or closed ended cylinders. These small structures can form into single walled cylinders or multi-walled structures. Nanotubes have great tensile strength because of their interlocking "carbon-to-carbon" covalent bonds, which form a large molecule. [8] Nanotubes are 100 times stronger than piece of steel that is the same diameter. They have the ability to resist bending. These structures are light and have a density that is about one-fourth the density of steel. They can conduct heat and cold, and have a high thermal conductivity.



(Nanotubes)

Size and Scale

What is size? The definition for size is based on the context in which it is used. Size can be the physical magnitude of something (how big it is). [9] Because differences in size are often apparent, we do not give it a lot of thought. Size governs the boundaries for all living and nonliving matter. If we were to compare the mass of a bee to a blue whale we find the bee has a mass of 100 mg or 10^{-1} g and the blue whale has a mass of 100 tons or 10^{8} g. However, do we really understand how size causes each animal to function differently and exhibit different properties in order for each animal to survive?

To define the size of various substances we must use some form of measurement or a tool of measurement. We use these tools to tell us how much or what amount of a given material exist. We use different tools to measure different materials. If we need to know the length of a solid, we use a ruler. To determine the volume of a liquid we may use a measuring cup or a graduated cylinder. Both of these tools use a reference point to help us determine the measure of the substances being observed. If we use some standard unit of measure to determine size, we are determining a quantitative or absolute size. [10] Reference points also help us make measurements. Reference points involve quantitative measurements. Quantitative measurements are absolute. If the disturbance is negligible, the object is large in an absolute sense; a nonnegligible disturbance means an object is small. Absolute size does not involve comparisons of one object to another.

Relative size is determined by comparing one object to another object; an object is large or small in comparison to another object. A relative measurement may involve comparing a rock to the palm of your hand. If the rock fits inside the hand, it would be considered small. If your hand could rest upon the rock, it would be considered large. Many students can make measurements that involve relative size; however, they may lack accuracy in making absolute or quantitative measurements.

Scale can be defined as an ordered reference standard such as a scale of 1 to 10. [11] Scale can also be considered the ratio of two measurements or the size of an object as compared to a model or representation of the object. [12] When we discuss the microscopic world, we examine changes in the scale of an object. Objects at the micro-scale can range in size from .1 µm to 100 µm or in regards to powers of ten from 10^{2} nm to 10^{5} nm. The nanoscale, which is the scale below the micro scale, exists in the range of 1 nm to 100 nm or range from 10^{-9} to 10^{-7} meters. To be considered an object at the nanoscale at least one dimension of the object must fit within the nano-scale range (this is, one dimension must be less than 100nm). A DNA molecule is a good example of an object with one dimension in the nanoscale range. Although a single DNA molecule can be up to 5cm long it is only 2nm wide. The following website provides an excellent demonstration of how objects change in size as scales decrease: http://learn.genetics.utah.edu/content/begin/cells/scale/

Scientific notation is useful for describing objects at the nano-scale; scientific notation allows us to relate the size and scale of objects to well known metric units without using long strings of zeros as placeholders. To use scientific notation, one must understand that negative powers of ten are the reciprocal of the powers of ten. For example, if we stated an object was 10^{-3} m, it means the object is 1/1000 of a meter. When working with substances smaller than one and greater than one the powers of ten become useful. Addressing objects based on varying scales helps one conceptualize how large or small an object really is. Use of scientific notation and metric units in science can help clarify size as it relates to scale.

Size and Strength

Strength is the amount of load an object can sustain before it breaks. [13] Strength is a mechanical property that is related to the physical structure of a material. [14] As an object gets smaller its relative strength increases, because of the number of imperfections an object has decrease as the size of the material decreases. The larger an object is the number of imperfections it has can increase. The more imperfections an object has the more weak spots it may have. Very small objects tend to have insensitivity to imperfections and are therefore stronger. Carbon nanotubes are very tiny and very strong. The size of these very tiny structures accounts for their increased strength.

