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Nanotechnology for Enhancing Math, Science, and Language Arts in the Elementary Grades: How Small Is Your Future?

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Introduction and Rationale

A voice came over the intercom, "Mrs. Moorman. Can you please report to room 123, our conference participants have arrived." I was meeting with one of my Enrichment students and his parent to discuss how he was feeling about school and why he was frustrated. I sat and listened as he explained how he liked school and liked learning but was bored in the classroom. He was a bright child, and he explained his frustration with learning something quickly and then having to wait for explanations and review while the rest of the class caught up. He was frustrated because he got it the first time and wanted to move on or, to put it in his words, "I just want to learn". What I got from his discourse was that he wanted more meat in his education than what is offered in the standard curriculum. My memory of this student-led conversation is what drives me to want to offer more to my students and develop a curriculum unit that adds substance to the skills we teach our students in Math, English Language Arts, Science, and Social Studies. Once students have mastered grade appropriate skills, or even advanced grade skills, then what? That is exactly what this student was saying, 'OK I've learned the material in this chapter, so now what? What do I do with the information I've learned and how can I use it?'

I teach Enrichment Math and Language Arts to the high achieving students selected primarily on the basis of their MAP test scores (NWEA — Measurement of Academic Performance). Our Enrichment program is structured as a pullout program with allocated class times ranging from 30 to 55 minutes for students in grades 1-5. Our operating premise is that high achieving students often do not meet their expected target growth goals in the regular classroom, particularly in subjects of their academic strength. In the regular classroom we often teach to the middle achievers and give that extra time and/or focus to the lower achieving students. Often our higher achieving students find themselves unchallenged and/or bored, as pointed out above.

Nanotechnology is an excellent topic to integrate into an existing math and/or science curriculum in order to either engage students in applying the math skills they have learned or explore the relevance of what they have learned about small organisms in their science units. It is also a topic that acknowledges the relationship between things that we have already observed in the real world and the new field of nanoscience.

This unit is an introduction to or overview of Nanotechnology intended for 5 th graders with the potential for adaptation for lower grade elementary students. Much of the information in this unit is at the conceptual level so that students and teachers can grasp the idea of what is going on, rather than the detailed explanations of the biology and chemistry underlying the processes. This overview describes the structure of matter including atoms and molecules, and how matter can be assembled into materials of nano-size. Differences in size will be illustrated by comparisons among objects that we see everyday and objects that are always around us, but we cannot see.

As we talk about innovations in nanotechnology, the concept of self-assembly will be explained and illustrated. Some of the differences in material characteristics at the nanoscale are identified including properties such as colorlessness, stronger bonds or increased stickiness, increased strength, and increased surface area. The topic of scale is also addressed by developing the relationship between size and common metric scales of measurement. Within this topic the focus is on equivalent measurements between the different size regimes such as macro, micro, and nano. This information will be related to instrumentation as well as functionality. Because this unit is intended for 5 th grade elementary students, I avoid complex calculations or computations: although the unit does introduce conversion factors within the metric scale, exponential notation, scientific notation, fractions, decimals, and percents. The information is kept manageable from a depth of knowledge perspective, but it is challenging and new enough to engage students and entice them into the field of nanotechnology.

One theme of nanotechnology is that materials made from the same atoms can have different properties, depending on the arrangement of atoms within the material. To illustrate this point, the unit discusses the various materials that can be made from carbon atoms: graphite, diamonds, buckyballs, and nanotubes.

Another theme of the unit is biomimicry, or the design of objects based on copy of patterns found in nature. There is a lot that we can learn from nature. Within the field of biomimetics there is exploration of its usefulness in the design of innovations. Through various activities, connections are made to some of the critters that elementary students study in their science kits including: crayfish, Bess beetles, grubs, butterflies, moths, crickets, mealworms, guppies, millipedes, and rollie-pollies. By examining critters that students have already been exposed to, and looking at them from a biomimetic perspective, the usefulness of studying those critters is reinforced. Students will better understand why we study nature and what relevance it has to our future. With that in mind, careers related to the field of nanotechnology are identified and researched so that potential career paths and opportunities can be identified, by looking at what would be involved to work in this new field of scientific study.

I have suggested at least one activity related to each major topic identified in order to cover the range of topics in an engaging way and to demonstrate more clearly the specific topic.

Objectives

Nanotechnology is one of those buzz words I heard from time to time but had no clue what it meant. I teach first through fifth graders who upon entering the work force will be faced with an employment market filled with 'nano' somewhere in the job title or description. While I do not want to go too far over the comprehension level of my students, I want to expose them to concept of nanotechnology, since it seems clear that it will play a large role in their futures.

The overall objective of this unit is to provide an overview of Nanotechnology. I hope to take the mystique out of the idea of and word nanotechnology. Hopefully, at the completion of this unit, the reaction to nanotechnology will no longer be "Oooooo what's that?" but rather "Nanotechnology? Sure I know what that is, it's easy and important. Want me to explain it to you?" That would truly be music to my ears. The objective here is that students will gain a conceptual understanding of nanotechnology, be able to explain it for someone else's understanding and comprehend how it impacts their lives today and in the future.

In addition, I hope to help students develop an appreciation for the nanoscale and how small things are that are nanoscopic. They will come to understand that the nanoscale is extremely small and that working at that scale requires different kinds of tools and instruments in order for scientists to study the phenomena that takes place at that scale.

I intend to integrate nanoscience into my math program: therefore, a primary objective is for students to become fluent in the different ways large and small numbers can be represented mathematically. I intend for students to become comfortable with representing numbers written in words and their equivalent fraction, decimal, positive and negative exponents, and scientific notation formats. I will also integrate this unit into my language arts program. Part of our language arts curriculum involves the ability to decode words for meaning using Latin or Greek roots and affixes. Specific words relevant to topics of this unit lend themselves nicely to decoding according to their Latin or Greek origin.

An additional objective is to introduce students to the structure of matter so that they understand four basic principles of matter: all matter is made of atoms, atoms are in constant motion, molecules have size and shape, and molecules in their environment have unexpected properties. Students will be exposed to the structure of atoms at a very basic level and introduced to four physical forms of carbon to illustrate the concept that the size and shape, but primarily shape, of molecules can have a significant impact on the properties of the material. The different forms of carbon, and their different relative shapes, will be related to their varying properties.

Another objective, one that is close to my feelings about the universe, is for students to realize that nature has many, if not all, of the answers to questions and problems that humans are facing in the world today. I want students to develop an appreciation for nature and learn from it. I hope to promote an underlying discussion about whether humans can discover, create, or invent anything that is really new. Are all of our inventions and creations just a copy of what nature has already accomplished?

A final objective is for students to explore how super powers or characteristics found in the natural world, either in the Animal Kingdom or the Plant Kingdom, can be mimicked to solve human problems. Hence, as part of this objective, students come to know and understand what biomimicry is and the value it serves to learn from the lessons nature has to teach.

Background

It is important to clarify what Nanotechnology is. Nanotechnology is a relatively new field of scientific study. 'Nano' comes from the Greek word *nanos* meaning midget or dwarf and *technology* means applying scientific knowledge to make things. Therefore, 'nano' + 'technology' = nanotechnology, meaning controlling structures at the very small nanometer scale, to make new things. These new things are based on principles learned from nanoscience. Now breaking 'nano' and 'science' down, as we did with 'nanotechnology', we find that 'science' is the systematic study of structures and behaviors in the physical and natural world therefore nanoscience is scientific knowledge based on the nanoscale. [1] So, to sum it up, nanotechnology is the study and use of materials and structures that are measured on the nanoscale between 1 and 100 nanometers. These terms may be foreign to you, as they were for me initially. So let's start by considering how small things are in the world of nanoscience.

