Subject Area: g-College Prep Elective

Grade Level: 9-12

Unit Value: 1.0 (one year equivalent)

Pre-Requisites: Algebra 1

Co-Requisites: Biology

Brief Course Description

Course: Nanotechnology

Nanotechnology is an exciting new field of study that cuts across all scientific and engineering disciplines. It is concerned with the unique properties associated with assemblies of atoms or molecules on a scale between that of the individual building blocks and the bulk material. Such an ability to control assemblage of material between these two limits provides the potential for improving many evolutionary and revolutionary technologies. Some of the newest developments in biotech and the high-tech industries are based on nanotechnology.

This year-long, project-based course will introduce students to several important aspects of nanotechnology, as well pointing to the on-going development of new nanomaterials technology based on nanoscale phenomena. Some aspects of the societal and economic factors influencing nanotechnology development are also covered. The major topics covered in the "i-Nano" course are:

(1) Properties of Nanomaterials—explore the origins of the physical, chemical and biological properties of materials, and the applications of nanomaterials
(2) Tools for Probing the Nanoworld—explore the use of instruments for measuring properties and phenomena in nanoscale structures and devices
(3) Design and Fabrication of Nanomaterials—explore the modeling, simulation, and top-down and bottom-up fabrication approaches of nanoscale structures and devices
(4) Nanomaterials for Energy, Environment, and Pharmaceuticals—explore surface-to-volume-ratio relationship of nanostructure materials and their applications as catalysts, storage space for energy-rich gases, and chemicals for medication
(5) Impact of Nanotechnology—explore the current and impending impacts of this emerging field on various consumer marketplace and industries, as well as, its impact on the integrity, diversity and continuity of life on earth

Course Goals and/or Major Student Outcomes

It is estimated, by the year 2015, that newly derived nano-based technologies and products will help to generate at least $1 trillion/year of new business from pharmaceuticals, new materials, electronics, chemicals, aerospace, tools, etc. The new technologies promise to improve healthcare and the sustainability of agriculture, food, water, energy, environment, etc. To carry out and sustain these new businesses, it is estimated that 2 million nanotech workers are needed worldwide, of which 40% will be in the US. Without a well educated and trained workforce, we might not be able to enjoy the quality of life we expect in the future!

The **i-Nano** course is designed to help educate our future citizens to be nanoliterate and help prepare a large cross-section of our population (the next generation of technicians, factory workers, doctors, engineers, teachers, scientists, entrepreneurs, writers and managers) in the skills and knowledge necessary to maintain the momentum of discovery and innovation that are characterized by these life-changing advances. The course materials and innovative learning tools (such as remote instrumentation and online simulation and modeling) will pique the interest of new generations of young learners and encourage them to enter nanoscale science and engineering (NSE)-related fields. New web-based learning technology will broaden student access to specialized nano instruments and offer them hands-on, inquiry-based projects that will bring NSE alive.

This course will adopt a modular approach to introduce various topics in nanoscale science and technology. It will implement design challenges at the end of each modular unit to help students apply and reinforce science and mathematical content knowledge by participating in the process of creating, modifying, or building something that solves a problem or meets a perceived need. The intriguing properties of nanoscale materials and phenomena provide an engaging design context for students to apply the underlying science concepts they learned in each module, as well as reinforce mathematical tools/concepts (such as algebra, geometry and trigonometry) used in the process of their design solutions. Like that of experienced scientist or engineer in the real world, technical innovation (in nanotechnology initiated by the students) will be a challenge made feasible when science knowledge, science processes, mathematical skills and technological design come together.

Course Objectives

The **i-Nano** course, which incorporates an innovative nanotechnology design approach, is structured to enhance student acquisition of many of the characteristics associated with learning, which are listed below:

- Piquing an interest in science and technology
- Improving teamwork skills
- Sharing responsibilities
- Appreciating the role of science in the real world
- Knowing how things work in the man-made world
- Knowing how things work in the natural world
- Overcoming a fear of failure
- Understanding concepts as opposed to memorizing them
- Applying learned content knowledge in a new context
- Willing to take risks in order to advance an idea
- Being willing to pursue a new direction
- Discovering and improving one's new talents and skills
- Making decisions based on criteria and data

- Understanding the importance of controlled and varied parameters
- Experiencing the reality of no "right answer"; look for a "best answer"
- Developing the skills of innovation
- Thinking in unconstrained ways or "outside the box"
- Appreciating critical feedback