Movies often depict gigantic monsters that have extraordinary strength. The gigantic beast is often depicted as a fast moving building wielding creatures. In reality, they would not be able to overcome the affects of size. In truth, King Kong's strength would be diminished because of his size. First, he would not be as active as portrayed because of his size. Second, the strength of a bone is proportional to its cross-sectional area. This means King Kong's bone structure could only support a maximum amount of mechanical force before it would break. The actual load a bone can withstand is proportional to the mass of the object. The hero in "The Incredible Shrinking Man was about an inch tall. In the movie, he was depicted as struggling to lift a needle. In reality, he would have been able to wield the needle around without any problem. His muscle strength would have increased 70 fold. The ratio of his ability to generate force is based on his body mass and would be 1/length; making him proportionally stronger. Smaller animals are proportionally stronger because the forces their muscles produce are proportional to the cross-sectional area. Their weight is proportional to its volume.

Surface Area and Size

Surface area and size change at disproportional rates when one dimension's length at a given scale changes. [15] The surface areas of nanoparticles are responsible for some properties at the nanoscale. As size decreases the surface area increases. For example, a packet of sugar, which has many small particles of sugar, would dissolve in a solution faster than a sugar cube, or large particle of sugar, because the packet of sugar particles has a greater surface area than the cube of sugar.

Surface area causes changes in the reaction time of a substance. The greater the surface to volume ration is as it relates to a reacting substance the faster the reaction time. The amount of exposed surface area increases drastically at the nanoscale level, which is the reason the reaction times for chemical reactions increase. Substances at the nanoscale level have a greater surface-to-volume ratio, which causes them to react very quickly. Small particles have a greater percentage of atoms on their surface, which accounts for the increased surface to volume ratio.

Size Dependent Properties

Properties are the characteristics that determine how a substance behaves, functions, or appear. Properties are generally measured by looking at large aggregations of atoms or molecules ($\sim 10^{23}$). [16] Some properties are size dependent: the size or surface area of the particles determines the functionality, behavior, and appearance of the material. Size dependent properties can be categorized as size-dominated or surface-dominated.

Electrical properties can change at the nanoscale. Some materials that are conductors in bulk form may become semiconductors or poor conductors at the nanoscale. Some materials that were semiconductors may become conductors or superconductors. The confinement of electrons results in the electrical properties that occur at the nanoscale.

Optical properties are also size dependent. Electrons cannot move about as freely at the nanoscale and become restricted. The confinement of the electrons causes them to react to light differently. Gold for example will appear gold at the macro scale in bulk form. However when it occurs as nanosized particles its color is red. Nanosized zinc oxide particles will not scatter visible light, which causes sun block to appear transparent. Large zinc oxide particles used for sun block scatter visible light and appear white. Quantum dots change in their optical appearance as the size of the particles decrease creating different colors.

The second category of surface dominated properties involves properties controlled by their surface area. Melting point, rate of reaction, capillary action, and adhesion are properties that are controlled by their surface area. Gold provides an example of how melting points of a material can change with size. At the macro scale, gold has a melting point of 1064 º C. As its particle size decreases to the 100 nm to 10 nm diameter its melting temperatures drops about 100 ºC. As the size reduces to about 2 nm the melting point decreases to about half of the melting point at the macro scales level. Gold will no longer conduct electricity when it becomes less than 10nm.

Strategies

The instructional format for my school is a modified block schedule. Students attend all seven periods on Mondays and follow an odd even block schedule Tuesday through Friday. Monday class periods are 55 minutes and block classes are ninety minutes. The instructional format is the three- part lesson with an opening, work period and closing. The bulk of the ninety- minute period block is the work period. Multiple strategies will be utilized for class periods to ensure effective delivery of content and the desired learning outcomes.

Technology Integration

Mobile wireless labs will be utilized throughout the unit for students to experience videos and interactive activities related to size and scale. Students will have an opportunity to view objects at the macro scale to the nanoscale using pre-assigned websites and interactive games. The technology approach will help students conceptualize and visualize objects in the various worlds of size.

Think Share Pair Proximity Partners

Students will work with proximity partners to complete a think share activity. The pair will discuss their topic and use critical thinking skills to review and learn key concepts. Each pair will have to discuss and relate information they have learned to questions or activities provided on an assigned topic from the unit.

Inquiry Based Explorations

Students will conduct independent and group labs. Students will have an opportunity to see how surface area, adhesion, magnetisms and physical arrangement of objects change with size.

Graphic Organizers

Students will create various types of graphic organizers such as foldables, flip charts, KWL's, and vocabulary maps to review, learn, and understand concepts taught. Students will use various graphic organizers to help them understand complex ideas and organize the information so they can use them at their individual levels of need.