How Small are Nanoparticles Measured on the Nanoscale?

The size of a nanometer can be visualized through mathematical representations, relative comparisons, concrete examples, and visual representations. You may want to take out a meter stick for this first explanation and follow along to help with the visual connection.

- One meter is equal to 100 centimeters; 1 centimeter is $1/100^{th}$ of a meter also represented as .01m.
- One centimeter is equal to 10 millimeters; 1 millimeter is $1/10^{th}$ of a centimeter represented as .1cm and $1/1000^{th}$ of a meter represented as .001m.
- One millimeter is equal to 1000 micrometers; 1 micrometer is $1/1000^{th}$ of a millimeter represented as .001mm and $1/1000000^{th}$ of a meter represented as .000001m.
- One micrometer is equal to 1000 nanometers, 1 nanometer is $1/1000^{th}$ of a micrometer represented as .001m.
- One nanometer is one billionth of a meter or $1/1,000,000,000^{th}$ of a meter represented as .000000001m.

1. To put it differently, one meter is equal to one billion nanometers. So, any particle that measures between 1 and 100 nanometers or between one billionth and one 10 millionth of a meter is a nanoparticle. A nanoparticle is a minute portion of matter that is measured on the nanoscale between 1 and 100 nanometers or between $1/1,000,000,000^{th}$ of a meter and $1/10,000,000^{th}$ of a meter represented as between .000000001m and .0000001m. The chart in Figure 1 is a visual representation of the equivalent mathematical representations that lead us from one meter to one nanometer.

Relative comparisons may be helpful to grasp the concept of the smallness of the nanoscale. Now I include scientific notation.

- A standard school bus with a length of 12 meters is 12,000,000,000 (12 billion) nanometers long or 1.2×10^{10} nm.
- An average 20 cm long pencil is 200,000,000 (200 million) nanometers long or 2×10^{8} nm. Look at a piece of your hair. A human hair is about 80 micrometers or 8×10^{1} m in diameter that translates into 80,000 (80 thousand) nanometers thick or 8×10^{4} nm.
- One inch equals 2.54 centimeters or 2.54×10^{0} cm, 25.4 millimeters or 2.54×10^{1} mm, 25,400 micrometers or 2.54×10^{4} m, and 25,400,000 (25 million four hundred thousand) nanometers or 2.54×10^{7} nm.

- A mosquito is about 5mm or 5,000,000 (5 million) nanometers long or $5x10^{6}$ nm.
- The common reddish-brown house ants are approximately 2 to 3 millimeters long or 2×10^{0} to 3×10^{0} mm, about 2,000 to 3,000 micrometers in length or 2×10^{3} to 3×10^{3} m in length, and nearly 2,000,000 to 3,000,000 (2 to 3 million) nanometers or 2×10^{6} to 3×10^{6} nm long.
- A red blood cell, the cell that gives our blood color, is approximately 7 micrometers in diameter or 7×10^{0} m, and 7,000 (7 thousand) nanometers in diameter or 7×10^{3} nm in diameter.
- Many of us dread grains of pollen, particularly during the onset of spring. Pollen grains range in size from 25 to 50 micrometers or 2.5×10^{1} to 5×10^{1} m and 2,500 to 5,000 nanometers or 2.5×10^{3} to 5×10^{3} nm. Billions of pollen grains will fit into one teaspoon (can you prove this?).
- Bacteria are abundantly distributed in soil, air, water, in and within the tissues of plants and animals. The diameter of bacteria is usually 1 to 3 micrometers or 1×10^{0} to 3×10^{0} m and 1,000 to 3,000 nanometers in diameter or 1×10^{3} to 3×10^{3} nm in diameter.
- I think it is safe to say that we have all seen at least one butterfly in our lives. Try to envision how delicate and thin the wings of a butterfly are. Well, some butterfly wings are made up of scales that are each 90 nanometers thick or 9×10^{1} nm thick. About one thousand of these butterfly wing scales, stacked on top of each other, would fit across a single human hair.
- The virus that causes the common cold is 20 nanometers in diameter or 2×10^{1} nm.
- Many atoms, which are the building blocks of all matter, are smaller than 1 nanometer in diameter. The width of a single water molecule that is made up of two hydrogen atoms and one oxygen atom is one nanometer, pretty minuscule. [2]

When we think of particles that are being manipulated on the nanoscale, we are thinking about particles or pieces of matter that are somewhere between the size of a scale on a butterfly wing and a water molecule. (To see the relationship between objects at the different scales identified above, please visit http://learn.genetics.utah.edu/content/begin/cells/scale/. It shows different objects at different magnifications and scales.) A suggested activity to help students understand the smallness of the nanoscale is "Cutting it Down to Nano". This activity can be obtained from http://mrsec.wisc.edu/edetc.

This unit also provides an introduction to the concept of negative exponents. It is represented here simply as the exponential representation of the denominator of a fraction representing division by powers of 10. It may be helpful to refer back to the metric comparisons identified earlier.

- 10 Centimeters = 1/10m = .1m = 10^{-1} m (one tenth of a meter)
- 1 Centimeter = 1/100m = .01m = 10^{-2} m (one hundredth of a meter)
- 1 Millimeter = 1/1000m = .001m = 10^{-3} m (one thousandth of a meter)
- 100 Micrometer = 1/10000m = .0001m = 10^{-4} m (one ten thousandth of a meter)
- 10 Micrometer = 1/100000m = .00001m = 10^{-5} m (one hundred thousandth of a meter)
- 1 Micrometer = 1/1000000m = .000001m = 10^{-6} m (one millionth of a meter)
- 1 Nanometer = 1/1000000000m = .000000001m = 10^{-9} m (one billionth of a meter)

What is the Relationship Between Size and Scale?

Very small objects need to be measured on a scale that is appropriate for their size. For instance, as seen in some of the examples above, it would not make sense to measure a school bus at the nanoscale because the numbers would just be too big and cumbersome to manage and would lose their meaning for the individual(s) interested in the measurements. Based on this concept, it is helpful to understand how the various ranges in size are classified into different scales.

Humans live in the macroscale. This is the world that we experience directly. We can see macroscale objects with our naked eye, without the help of special tools or instruments (excluding any form of eyeglasses or contacts). Within the macroworld, the behavior of matter is predictable using classical mechanics. Objects in the macroworld fall within the approximate range of greater than10^{-4} m (or 100m).