The **i-Nano** course is also designed to reinforce the following science and math skills/content knowledge:

Big ideas in nano—every scientific domain is built on a set of core concepts, the understanding of which is essential to the domain. Big ideas form the very core of a domain. They are critical for basic competency because deeper understanding depends on these basic ideas as the building blocks for future science understanding. Big ideas may be cross-disciplinary. That is, they may be thought of as "big ideas" in science. In fact, the nature of big ideas in nanoscience and nanotechnology is that they are interdisciplinary. Thus a mastery of concepts included in these nano big ideas will allow students to gain a deeper understanding of topics in traditional science disciplines, such as physics, chemistry or biology.

Upon completion of the **i-Nano** course, students will have a working knowledge of the following big ideas in nanoscale science and engineering (Size and Scale, Structure of Matter, Size-Dependent Properties, Dominant Forces, Self-Assembly, Tools & Instrumentation, Models & Simulation, Nano & Society):

- **Size and Scale**
  Concepts related to size and scale have both mathematical and scientific components and even extend to other disciplines such as geography and history. For this reason, fostering connections among subject areas may support student learning in all areas. In order to communicate the size of things in any subject area, standard measurement units and numerical values are required. The type of units and magnitude depend on the application and the amount of experience that students have. This subject matter tends to fall in the domain of mathematics, but by linking it to science content, student understanding in both disciplines may benefit as one reinforces the other. An understanding of the magnitude of numerical values is necessary before skills at estimating relative quantities and sizes of things can be developed. In history, the timeline is much greater than an individual's life experience. In geography, the scales on maps indicate the size of the representation relative to the real thing. Thus, concepts of size and scale permeate many aspects of the school curriculum.

  However, size and scale are not simply academic constructs; they also impact our daily lives. When cooking for a large crowd, cooks scale up the recipe and increase the ingredients proportionally. Travelers use scaling skills to translate the scale on a map to the real distance that they will travel. As students gain experience both in and out of school, they can begin to relate the values and units to the world around them. Because the relative magnitude of these scales is often large, scientific notation becomes a useful means of communicating very large and very small numbers.

Implementing this type of notation lends itself to categorizing the size of things by orders of magnitude.

Strong support from mathematics is required before students will be able to apply the concept of surface area to volume ratio to scientific concepts. Students must learn about ratios and proportions, as well as develop an understanding of what area and volume are and how to calculate them. Only after all of that is well understood can students connect that understanding with how SA/V (surface area-to-volume ratio) affects properties and behaviors of matter.

- Factors relating to size and scale (e.g. size, scale, scaling, shape, proportionality, dimensionality) help describe matter and predict its behavior.
- Size and scale are intrinsically linked. Size is defined as the actual extent, bulk, or amount of something. Scale has several definitions. Scale links the size of an object to a numerical representation of that size in conventionally defined units (e.g., meters, grams, gallons, light years, acres). Properties like size, length, and mass can exhibit large differences in magnitude (Benchmarks). Those large changes in magnitude are often defined as scales, or 'worlds' (e.g., micro-, nano-, atomic-, astronomical). Defining these worlds is important because doing so determines the physical laws that are needed to explain how objects within that world behave. Scale also can link representation to reality. For example, the scale on a map provides a connection between a visual length on the map and a distance in the real world. Scaling links to proportionality and how changes in size are manifested in how a system works.
- Not only the size of objects or systems changes with scale, but also the way in which they function or behave also changes with scale. For example, even small changes in linear size yield larger relative changes in area, and even larger changes in volume. Thus, if a property is dependent on volume (e.g., heat capacity, mass), then it will change much faster than properties dependent on area (e.g., cooling surface, absorptivity) for a given change in size. Many of the special properties that matter exhibits on the nanoscale result from the effect of size on the surface area to volume ratio (SA/V). In chemistry, this relates to the number of atoms on the surface relative to that of the bulk material. Because the surface atoms/molecules interact with the environment, SA/V has a significant effect on chemical reactivity. For example, nutrient uptake from the small intestine is more efficient by the millions of projections, or villi, that increase the absorptive surface area. Burning a log is different from burning an equal mass of twigs.
- Shape also affects the proportionality between surface area and volume. A 10 x 10 x 10 cm cube will have different properties than a 1 x 10 x 100 cm shape. Both have a volume of 1000 cm^3, but the surface area of the cube is only 27% of the surface area of the other shape. If they were both blocks of ice, under the same conditions, the cube would melt more slowly.
- Predicting the behavior of a system at one scale does not necessarily translate to behavior at another scale. Thus "size and scale" includes concepts not only of size and scale, but also of scaling, ratios and proportions, and shape. In

addition, the dimensionality of each of these concepts is also important. Length, area, and volume change disproportionately and thus affect each of these concepts differently.