Cooperative Groups

Student groups will consist of students from varying levels so they can learn from each other. Each group will have to work together to accomplish a common task or produce a specific product or to reach a given outcome. The teacher will function as a facilitator to ensure groups stay on task and meet the goals of the group.

Reading across the Curriculum

Students will be given a list of pre-approved books to choose from that relate to size, scale and nanotechnology. Each student will select one book to read to help him or her meet the 25-book campaign challenge for English Language Arts. Students will also read printed portions from "Prey". Each student will complete a Read for Points activity sheet that explains their feelings about both their book and the reading from "The Prey" and how they relate to the unit. Students will explain how their book affects their thoughts on nanotechnology's impact on today's society.

Pre and Post Assessments

Pre-Assessments will assess what the students already know about size, powers of ten, and scale. Responses from pre-assessments will help fine tune lessons so they are more appropriate for each group being taught. Students will range from general classes to gifted and talented classes. This method allows for differentiation of lessons to meet the needs of the participating students. Post assessments will provide information to determine if the desired goals and objectives for the unit were met. Posttest will also determine if some students still need additional help in the form of remediation or individual tutoring.

Class Activities

Prior to the introduction of the unit students will have learned about the structure of atoms. They will use this knowledge to help them understand size and the properties of matter. A pre-assessment will be given entitled " Fact or Fiction Extreme Size Card" from the book *Extreme Science: From Nano to Galactic* to determine what students know, understand, and believe about size and scale. The pre-assessment will help to uncover any misconceptions students may have about size and scale so these areas can be addressed as the unit is taught. Once the unit opener is complete, a discussion and review of the fact sheet answers will occur.

Activity One: Size and Scale of Objects

The activity will use the three-part lesson format. The opening activity entitled "How Small are Atoms" will connect to student's prior knowledge of atoms and introduce the concept of nano scale and atomic scale objects. The activity requires students to cut a strip of paper in half and discard one-half of their remaining strips each time they fold the paper to try and achieve thirty-one cuts. Students quickly discover as they fold and cut their sheet that each fold makes it harder to cut the paper. Most students will make 10 cuts before they can no longer cut the strip. The activity gives students a good visual picture of how small a nano meter is. The activity can be obtained by visiting the Molecularium website:
http://molecularium.com/documents/teachers_guide.pdf

The Work period will start the second part of the lesson. Students will be assigned a Think-Share partner to work with. Each pair will be given an activity sheet with 20 items on it that they must rank according to size. They will only be allowed to work with their partner and will have 25 twenty minutes to complete the activity. Students will have to write a brief explanation for each choice they make based upon the key provided with the activity. Once groups have finished or the allotted time has elapsed, a review of the responses will be conducted. The review will prepare students for the closing activity. The closing will involve a Zoom Activity. Upon entering the classroom, each student will receive a numbered picture. The students will have 20 minutes to work with their assigned cooperative group once the activity timer starts. The goal is for students to sequence the pictures in the correct order based on the size of the objects. The challenge is that students may only look at their picture and cannot share it with their group. The group must figure out how to sequence the pictures without looking at one another's pictures. Once they feel they have all the pictures in order they can remove their individual pictures from the envelopes. A discussion that includes seven questions will be completed. Each student will complete the questions and submit them at the end of class along with a closing quiz on the Scale of Objects. The Zoom Activity can be obtained by visiting the wilderdom website:

http://wilderdom.com/games/descritions/Zoom.html

Activity Two: One in a Billion

This activity is designed to help students understand and build a mental visual of one-billionth. Students will be conducting hands- on dilution exploration to learn about parts per billion. Game cards that match the activity will be provided to help students understand concepts. The opening activity will involve students visiting the following website "Cell Size and Scale" via the mobile laptops lab. This activity will provide students with a good visual tool that can be scaled up or down for comparisons of objects at different scales. The purpose of the activity is for students to acquire a visual concept of size as we move from one scale to another. Students will be able to manipulate the program with a partner to discover how tiny nano scale and atomic scale items are. The website for the activity is: http://learn.genetics.utah.edu/content/begin/cells/scale/

Once students have completed the opening activity, a review of the lab will be occur and lab materials reviewed to ensure each group has their required materials and understands safety precautions to be followed. A tutorial using an online video will review powers of ten. The video will help students compare and understand the size of materials in the macro world, micro world and atomic world. The classroom promethean board will provide access to the video. The power of ten video website is: http://micro.magnet.fsu.edu/primer/java/scienceopticssu/powersof10/index.htm