Objects too small to see with the naked eye vary in size within the world of invisibility. Individual cells are typically the representative benchmark objects for the microscale. Microscale objects can only be seen with the aid of a magnifying device such as an optical microscope. Matter in the microworld falls within the range of 10^{-7} to 10^{-4} m (or .1 to 100m, 10^{2} to 10^{5} nm). Classical mechanics is generally an adequate method for explaining the behavior of objects within the microworld. The nanoworld is the next smaller scale after the microworld. Objects within this scale are defined within the range from 10-9 to 10-7 m, (or 1 to 100nm). Representative benchmark objects for the nanoscale include the diameter of the DNA helix and the diameter of a buckyball. Optical microscopes cannot be used to observe matter at the nanoscale. If at least one dimension of an object falls within this range it is considered to be nanoscale matter. At this scale, classical mechanics is not a reliable method for predicting the behavior of matter; it becomes necessary to apply quantum mechanics. Objects smaller than one nanometer are classified in the atomic scale. The atomic scale includes individual molecules, atoms, and subatomic particles that include protons, neutrons, and electrons. The representative benchmark object for the atomic scale is the hydrogen atom. The behavior of atomic scale matter is explained by quantum mechanics. [3]

The scale of the smallest dimension of an object determines how it is classified. The divisions between the macro, micro, nano, and atomic worlds are not absolute but are helpful because they group matter by the methods or models useful for explain their phenomena and the tools used for observation.

A suggested activity for this concept is for students to match objects to their particular measurement scale.

Nanoscale Tools and Instruments.

To observe matter at the nanoscale it is necessary to use instruments that have probes that are smaller than the wavelength of visible light. [4] Several types of Electron Microscopes that can magnify samples from 10 to 1,000,000 times using the energy from electrons are used to observe nanoscale matter. Three types of electron microscopes used include the Scanning Electron Microscope (SEM), the Transmission Electron Microscope (TEM), and the Analytical Electron Microscope (AEM). The SEM scans the surface of thick or thin samples using a focused beam of electrons. [5] The TEM sees through a sample facilitated by a wide beam of electrons that pass through a thin slice of a sample forming an image with a 3-D appearance. [6] The AEM is built to look inside materials at a high magnification. The AEM provides very high-resolution images and information on a material's atomic composition, molecular bonding, and electrical conductivity. Using this microscope, researchers can obtain detailed information on the molecular makeup of nanomaterials, data on specific properties, and the performance of structures made from them. [7]

Scanning Probe Microscopes are another category of microscopes used to study the surface character of atomic-scale and nano-scale materials. They have a fixed or mounted probe tip/stylus on the end of a tiny beam. Some of the microscopes in this category include the Scanning Tunneling Microscope (STM), the Atomic Force Microscope (AFM), and the Laser Scanning Confocal Microscope (LSM). The STM uses a fixed probe tip to measure a material's surface electrical characteristics. "A tunneling current is created when the sharp conducting tip is placed very close to a conducting surface with a voltage difference between them." When the tip moves up and down it tracks and records the surface of the sample. [8] The AFM uses a mounted probe tip on a flexible laser beam. The ridges and valleys of the samples surface cause the probe tip to raise and lower as it drags across the surface. It can operate in contact or non-contact mode. The quality of the resolution of the image is determined by the sharpness of the probe's tip. [9] The LSM uses ultraviolet laser light and scanning mirrors that sweep across a sample. Several single slice images are pieced together by a computer to create a three dimensional image on a computer monitor. This microscope has the ability to create high-resolution images. [10]

Structure of Matter at the Nanoscale

Now that we have descended to the nanoscale and have a good sense of how small this world is, we can talk about the structure of matter. Here, I focus on four principles:

1. All tangible things are made up of atoms.
2. All atoms are in constant motion.
3. Molecules, which are collections of atoms that are bound together, have size and shape.
4. Molecules that are in pieces of matter with nanometer-scale dimensions sometimes have unexpected properties.

All Tangible Things Are Made Up of Atoms

Atoms are the underlying and essential building blocks of matter: matter is any physical substance that occupies spaces and has mass. The tangibles that are made up of atoms include large objects such as the sun, the earth, and the moon. Obviously these would be made up of an incredible number of atoms. To illustrate the point of how small atoms are, one million atoms could be laid across the head of an average pin. One molecule of water contains 3 atoms: 2 hydrogen and 1 oxygen; a buckyball consists of 60 atoms; one cubic centimeter of air, which is about the size of a sugar cube, contains approximately 10^{19} atoms. [11] With that in mind, the number of atoms in the sun, earth, or moon is unimaginable.

Atoms Are in Constant Motion

It might be surprising to you to learn that ice, which is frozen water and appears to be a motionless solid, contains molecules that are in constant rapid motion. The molecules in frozen water are constantly moving in the form of vibrations. We cannot detect the vibratory movements with our naked eyes, because movements at the nanoscale level and below are impossible to see without help from special types of microscopes (which are discussed later in this unit). The motion at the nanometer scale is atomic motion; therefore, it is difficult to see the motion of a particular atom because, first, atoms are virtually indistinguishable, second, the movements are very rapid and, third, there is an enormous number of atoms packed together in any given object.

Molecules Have Size and Shape

Atoms come together to form molecules through intramolecular chemical bonds, which are very strong and usually cannot be broken without the input of considerable energy. There are two kinds of intramolecular bonds: ionic bonds and covalent bonds. In covalent bonding, the atoms share electrons equally. Ionic bonds are based on the concept that opposites attract. To understand the basis of this attraction of opposites, it is helpful to understand the make-up of atoms. Atoms are made of subatomic particles: protons, neutrons, and electrons. Neutrons, as the name suggests, are neutral and have no electrical charge. Protons have a positive electrical charge. Protons and neutrons are collected within the nucleus of the atom. Electrons circle the nucleus of the atom and have a negative electrical charge. Atoms that do not have the same number of electrons and protons are called ions. If an atom has more protons than electrons the atom has a positive charge. On the other hand, if an atom has more electrons than protons, the atom has a negative charge. Protons and electrons are electrically attracted to each other (opposites attract): an ion with a positive charge will be attracted to an atom with a negative charge. When atoms bond together, either by ionic or covalent bonding, they produce larger building blocks of matter that are called molecules. Chemical reactions primarily involve atoms or groups of atoms and interactions between their electrons. An example of a molecule formed by ionic bonding is table salt or NaCl - sodium chloride; an example of a molecule formed by covalent bonding is water or H_2O.

Molecules generally have a certain shape due primarily to the way the atoms bond together. The angle of the bond that holds the hydrogen atoms to the oxygen atom causes water molecules to have the same shape. Larger molecules have more complex shapes. Often it is the shape of a molecule that contributes to its function because its shape results from the atoms and their intermolecular bonds and interactions. [12]

Molecules at the Nanoscale Have Unexpected Properties

At the molecular level gravity is no longer the dominant force. Electrostatics (charge interactions) and surface tension become more important. At the nanoscale small particles interact with light differently and ultimately can become colorless. Gold turns a different color at different sizes on the nanoscale. Gold progresses from the gold color we know it as to blue, red, yellow, and then colorless as it gets smaller on the nanoscale. [13] This is due to the diffraction, or bending, of light. The different sized particles diffract different colors of light. Gold particles at 25 nanometers in size diffract the color red. [14] The nanoworld can best be described as a sticky environment because electromagnetism is the dominant force. The phenomenon of static electricity is a visible illustration of electromagnetic interaction. Keep in mind that atoms are in constant motion, therefore when molecules come in close proximity to one another they stick together through what is know as weak interactions. [15] Weak interactions can be further explained by van der Waals force. It is defined as weak intermolecular bonds that result from the temporary attraction of electrons. The constant movement of electrons within molecules causes electrostatic attraction, what we often refer to as static electricity when we experience a shock while walking across a carpet. When the electrons move the attraction is eliminated, causing only a temporary intermolecular bond. [16]

Manipulation of Nanoparticles

Now that you understand how really small the nanoscale is, you might be asking yourself how on earth does someone manipulate atoms when you can't see or touch them to build from the bottom up. There are two ways atoms and molecules are manipulated at the nano level. They can be physically manipulated through the use of the microscopes or guided into position through the process of self-assembly.