- Size and scale often affect how matter behaves in surprising ways. As the size or mass of an object or material approaches the nanoscale, predictions of the behavior of matter begin to fail using classical mechanics.

- **Structure of Matter**

  All matter is made up of atoms, but it is the arrangement of those atoms that determines the properties of a material. The electron configuration of an atom determines how it interacts with other atoms thus electrical forces dominate the interactions between atoms. These ideas are currently in the science standards; they provide a critical foundation for understanding the properties and behavior of nanoscale objects and materials. Nanoscale materials themselves are made of atoms, molecules or other nanoscale objects, therefore many of the same principles apply. The same types of electrical forces dominate the interactions as those found between atoms when they form molecules. Likewise, the type of building blocks and their arrangement largely determines the properties of the material.

  - All matter is composed of atoms that are in constant motion. Atoms interact with each other to form molecules. The next higher level of organization involves atoms, molecules or nanoscale structures interacting with each other to form nanoscale assemblies. The arrangement of the building blocks gives a material its properties.
  - The atomic theory describes a model in which matter is composed of discrete units called atoms. The arrangement of these atoms determines the properties of a material. As the size of a material approaches the nanoscale, the material exhibits novel, often unexpected properties. Nanotechnology exploits these properties to create new materials and devices.
  - The particle nature of matter is also important because some properties at the nanoscale can be related to properties common to all atoms. Interactions between atoms are determined by their electron configuration thus they are dominated by electrical forces. (These ideas are currently in the science standards; they provide a critical foundation for understanding the properties and behavior of nanoscale objects and materials.) The principle that the atoms that compose all of matter are in constant, random motion has implications on the nanoscale because the small number of atoms contained in a nanoscale object is sometimes small enough that the motion of an individual atom affects the properties and behaviors of the whole. In addition, electrical forces and thermal motion are essential to the formation and functioning of assemblies.
  - The specific properties of the constituent atoms are sometimes related to the interesting properties at the nanoscale. For example, a carbon atom can accommodate many bonding patterns. The different ways that carbon atoms bond with each other afford very different materials with very different

properties. For example, the bonding pattern (sp2) that is exhibited in carbon nanotubes contributes to the extremely high tensile strength of the material.

- **Size-Dependent Properties**

Identifying the properties and characteristics of materials is one of the fundamental concepts of science. As such, from their earliest experiences with science, students begin to describe the properties of objects around them. Initially, they rely on properties such as size, shape, color, weight and the material of which it is made. Many of these properties seem unreliable for describing something because they change. For instance, a solid may break into pieces, or an object may be artificially colored. These types of properties are generally designated as extensive properties.

The descriptive problems that are due to properties' changeability are overcome with the introduction of intensive properties such as density, melting point, boiling point and solubility, which do not change and are "independent of the amount of material". The only exception mentioned by these sources is that the individual atoms and molecules do not share the same properties as the bulk substance. These types of properties prove to be useful for comparing different materials and predicting their behavior within the macroscale world. However, as the amount of the bulk material gets smaller and approaches nanoscale size, these "properties that never change" do change. Thus, with the coming of the nanoscience revolution, it is no longer sufficient to teach properties of matter as a dichotomy of bulk, or macroscale, properties versus atomic or molecular properties. Instead, it has become relevant to discuss the properties of matter using more refined levels. No longer can we clearly categorize properties that do change (extensive) from those that do not (intensive), because *all* types of properties can change depending on the scale. The use of intensive and extensive categorization must be linked to scale, as they the terms are meaningful only when describing matter at the macroscale. Characterizing the transition between the macroscale and atomic scale will lead students to a much deeper understanding of matter and how it is put together.