The following questions will provide an introduction to encourage students to think about size. Which number is larger: one billion or one million? Which quantity is bigger: one part per million or one part per billion? Students will be asked to create a chart that has five to six examples of items they think represent one billion and one billionth. A short review on parts per billion and percent will be providing students with background information for the activity. Students will work in pairs to set up and conduct the lab. The problem provided for the students is, at what concentration, will the solution appear colorless? Students must complete their individual data sheets and questions that relate to the observations from the lab. The source for this activity can be found in "Nanoscale Science: Activities for Grades 6-12.

Activity Three: Unique Properties at the Nanoscale

This activity will provide students with an opportunity to perform several different labs to discover how size affects various properties of matter. The activity will be set up using five different lab stations. Safety precautions will be at each station. All materials will be at the stations prior to the students' arrival. Written instructions should be at each station to help students with the lab.

The teacher should function as a facilitator to help students who may experience challenges. The topic for the labs will be surface area.

The opening activity will require students to read and take Cornell notes using the student-reading guide provided with the lab. Students will be encouraged to use their notes to help them accurately explain their observations once they have finished the lab rotations. Questions will be entertained once students complete the student reading activity to ensure all students understand the information. The work period will involve students rotating from station to station at fifteen-minute intervals.

Station One: Provides students with an opportunity to compare varying surface area to volume ratios for two samples of the same substance and mass, but different particle size. Students will write the lab in their science lab books and include diagrams and explanations of their observation. Students will develop data tables to record their observations.

Station Two: Provides students with an opportunity to see how surface area can affect the speed at which a reaction occurs. Students must wear safety glasses to conduct this activity. Once students complete the activity they must record their data and complete the questions for the lab before moving to the next station.

Station Three: Allows students to observe how surface area affects the speed of boiling when the volume is the same but the surface area changes. Students will complete lab sheets after observations are completed. (Teacher Reminder) The teacher needs to remind students to record the time it takes for their substance to boil.

Station Four: This station demonstrates the effects of increased surface area to volume ratio on the rate of combustion (burning). The teacher needs to instruct students not to pickup hot items with their hands or paper towels, and to tie their hair tied back for this activity as a safety precaution.

Station Five: Demonstrates the effect of varying surface area to volume ratios of the same material on the rate of reaction.

Each activity requires the students to complete a lab activity sheet that they will place in their interactive science notebook. Once students have completed all the lab rotations, a brief discussion of the observations will ensue. The closing for this activity will be students' completion of the lab report. Students should complete all rotations within a fifty-minute period.

Activity Four: Culminating Reading Across the Curriculum Activity

The final activity for the unit will involve students selecting a science fiction book from the approved library list for nanotechnology. All books have something to do with nanotechnology or size. Students will select their books at the beginning of the unit. Daily reading time will occur during the morning flex period for students to complete class assigned reading materials. The reading component connects to our school-wide 25-book campaign that is spear headed by the English department. Once students have completed their book they must complete a written report by the assigned due date for the activity. All students must complete a reading worksheet and create some type visual to depict something about size discussed in the book. As a group, we will discuss information from the books to see if the books ideas were more facts or fiction. Students will have to explain why some ideas expressed in their books could be factual, while others would lend themselves to fiction in regards to the size, function, and properties of matter. Once we have concluded the activity students will need to think about how nanotechnology will influence them in the future and write a future impact statement. Their future impact statement should include their position on nanotechnology from the standpoint of pro nanotechnology or against nanotechnology. An explanation that provides support for the students' position regarding nanotechnology (pro or con) should be included in the impact statement. A special bulletin board that displays the book visuals, book reports, and impact statements will be created to share information with the entire school.