How is Physical Manipulation Accomplished?

A lot of progress has been made regarding nanoscale manipulation. Some of the more significant advances involve electron microscopes including computer-controlled SPM, optical tweezers, and nanomanipulators. Real-time, hands-on manual nanoparticle manipulation can be accomplished through computer-controlled scanning probe microscopy. These computer-controlled SPMs are still in a rudimentary state but basically provide a virtual environment, similar to a virtual reality game, whereby researchers have virtual surface accessibility. Optical tweezers use a focused beam of light directed onto a particle in liquid. The light's force is strong enough to keep the particle relatively still. If it moves the light will push it back in place toward the center of the focus. Nanomanipulators are used in conjunction with SEMs and TEMs and use a type of crystal tip that has the ability to generate a voltage in response to mechanical energy. Nanomanipulators are useful in testing the newest electronic circuit boards and integrated circuits. [17]

What is Self-Assembly of Molecules?

Self-assembly can be defined as the ability of atoms and molecules under specific conditions to spontaneously arrange and organize themselves into a structure or pattern without specific clearly defined control from an outside force. [18] The conditions that make self-assembly work are:

1. The right combination of ingredients (nanoparticles or base elements like phosphate, sodium, chlorine that exist in certain substances)
2. The appropriate environment, like water or oil, for the ingredients
3. Reversible binding force
4. A driving force or catalyst to start the self-assembly process. (Note: See the Activity 'Experiencing Self-Assembly' in the Classroom Activities section as a way to introduce the concept of Self-Assembly).

How do we use Self-Assembly?

When the topic of self-assembly arose I questioned whether the concept of self-assembly, as it relates to nanotechnology, is really new. The concept is not new, but what is new, is the ability to see what is happening at the nanoscale. Basic food preparation involves nanotechnology employing the process of self-assembly at some level. I'll explain how.

One way to take advantage of self-assembly to manipulate matter and create nanoparticles is first to create an emulsion. Making emulsions is not a foreign concept and is something many of us have done. Examples of emulsions that we can relate to include: mayonnaise, peanut butter, and salad dressing. An emulsion is defined as a suspension of small drops of one liquid into a second liquid within which the first liquid does not mix. A common illustration of two liquids that would result in an emulsion is oil and water. To illustrate this idea if you take the yolk of an egg, lemon juice, and oil and create mayonnaise you are taking the first step a nanotechnologist takes to create nanoparticles, in a very crude sense. Measuring and gathering the egg yolk, lemon juice and oil is the ingredient step of self-assembly, putting all the ingredients in a bowl establishes the environment, using the electric mixer to blend the ingredients provides the driving force, and the weak intermolecular interactions that occur within the mixture takes care of the reversible binding forces. Blend the solution until there is a cloudy mixture. This emulsified mixture is composed of the dispersed droplets of oil and lemon juice suspended in the egg yolk.

The process is explained in nano terms here. The oil is comprised of individual phospholipid molecules. These structures have a hydrophilic (water soluble) part and a hydrophobic (water insoluble) part. They arrange themselves into two layers that surround or encase the water, or in this example the lemon juice. The hydrophobic parts arrange themselves facing away from the lemon juice and the hydrophilic parts arrange themselves facing the lemon juice creating a liposome encapsulating the lemon-juice. Nanoparticles are created using a similar process with a few additional steps. An emulsion is created with the liposomes encapsulating the intended drug suspended in the emulsion. The emulsion is then lyophilized, which is a process that involves freeze-drying and evaporation. Once the liquid has dissipated, what remains are nanoparticles containing the drug or other intended substance.

(An activity that I recommend to engage students in visualizing the concept of self-assembly is to make homemade bubbles. Follow this activity up with the information provided in Issue 6 of Nanooze 2008 starting on pages 4-5. This contains illustrations and a detailed explanation of the process of self-assembly.)

Nanotechnology Revisited

Now that we have a grasp of the structure of matter, and how atoms and molecules fit into that structure, let's revisit nanotechnology. Nanotechnology is a new field of scientific study that involves manipulating individual atoms and molecules to create new things on an extremely small scale. It builds things from the bottom up- atom by atom, and molecule by molecule. The ability to control how atoms and molecules are put together in order to precisely control the characteristics of what you are making is the basis of nanotechnology. You might ask yourself how the manipulation of atoms or molecules affects the characteristics of a substance. Carbon provides a good example of how the differences in the ways atoms are assembled can result in materials with different characteristics. The differences in these characteristics exemplifies that molecules have size and shape: in addition, the shape of a molecule affects its properties. To date, scientists are aware of the following different physical forms (or allotropes) of carbon: graphite, coal, diamond, buckyballs, and carbon nanotubes, all of which occur in the natural environment. Graphite, coal, and diamond exist at the macro scale or the scale that we can see things with our naked eye. Buckyballs and nanotubes exist at the nanoscale and can only be seen with powerful microscopes. In each of these forms, the carbon atoms interact with each other differently, resulting in materials that exhibit different properties.

Graphite

Graphite has a layered flat structure. The structure itself is rather complex, but it is primarily in a 2 dimensional plane and the atoms of carbon are arranged in a pattern similar to chicken wire. In graphite, each carbon atom bonds to three other carbon atoms and form single layers of hexagonal-shaped carbon atom rings. These hexagonal shaped rings stack on top of each other in sheets. The material graphite is relatively soft, because the structure consists of these flat sheets that can slide across each other. Think of playing cards, if you stand them on their edge they are reasonably strong but when laid flat they will slide over other cards and will bend or break if too much force or pressure is used. Soft, light, and flexible, this is the form of carbon we commonly find in the lead of a pencil; it is also the basic substance in coal. When we write with a graphite pencil small pieces of the graphite rub off onto the paper by friction and then stick to the paper, forming whatever letters or shapes were drawn. Graphite molecules within the sheets are held together through covalent bonding. Each atom uses three of its electrons to form simple bonds with its three closest neighbors. Graphite has the sensation of a slippery powder and is often used as a dry lubricant on locks and athletic equipment. Some of the properties of graphite include a high melting point, insolubility in water and organic solvents, and good conduction of electricity. [19]

Diamond

Diamond atoms are arranged into a 3 dimensional solid structure, also formed through covalent bonding. The structure is an extended 3-D network in which one carbon atom is covalently bonded to four other carbon atoms. Diamond's crystal structure makes it extremely hard, suitable for cutting and grinding through industrial steel and other heavy-duty, industrial-strength manufactured materials. It is the hardest known solid. Diamond has a very high melting point and is not soluble in water or other organic solvents because of its strong carbon-carbon covalent bond. In addition, it does not conduct electricity because all of the electrons are packed tightly between the atoms and cannot move easily throughout the solid; diamond consequently is an insulator. When we think of diamonds we think of them as precious gems with a magnificent brilliance and shine. Scientists, on the other hand, think of diamonds with respect to their range of phenomenal and exceptional properties. In addition to being the hardest known material to date, it is also the stiffest and least compressible. Diamonds are the best thermal conductors with very low thermal expansion. They do not react with most acids or bases. [20]

Buckminsterfullerene (Buckyballs)

In 1985 a team of three chemists, Robert Curl Jr., Sir Harold Kroto, and Richard Smalley discovered a new form of carbon made up of 60 carbon atoms. The newly discovered carbon molecule was given the official name Buckminsterfullerene; the name given to the new carbon family was fullerenes. Fullerenes are three-dimensional cage-like spheres that closely resemble a soccer ball consisting of a spherical pattern of hexagons and pentagons. [21] Individual buckyballs are hard, possibly harder than diamonds. As a bulk substance, however, they are relatively soft, because every buckyball can move with respect to all of the others. Potential applications for buckyballs currently being investigated include its use as a lubricant or superconductor. [22]

(Note: A good activity to introduce here is one that involves cutting and folding a net (a truncated icosahedron) resulting in a buckyball-like structure.)