- The properties of matter can change with scale. In particular, as the size of a material approaches the nanoscale, it often exhibits unexpected properties that lead to new functionality.
- Properties are generally defined as those qualities or characteristics that determine the nature of a material. They are the source of the functionality of a material; that is, they determine how it appears, how it behaves, how it interacts with and reacts to the environment, and for what applications it might be useful. However, while many properties are constant on a given scale, changing the size or shape of a material can lead to changes in its properties. In particular, as the size of a sample decreases and approaches the nanoscale, materials will exhibit different properties that are often unique and unexpected. For instance, spheres of gold with diameters of 1 m, 1cm and 1 mm will all be shiny and gold-colored, and will exhibit metallic properties such as malleability and conductivity. On the macroscale, all of these properties remain the same. However, when spheres of gold become very

small, those properties change. On the nanoscale, the color of gold particles becomes very sensitive to size. Gold spheres with a diameter of 13 nm suspended in solution (a colloidal solution) afford a red color. At sizes less than 10 nm, gold loses its metallic properties and is no longer able to conduct electricity.

- The source of the unique properties observed on the nanoscale may be either surface- or bulk-related. Surface-dominated behaviors are governed primarily by changes to the surface area-to-volume ratio that occur from changes in size or shape, while bulk dominated behaviors are related directly to the size or shape of the object or material.
- The unique properties of matter at the nanoscale promise new applications for familiar materials. The fact that properties change with scale is at odds with the traditional concept of "intensive properties" which are defined as independent of the amount of material. However, that definition only applies on the macroscale. As the size of the material gets smaller and approaches the nanoscale, some of those intensive properties do, indeed, change. Therefore, properties can no longer be categorized without qualification as those that do change (extensive) and those that do not (intensive) because all properties can change depending on scale.
- The properties that are relevant to nanoscale science include optical, magnetic, mechanical, chemical and electrical characteristics of materials. The nanotechnology revolution revolves around exploiting these properties to solve problems that impact all aspects of society.

- **Dominant Forces**

  The idea that electrical forces dominate at the nano- and atomic scales includes not only chemical bonding, but also interactions between nanoscale structures both natural (e.g., proteins, DNA) and fabricated. Little, if any, curricular emphasis is typically put on the different electrical forces that are responsible for intermolecular interactions. Shape tends to be presented as the primary determinant of recognition. For example, it is impossible to explain the specificity of the biomolecular interactions that regulate the function of all living organisms only using shape. Rather, the different types of electrical forces primarily control the strength and specificity of interactions.

  In addition, while students learn about the different forces that are involved in interactions in biology, they often do not connect those to what they learn in chemistry. For example, the hydrogen bonds that explain the behavior of water should be connected to the hydrogen bonds that keep the strands of DNA together. Too often, students learn the terminology without understanding what it means; therefore, they do not connect the two ideas. Emphasizing this type of connection may help support the concept that the dominant forces on the nanoscale are the same, regardless of the objects participating in the interaction.

  - Nanotechnology exploits the unique properties of matter on the nanoscale to create structures with new functionality. In order to design and build nanoscale structures, it is critical to understand *how* they are structured, which includes how they are held together. Therefore, it is necessary to have an understanding of the electrical forces that dominate the interactions between the atoms, molecules and nanoscale structures that create nanoscale assemblies and materials.

- All interactions can be described by multiple types of forces, but the relative impact of these forces changes with scale. On the nanoscale, a range of electrical forces with varying strengths tends to dominate the interactions between objects.
- The behavior of matter can be described by four fundamental forces: gravitational force, electromagnetic force the nuclear force (or strong force), and the weak force. Gravitational force is the dominant force at the macroscale. It describes a force between masses that is always attractive. At the nano- and atomic scales, forces derived from electrical charges dominate. They are a subset of the electromagnetic force, and represent a range of electric forces. Examples of these types of interactions include chemical bonding and intermolecular forces. The nuclear (or strong) force is responsible for keeping the components of atoms together thus is dominant on the sub-atomic scale. The weak force is associated with radioactivity (i.e., beta decay) and other nuclear reactions.
- Small objects (e.g., atoms, molecules, nanoparticles) interact in a variety of ways, all of which are dominated by forces that are electrical in nature. These electrical forces create a continuum of forces that predominantly describe all interactions within matter on that scale, the strength of which depends on the entities involved. Historically, these forces are divided into discrete categories: Ionic bonding and interactions, metallic bonding, covalent bonding, hydrogen bonding, van der Waals forces, and covalent bonding. While these categories facilitate communication, none of them exist in pure form.
- Ionic interactions occur between ions that have opposite charge of an integer value. An example of this type of interaction is ionic bonding, which involves interactions that are based on electrostatic forces between two oppositely charged atomic and/or polyatomic ions.
- In metallic bonding, electrons are delocalized throughout a lattice of atoms. It involves the attraction between the positively charged metal ions and the delocalized electrons and is responsible for the physical properties of metals such as conductivity, malleability, heat conduction and luster.
- Covalent bonds are characterized by the *sharing* of one or more electron *pairs* between atoms. This attraction holds molecules together. This type of bond tends to be used to describe interactions between non-metals that have similar electronegativities. These bonds can occur within individual molecules (e.g., H_2O, O_2), and within covalent network solids (e.g., diamond, quartz).
- Hydrogen bonds occur between very specific types of atoms or molecules. They consist of an interaction between two partial charges of opposite polarity. Hydrogen bonds generally occur between hydrogen atoms attached to an oxygen, nitrogen or fluorine atom, which gives the hydrogen atoms a partial positive charge. The hydrogen atom will interact with an atom that has a lone