Notes

1. 1 Richard Booker and Earl Boysen, *Nanotechnology for Dummies* (Hoboken, NJ: Wiley Publishing, 2005), 40.
2. 2 John Tyler Bonner, *Why Size Matters* (Princeton, NJ: Princeton University Press), 4-5. Shawn Y. Stevens, LeeAnn M. Sutherland, and Joseph Krajccik. *The Big Ideas of Nanoscale Science and Engineering*, 80.
3. 3 Bonner, *Why Size Matters*, 5.
4. 4 Stevens, *The Big Ideas in Nanoscale Science and Engineering*, 80.
5. 5 Stevens, *The Big Ideas in Nanoscale Science and Engineering*, 78.
6. 6 Nanosense "Unique Properties at the Nanoscale" (2010) http://nanosense.org/activities/sizematters/10.
7. 7 Nanosense "Unique Properties at the Nanoscale." 10.
8. 8 Booker, *Nanotechnology for Dummies*, 73.
9. 9 WordNet Search-3.0" "Size" (2010) http://wordnetweb.princeton.edu/perl/webwn
10. 10 Stevens, *Big Ideas in Nanoscale Science and Engineering*, 78.
11. 11 WordNet Search -3.0 "Scale" (2010) http://wordnetweb.princeton.edu/perl/webwn
12. 12 WordNet Search-3.0 "Scale".
13. 13 Fathom Archive, "The Biology of B-Movie Monsters", 6.
14. 14 Nanosense "Unique Properties at the Nanoscale" (2010) http://nanosense.org/activities/sizematters/37.
15. 15 Stevens, *The Big Ideas of Nanoscale Science and Engineering*, 83.
16. 16 Nanosense "Unique Properties at the Nanoscale"5

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Teacher's Annotated Bibliography

Bonner, John Tyler. *Why Size Matters: From Bacteria to Blue Whales*. Princeton: Princeton University Press, 2006.

Good resource for explaining the importance of size in our lives and nature.

Boyden, Richard D. Booker, Earl. *Nanotechnology For Dummies* (For Dummies (Math and Science)). New York: For Dummies, 2005.

Good job explaining complex subject matter.

Falvo, Michael R., M. Gail Jones, and Amy R. Taylor. *Extreme Science: From Nano to Galactic* (PB237X). Danvers, Ma: National Science Teachers Association, 2009.

Good activities and explanations to help teachers and students.

Fayer, Michael D. *Absolutely Small: How Quantum Theory Explains Our Everyday World*. New York: Amacom 2010.

Good resource but geared more for high school and above.

Jones, Richard A. L. *Soft Machines: Nanotechnology and Life*. New York: Oxford University Press, USA, 2008.

Great job explaining self-assembly and the influence of size on nanosized particles. Good an easy to understand.

Krajcik, Joseph, Shawn Stevens, and LeeAnn Sutherland. *The Big Ideas of Nanoscale Science and Engineering: A Guidebook for Secondary Teachers* (PB241X). Danvers, Ma: National Science Teachers Association, 2009.

Good resource for teachers. This source is an excellent resource for connecting main ideas about nanoscience to national science standards. It is very specific about which concepts students need to learn.

Michael C. LaBarbera. "The Fathom Archive: The University of Chicago Library: Digital Collections." The Fathom Archive: The University of Chicago Library: Digital Collections. http://fathom.lib.uchicago.edu (accessed July 30, 2010).

This article did a good job explaining the size strength relationship

Williams, Linda. Chemistry *Demystified (TAB Demystified*). 1 ed. New York: McGraw-Hill Professional, 2003.

Good reference for chemistry. Written in a format that teachers and students could understand.

Student Annotated Bibliography

Falvo, Taylor, Broadwell, Jones. *Nanoscale Science*. Arlington: NSTA Press, 2007.

Good student resource. Great lab activities to help teach about nanoscale objects and size.

"Learn.GeneticsÃ¢ ¢." Learn.GeneticsÃ¢ ¢. http://learn.genetics.utah.edu/content/begin/cells/scale/ (accessed July 12, 2010).

Excellent site for students to visualize how size changes as you move from one scale to the next.

"NanoSense Unique Properties at the Nanoscale." NanoSense. http://nanosense.org/activities/sizematters/ (accessed July 30, 2010).

This is a good resource for labs that relate to size dependent properties, size, scale, andproperties of matter.

Appendix A: Implementing District Standards

> Dekalb County 8 th Grade Physical Science Standards –S8P1 Students will examine the scientific view of the nature of matter.

This unit will allow students too discover how properties can change at the nanoscale.

Dekalb County Characteristics of Science Standards

- S8CS6 Students will communicate scientific ideas and activities clearly.
- S8CS4 Students will use tools and instruments for observing, measuring, and manipulating equipment and materials in scientific activities utilizing safe laboratory procedures.
- S8CSStudents will use the ideas of system, model, change, and scale in exploring scientific and technological matters.