Carbon Nanotube

In 1991, six years after scientists discovered, or should I say recognized the buckyball structure, Sumio Lijima, a Japanese physicist, recognized a different form of carbon. He noticed nano-sized threads in a smear of soot.

These threads turned out to be very thin threads of pure carbon only a few nanometers in diameter but many nanometers long. Carbon nanotubes are long tubular molecules of carbon structurally similar to buckyballs. They can be described as cylindrical fullerenes that have an extended structure resembling a tube of chicken-wire fencing. A carbon nanotube can carry an electrical current and, therefore, may be thought of as the world's smallest wire. [23] Carbon nanotubes can act as semiconductors, which is a substance that will conduct electricity under certain environmental circumstances and not under others. This property makes them good materials for controlling electrical current, which is important for the manufacture of computer chips because they can act like small switches turning on and off determined by whether they are allowing electrons to flow or not. Carbon nanotubes are incredibly strong, stronger than steel, very lightweight, and flexible. They are one of the strongest and most rigid materials known to date and possibly the strongest material known. They are currently being used in tennis rackets and bicycles, making these items very strong and extremely lightweight. (An activity involving the construction of different molecules based on a set of materials is a good illustration of this concept.)

How does DNA Work?

Understanding the building blocks of a structure or material is crucial for comprehending its function and properties. For instance, it is important to understand that proteins, which are at the nanoscale, are objects that carry out critical functions within all living organisms. To understand proteins and their production it is helpful to understand DNA, DNA replication, and protein production. Following is a cursory description of the structure and function of DNA.

DNA exists in the nucleus of all cells and has the information or blueprint in every cell for every protein the body uses. Put another way, every cell in the body has the same DNA, but only uses what it needs. A portion of DNA that is specific to a certain type of protein is called a gene. When the nucleus receives a call that more proteins are needed, the manufacturing of just the right protein begins. The DNA, which is in the form or a double helix, unzips itself, similarly to how you unzip a zipper giving you two separate halves. Now it takes a portion (called a gene) of one side of the DNA and creates a negative of that gene in the form of messenger RNA. The creation of the gene negative is referred to as transcription. The messenger RNA receives the gene negative, which can be looked at as a recipe and ingredients, takes it out of the nucleus to a ribosome, which can be considered the translator of the gene code or factory using the recipe and ingredients. At the ribosome the ingredients are matched with their complimentary ingredients, according to the recipe, to produce the appropriate protein for that gene code.

A plasmid is a DNA molecule that is separate from chromosomal DNA described earlier. This is most often a small double stranded circular form of DNA that carries genes that specify certain characteristics. These genes are what tell the plasmid what type of protein to make when it is expressed. Plasmids occur naturally in bacteria and function as a means for these microorganisms to exchange genes. They live outside of the nucleus and are able to function because of their own genetic structural make up. Plasmids can self-replicate when introduced to a cell; they also can be used as templates to create proteins. When introduced to a cell they replicate and grow creating whatever protein they have a recipe for. The functionality of a plasmid is useful in genetic engineering.

Why do I mention DNA, protein production, and genetic engineering? These are all naturally occurring life processes that scientists and researches in the medical field can now understand and use to accomplish medical feats through manipulating and mimicking processes in Nature.

What is Biomimicry?

Biomimicry is a new scientific discipline. 'Bio' comes from the Greek word bios meaning life and 'Mimicry' comes from the Greek word mimesis, which means imitate. Therefore, 'bio' + 'mimicry' = biomimicry, meaning imitating the best ideas and processes from nature and using them in innovative designs and processes to solve human problems. Biomimetics is the science of mimicking biology or nature. Nature has established itself in the field of complex engineering for over a billion years; in this enormous amount of time, complex biological processes, systems, and functions have been fine-tuned. The goal of biomimetics is to figure out how nature performs its complex functions, so that we, or scientists, can develop techniques that copy what nature does so efficiently. The core idea of biomimicry is that nature has already solved many of the problems we are still wrestling with. Not only does humanity want to copy nature's processes, its biomimetic goal is actually to surpass what nature does by doing it better.

Velcro, something familiar to all of us, is a product of biomimicry. In 1948, a Swiss inventor returned home from a nature hike with his dog both covered with burrs, the plant seed-sacs that cling to animal fur for transport to new fertile planting grounds. Microscopic inspection of one of the burrs that was stuck to his pants revealed small hooks that enabled the burr to cling to the tiny loops in the fabric of his pants. From that discovery, George de Mestral came up with the idea of the two-sided fastener commonly known today as 'Velcro' [24]

Stain and water resistant fabrics are a form or biomimetics because one of the processes used for creating this property is mimicked after the lotus leaf referred to as the lotus effect. Wilhelm Barthlott, a German botanist, was the first to explain the phenomenon. The lotus effect is based on the very fine surface structure of the lotus leaf, which is coated with hydrophobic wax crystals approximately 1 nm in diameter. Rough surfaces on a nanoscale reduce the contact area between the water and the solid and therefore are more hydrophobic than smooth surfaces. The contact area of the lotus leaf is 2-3% of the droplet-covered surface.

The Shinkansen Bullet Train of the West Japan Railway Company travels 200 miles per hour and is the fastest train in the world. The problem it encountered was its noise level. The changes in air pressure, resulting from the train's emergence from a tunnel, produced loud thunderous sounds heard by residents one-quarter a mile away. Eiji Nakatsu, the train's chief engineer and an avid bird-watcher, modeled the front-end of the train after the beak of Kingfishers. Kingfishers dive from the air into bodies of water with very little splash to catch fish. This biomimetic design resulted in a quieter train, using 15% less electricity, and with a 10% increase in speed.

Although the concept of biomimicry is old, evidenced by the Wright Brother's invention of the first flying machine modeled somewhat after the flight of birds, the field has been enlarged by the capability to see matter, processes, and structures at the nanoscale. Biomimetics is applicable in many areas of society involving, but not limited to, medicine, textiles, cosmetics, energy, pharmaceuticals, military, sports equipment, and others. In the field of medicine, biomimicry occurs at the cell and molecular level for purposes such as drug delivery, cell regeneration, destruction of damaged or diseased cells, genetic engineering, and protein production. In the area of industry, new products have been developed to solve societal problems or enhanced to provide more desirable properties such as increased strength but reduced weight, stain and/or water resistance. Other areas interested in biomimicry are military, ecologists, environmentalists, and energy producers.

Biomimetics Past, Present and Future

Much of what is now learned from nature is occurring at the nano level. Processes and functions that occur at the nanoscale level facilitate nature's desirable characteristics and/or properties observed in the macro world. The emergence of nanotechnology and its accompanying tools and instruments are making these scientific discoveries possible. As you read earlier the buckyball occurs naturally in nature, although scarcely; it is a natural phenomena. But we were not able to detect it until recently. That absence of detection did not prevent man from mimicking nature, perhaps even before he know that what he constructed already existed in nature. Here are some examples to illustrate this point.

Biomimetics in the Past

Buckminsterfullerenes were not discovered until 1985 by a team of three chemists, Robert Curl Jr., Sir Harold Kroto, and Richard Smalley. I mention the buckyball, which it is called for short, because it is an object of biomimetics before anyone knew they existed. The new C_{60} carbon molecule was named after an inventor and architect, R. Buckminster Fuller because it closely resembled-at a very different size scale-the geodesic dome that Buckminster Fuller built and made famous in 1965 at the New York World's Fair. That was 20 years before the C60 molecule, now commonly referred to as the buckyball was detected.

In the strictest sense of the word you may argue that this example is not really biomimicry since we didn't learn from what existed in nature first and then copy it. While that may be true, it is significant that the properties exist in both the naturally occurring substance and the structure that mimics it.

There is a legend in Santa Fe, New Mexico about a mysterious and ethereal spiral staircase that was built in the Loretto Chapel by an unidentified carpenter who travelled to Santa Fe in the late 1800s. The staircase is considered to be mysterious and ethereal because there is no center support. It is described as an incredible spiral with two complete 360-degree turns. It has no nails or screws of any kind and rests solely by its geometric balance and design. When you look at a picture of this spiral staircase, you immediately think of the double helix of DNA. Is this biomicmicry? What is biomimetic about it is the fact that, similar to the design of DNA, it is structural sound and takes up little space. DNA contains a humungous amount of information about genes and proteins at a nano level in a small amount of space, but because of its spiraling structure (and its ability to be condensed and packaged in this structure) it all fits in the nucleus of a cell. Similarly, because of the small size of the chapel and the height of the loft, conventional methods of building a staircase to the choir loft were not feasible. The spiral staircase mimics the design of the double helix that always existed in nature but of course we didn't know about it at the time. Again, is this an example of biomimicry? I think so.

Biomimicry Present and Future

The process of creating liposomes for the purpose of delivering a drug to a specific targeted area or cell in the body is a form of biomimicry. Enclosed capsules made from a lipid bilayer that has folded over itself mimic cell membranes and is an example of biomimicry. Using what we have learned about how lipid bilayers are formed, using that process to create liposomes, and then filling the capsule with a drug targeted for drug delivery to specific cells can be explained as a biomimedic process.

Creating a liposome and attaching a small piece of a virus to it so that the liposome can enter a cell is another example of biomimicry. Applying what we have learned about the ability of viruses to enter cells for the purpose of manipulating synthetic materials can be explained as a biomimetic process.

A team, led by Ashkan Vaziri, assistant professor of mechanical and industrial engineering at Northeastern; and Myoung-Woon Moon, of the Korea Institute of Science and Technology, created nanoscale and microscale patterned surfaces with adhesion and friction properties similar to that of the gecko footpad. Their hope is to generate applications ranging from adhesives to robotic movement and navigation. The principle of asymmetric adhesion used by many insects and gecko lizards, allows them to move on any horizontal, tilted, or vertical surface. Their remarkable climbing ability can be attributed to the elaborate fibrillar structures that cover their feet. Gecko lizards have one of the most efficient and interesting adhesion devices consisting of finely angled arrays of branched fibers called setae. Gecko toes are covered by millions of hair-like setae five micrometers in size. The ends are tipped with hundreds of spatula that bend and conform to the surface on which the gecko is moving. This is a phenomenon the research team hopes to mimic for the purpose of developing a "smart" adhesive that could adapt to environmental stimuli including a curvy surface or a rough edge. The research team has been experimenting with designing and creating a series of micropillars, (hair-like structures), exposing them to ion beam radiation, resulting in a dual-surface area with unique adhesion and friction properties similar to the properties and function of the gecko footpad. This technology, although not perfected yet, could lead to small high-tech robots able to climb with speed, precision and accuracy on uneven or slippery surfaces and a new generation of smart adhesives equipped to hold strong bonds with any surface. [25] This is a clear example of biomimetics at work for the future.

Strategies

While teaching this unit I plan to employ a variety of strategies providing the opportunity to teach to the different intelligences, strengths, and learning styles of my students. I teach Enrichment Math and English Language Arts, therefore I will be using strategies that can be transferred across both subject areas. Independent Practice will be integrated throughout the unit and presented as options on some assignments.

Technology Integration is a key strategy that will be part of this unit. Students will use the technology available to them in a variety of ways. They will use the software available in my school district, Kidspiration and Inspiration specifically at this point in time, to create various graphic organizers in order to organize data or represent other types of information in a visual way to maximize learning through visual representation. They will be instructed on the use and creation of spreadsheets in order to capture and represent specific data or information in a relevant chart or table format. Students will be engaged in interactive online websites that will present or illustrate concepts that might otherwise be inaccessible for them. Students will also use the available technology to conduct research, obtaining information pertinent to project assignments. The more simple applications of word processing and/or presentation development including importing illustrations into a document will also be part of the technology integration strategy.

The use of Visual and Graphic representations to explain a topic is going to be a significant strategy for delivering this unit topic. I know that I could not have grasped many of the concepts and ideas without visual representation so I know that my students wouldn't either.

Another strategy I believe to be highly effective is collaborative pairs. Students' working in pairs helps to promote discussion, which aids in clarifying content and concepts. The use of collaborative pairs reinforces social interaction, a significant part of learning and promotes student interaction effectively and manageably. It provides the teacher with the opportunity to check for understanding as students interact.

An additional strategy that expands on the theme of collaboration is cooperative teams. This will be presented as an option for larger, more time-consuming, projects. While most students don't object to working with a partner, not all students like working in a larger cooperative group of up to four students. This strategy will be presented as an option in order to be sensitive to the fact that one size does not fit all. I see this strategy being more relevant to a research project that will result in a team presentation or a panel discussion connected to resolving some type of societal problem through some form of biomimicry. This will be particularly relevant to students' study of one of the critters they have previously studied in their life sciences kits.

Writing across the curriculum is a strategy that will be utilized in this unit integrated with observation and making inferences, similar to what scientists do based on what they know about how certain elements and or molecular substances are expected to work or react. Creative writing will also be included as a component of this strategy. Students will be provided with choices for producing their written assignments. Some of the choices that come to mind include a technical information page, a comic strip or book, a short story, and a flipbook. I also envision integrating art into this strategy for those students who have excellent visual and/or graphic art skills.

Hands-on interactive activities are another strategy that will be an integral aspect for teaching this unit. This strategy may include teacher made and/or purchased manipulatives, paper cutting and folding. With regard to the idea of molecules and their shape students will be engaged in a manipulative activity whereby they create and record their different molecular structures. Setting up experiments using the scientific method will be a by-product of this unit resulting in science fair projects to be entered into our school-wide science fair.

Summarizing strategies are good to use with this unit particularly since the focal subjects are Math and English Language Arts. Summarizing will be used along with reading across the curriculum fostering non-fiction reading materials including current science related articles from newspapers and/or magazines. The Nanooze publication for kids and its accompanying supporting website will be a good resource for this purpose.

Brainstorming ideas, solutions, alternatives, etc. is a useful strategy to employ in this unit. It will provide students with the opportunity to think out of the box generating new ideas and revisiting old ones with a new twist. This approach will potentially create experiences that correspond to industry-type think tanks or research and development departments.

Extended thinking strategies will be employed to encourage students to analyze data, evaluate situations based on some predetermined criteria, draw conclusions through appropriate inferences, and synthesize or apply conclusions in an authentic situation or problem.

Independent Research

Students will conduct an independent research project involving biomimicry of their choice of critters including but no limited to crayfish, Bess beetles, grubs, butterflies, moths, crickets, mealworms, guppies, millipedes, and rollie-pollies. This project will involve their identification of a super power or unique characteristic that would be of interest to mankind to mimic and apply. Their responsibility will be to identify an authentic problem or opportunity for improvement that can be solved by applying the characteristic they've identified for their selected critter. The product they will produce will be modeled after the Biology Design Challenge that is on the Biomimicry Institute's website. The document will include the identification of an authentic problem or valuable enhancement, what nature can offer as a solution, and how the phenomena that occurs in nature might be applied. The assignment can also be approached differently by identifying an authentic problem first and then looking to see what in nature can be instrumental in helping to solve the problem identified. The website of the Biomimicry Institute will play an important role with this project in addition to other related websites. The website for the Biomimicry Institute is www.biomimicryinstitute.org.

Classroom Activities

Experiencing Self-Assembly

In this activity students will experience the concept of self-assembly and then write about what occurred as a way for them to summarize the process of self-assembly and the conditions that make it work. The classroom should be set up with 3-4 stations/areas that are labeled to simulate an environment. Suggested labels include Water, Sunshine, Air, and Land. You may choose to have different colored sheets of paper and markers as optional materials for students to use during the activity.

Have students go to any area of the room according to their personal preference for the label. Tell students that they are not to move to their preferred area until they hear the sound you specify, such as a bell or whistle. An option you may want to consider is to provide students with a card indicating the area they should go to in order to control the number of students at each station. Once at their stations, direct students to arrange themselves into some type of pattern or geometric shape. The arrangement you designate can be based on the topic you are covering in math at the time such as repeating patterns, 2 or 3 dimensional geometry, etc. One in their arrangements, instruct students to hold hands.

As you walk around, quickly sketch the pattern or shape each group has formed. You may choose to give this assignment to a student. In the sketch, each of their heads represents an atom or molecular structure and their arms represent the connecting bonds. Each group collective group of students represents a molecule or nanostructure. Follow up the activity with a discussion touching on points similar to: What did you do in this activity? What caused you to go to a specific section? How did you go about arranging yourselves into a pattern or shape? Did you find yourselves changing positions before you settled on a final pattern or shape?

After discussion, have students write an explanation of what they did and how it was accomplished. Make sure they understand the activity was a representation of self-assembly. Thy key points you want to make sure they include in their explanations and relate back to self-assembly are that they are the ingredients representing some element with its own specific properties, the signs represented preferred environments of the 'ingredients or elements', the sound, bell, whistle or other sound, was the driving force, and they were able to move around and change their positions until they settled on a final configuration representing weak interactions or reversible binding forces. Have student volunteers share their summaries and use them as a lead in to a more formal explanation of self-assembly of nanoparticles at the molecular level.

I Have Who Has

This is a whole group class activity that involves students reading a question from a card, another students answering the question with a response on their card and then asking a new question in a round robin fashion. The I Have Who Has Cards are included in the appendix for you to print and cut out for classroom use. A worksheet, consisting of a column of numbered terms and a column of lettered definitions, for students to complete during the activity should be developed as well. As the answers are given, students should match the correct lettered definition with the appropriate numbered term.

Math Representation Chart

For this activity students will be provided with an incomplete chart with headings for various ways to represent numbers mathematically including representations for: decimal, fraction, scientific notation, positive exponential notation, and negative exponential notation. The number will also be represented in words. The chart will have some of the cells filled in and students will be required to complete all of the remaining cells that are appropriate for that number.

Resources and Websites

Adams, Wade, and Linda Williams. *Nanotechnology Demystified*. 1 ed. New York: McGraw-Hill Professional, 2006. This book provides a general overview of nanotechnology. It familiarizes the reader with the terminology, the concepts, and the tools and instruments primarily used in the multidisciplinary field of nano-science. The book includes quizzes on the main points after each chapter.

Benyus, Janine M.. *Biomimicry: Innovation Inspired by Nature*. New York: Harper Perennial, 2002. This book is all about using nature as a source of inspiration for new innovations. It focuses on viewing nature as a model of what we can imitate or use as inspiration in our designs of nano-structures and nano-devices to solve human problems; a measure of the appropriateness of nano-innovations; and a mentor viewing and valuing nature as a teacher form which we learn, rather than as a source from which we extract and deplete.

Bonner, John Tyler. *Why Size Matters: From Bacteria to Blue Whales*. Princeton: Princeton University Press, 2006. In this book John Bonner provides an overview of what we know about the role of size in the living world. Size is introduced through the ideas and concepts behind giants and dwarfs. Questions regarding the physics of size as it relates to biology, the evolution of size, and the role of size with respect to function and longevity are presented. He provides formulas that illustrate the relationship of relationships involved with the physics of size e.g. weight and strength.

Bourne, Marlene. *MEMS & Nanotechnology for Kids*. First ed. Scottsdale: Bourne Research Llc, 2007. This book is written for kids with a fair amount of visual representations. It is written as an exploration and comparison of things that exist in the world at the micro-scale and the nano-scale. It is an easy and interesting read.

Boysen, Richard D. Booker~Earl. *Nanotechnology For Dummies (For Dummies (Math and Science)).* New York: For Dummies, 2005. This book is easy to read and presents the topic of nanotechnology in a way that makes it accessible and comprehensible to the lay person. It presents a clear explanation of what nanotechnology is, its application, and where it is headed. It doesn't answer all of the questions related to nanotechnology, but provides the basics for understanding the topic.

Falvo, Michael R., M. Gail Jones, and Amy R. Taylor. *Extreme Science: From Nano to Galactic* (PB237X). Danvers, Ma: National Science Teachers Association, 2009. A collection of investigations designed to help students develop a comprehensive sense of scale through interactive activities using the quantitative units and tools of science.

Forbes, Peter. *The Gecko's Foot: Bio- Inspiration: Engineering New Materials from Nature.* New York: W. W. Norton & Company, 2006.

Harmer, Andrea. *Nanotechnology for Grades 1-6+: Introducing Nan and Bucky dog.* Bloomington: Authorhouse, 2005. This book is written primarily for children but I found it to be suitable for adults as well. It is a very good introduction to the concept of nanotechnology and spends a fair amount of time explaining the size of a nanometer using different comparative representations. It includes a glossary of terms and hands on activities.

Johnson, Rebecca L. *Nanotechnology (Cool Science)*. Minneapolis: Lerner Publications, 2005. This book has lots of visual representations that aid in gaining a basic understanding of nanotechnology and is written at a level that upper elementary would be able to comprehend. It covers information on how small the world of nano is, the new tools associated with it, and the current use of nanomaterials and in the future. It includes a basic glossary of terms and websites for further research.

Jones, Richard A. L. *Soft Machines: Nanotechnology and Life*. New York: Oxford University Press, USA, 2004. This is a comprehensive book that explains the differences between the macroworld and the nanoworld. It focuses on the question of design rules that should be followed when working at the nanoscale. It discusses how cell biology works and the implications of physics at the nanoscale. Written for an adult audience.

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.

Nanooze: A children's online Science Magazine and a source for current and exciting information in science and technology and free classroom copies of the Nanooze publication for kids. www.nanooze.org

Nanokids: A series of 12 self-contained nanoscale science and technology lessons for grades 6-12. http://nanokids.rice.edu/mission.cfm

Science Museum UK Online: Information about nanotechnology and an interactive game. http://sciencemuseum.org.uk/antenna/nano

Understanding Nanotechnology: General information about nanotechnology and its applications. http://understandingnano.com

University of Wisconsin-Madison NSEC: Lessons for the K-12 science classrooms and after school groups. http://nsec.wisc.edu

Lawrence Hall of Science: Interactive games, videos, scale, and meet a scientist. http://nanozone.org

National Nanotechnology Initiative: this site has an Education Center link that provides information for K-12 students and teachers. www.nano.gov

National Nanotecchnology Infrastructure Network: Contains general information about nanotechnology, educational resources, and links to additional nanotechnology resources. http://education.nnin.org

The Biomimicry Institute promotes learning from and then emulating natural forms, processes, and ecosystems to create more sustainable and healthier human technologies and designs. It is an excellent resource for research projects. Has an ask nature feature and contains case studies of what has been learned from nature. www.biomimicryinstitute.org

Glossary

MEMS - Micro-Electronic-Mechanical Systems

Hydrophilic - 'water-loving' materials that are soluble in water; it is a molecule or part of a molecule that is attracted to water molecules

Hydrophobic - 'water-fearing' materials that do not dissolve in water; it is a molecule or part of a molecule that is repulsed by water molelcules

Allotrope - each of two or more different physical forms in which an element can exist

Lyophilize - to freeze-dry a substance

Matter - any physical substance that occupies space and possesses resting mass

Atom - the smallest particle of an element composed of three types of charged particles: protons (positive), neutrons (neutral), and electrons (negative)

Quantum mechanics - a theory of physics that describes physical interactions between atoms and molecules more accurately than classical physics

Probe - a small device, esp. an electrode, used for measuring, testing, or obtaining information

Endnotes

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1. 1 Andrea Harmer, Nanotechnology for Grades 1-6+
2. 2 Marlene Bourne, MEMS and Nanotechnology for Kids, 4-7
3. 3 Shawn Stevens, LeeAnn Sutherland, Joseph Krajcik; The Big Ideas of Nanoscale Science and Engineering, 79-80
4. 4 Shawn Stevens, LeeAnn Sutherland, Joseph Krajcik; The Big Ideas of Nanoscale Science and Engineering, 80
5. 5 Linda Williams, Nanotechnology Demystified, 49
6. 6 Linda Williams, Nanotechnology Demystified, 50
7. 7 Linda Williams, Nanotechnology Demystified, 51
8. 8 Linda Williams, Nanotechnology Demystified, 52
9. 9 Linda Williams, Nanotechnology Demystified, 53
10. 10 Linda Williams, Nanotechnology Demystified, 55
11. 11 Nanooze, Issue 2, 2007, 4-5
12. 12 Nanooze, Issue 2, 2007, 5

13. 13 Andrea Harmer, Nanotechnology for Grades 1-6+, 22
14. 14 Nanooze, Issue 3, 2008, 6
15. 15 Nanooze, Issue 6, 2008, 7
16. 16 Linda Williams, Nanotechnology Demystified, 45
17. 17 Linda Williams, Nanotechnology Demystified, 57-58
18. 18 Richard Booker, Nanotechnology for Dummies, 12
19. 19 Linda Williams, Nanotechnology Demystified, 13-14
20. 20 Linda Williams, Nanotechnology Demystified, 15
21. 21 Linda Williams, Nanotechnology Demystified, 12-13
22. 22 The Big Ideas of Nanoscale Science and Engineering, 14
23. 23 Rebecca Johnson, Cool Science Nanotechnology, 16
24. 24 http://inventors.about.com/library/weekly/aa091297.htm
25. 25 www.electroiq.com, Northeastern University, Collaborators Reproduce . . . Adhesion Properties

Appendix

Figure 1 Scientific Notation Chart

Scientific Notation and Units of length

10 m	10^{1} m	1000 cm	10,000,000 um	10,000,000,000 nm
1 m	10^{0} m	100 cm	1,000,000 um	1,000,000,000 nm
0.1 m	10^{-1} m	10 cm	100,000 um	100,000,000 nm
0.01 m	10^{-2} m	1 cm	10,000 um	10,000,000 nm
0.001 m	10^{-3} m	0.1 cm	1,000 um	1,000,000 nm
0.0001 m	10^{-4} m	0.01 cm	100 um	100,000 nm
0.00001 m	10^{-5} m	0.001 cm	10 um	10,000 nm
0.000001 m	10^{-6} m	0.0001 cm	1 um	1,000 nm
0.0000001 m	10^{-7} m	0.00001 cm	0.1 um	100 nm
0.00000001 m	10^{-8} m	0.000001 cm	0.01 um	10 nm
0.000000001 m	10^{-9} m	0.0000001 cm	0.001 um	1 nm
0.0000000001 M	10^{-10} m	0.00000001 cm	0.0001 um	1 Å ← 0.1 nm (1 angstrom)

Figure 1

I Have Who Has Cards

I have the first card.

I am not fond of water and will avoid it any way possible. I would describe myself by saying.

I am hydrophobic.

I love water and like to be in water as often as I can. I would describe myself by saying.

I am hydrophilic.

I contain the blueprint for all proteins for living organisms. How has the what I am known as?

I have DNA.

Who has the description of what I can do when my nano friends and I arrange ourselves into a pattern or structure.

I have self-assemble.

I love to copy what nature does. So how would you describe me?

You are biomimetic.

I am one billionth of a meter. Who has my name?

I have nanonometer.

There are one billion of me in a meter. Who has the name of the scale that I belong to?

I have nanoscale.

I make up all tangible matter. I would introduce myself by saying.

I am atom.

Who has the word for what we call 2 or more atoms that bond and hang out together?

I have molecules.

There are two types of bonds between atoms. Ionic bond is one of them. Who has the name for the other type of bond?

I have covalent.

Who has the name of those things that that cause atoms to bond together?

I have electrons.

I am a capsule made from a lipid bi-layer that has folded over itself. Who has what I am called?

I have liposome.

Who has the name of one of the functions I can serve in the medical field?

I have drug delivery.

Kids love to play with me by using a liquid and a wand and I am an example of self-assembly. Who has the name of what I am known as?

I have bubble.

I love mayonnaise. I was told that mayonnaise was an example of something scientists use to create nanoparticles. Who has what mayonnaise is an example of?

I have emulsion.

In order to make an emulsion there are 4 key features to help it happen they are the particles or ingredients, an environment to put them in, a reversible binding force and one other feature. Who has the other feature for an emulsion?

I have driving force often to be in the form of mechanical energy.

Who has the first card?