pair of electrons in its outer shell and tends to strongly attract electrons when interacting with other atoms (oxygen, nitrogen or fluorine atoms). While other atoms can act as partners in the interaction, the strength of the interaction is significantly diminished. Although they are relatively weak, they can play an important role in the structure and behavior of matter. For example, hydrogen bonding explains many of the special properties exhibited by water. It is also the force that lends specificity to the interaction between the two strands of DNA.

- Partial charges are generated by the non-uniform distribution of electrons. This non-uniform distribution can be permanent as in a polar molecule, or induced and nonpermanent, the result of time-dependent fluctuations in electron distribution. Attractive forces resulting from this non-uniform distribution of charge are often referred to as van der Waals forces. The permanent dipoles are formed when some atoms of a molecule tend to attract electrons, while others tend to lose them. This creates an uneven distribution of charge resulting in partially positive and negative regions of the molecule, or a dipole. Dipole-dipole interactions occur when the positive region of a molecule interacts with the negative region of another. Under some conditions, the electrons in neutral atoms are displaced momentarily to create a non-uniform distribution of charge and thus induce a dipole. The formation of the induced-dipole, allows atoms to attract each other electrically even though they are neutral. This induced-dipole/induced-dipole interaction is called the London dispersion forces, but is commonly referred to as van der Waals forces. The London forces act on *all* types of atoms and molecules, but increases in strength in proportion to the number of electrons.
- None of these forces exist in a pure form; they always share characteristics of one another. For example, hydrogen bonds have both a dipole-dipole character as well as a covalent character. Thus they actually create a continuum of electric forces, the strength and character of which are defined by the partners involved in the interaction. These forces are not only involved in interactions between atoms and molecules, they also dominate the interactions between objects at the nanoscale. Therefore, it is necessary to have an understanding of all of these forces in order to understand the function and behavior of matter on the nanoscale.
- Because the dominant forces in an interaction are largely determined by scale, the same forces govern many types of interactions. The electric forces that bond atoms together to form molecules are also involved in interactions between nanoscale objects, both natural and fabricated. Biological macromolecules are some of the natural nanoscale objects that fall into this category, including DNA, proteins, and the ribosome. The strength and specificity of the interactions between biological molecules is extremely important as they regulate the biological processes that maintain life. The type of electric force plays a role in the strength and specificity of an interaction. For example, DNA is a negatively charged molecule. During the process of replication, it is necessary to split the double helix into two separate strands. The proteins that are responsible for this function bind primarily through ionic,

or electrostatic, interactions between the negatively charged DNA strand and positively charged amino acids on the protein. This interaction is deemed nonspecific because the protein will bind to the DNA in the same manner no matter where it is on the strand. Proteins that bind to DNA with greater specificity regulate the replication process. In this case, the proteins combine ionic interactions with hydrogen bonding to bind to DNA. The limited number of partners that can be involved in hydrogen bonding makes the arrangement of the contacts more important. This increases the specificity of the interaction because the protein must interact with the DNA at a specific location, in a specific configuration, to in order maximize the interactions between them.

- **Self-Assembly**

  Self-assembly is not just a process used to advance the progress of nanotechnology; nature also uses self-assembly to build structures on every scale. The principles behind self-assembly are the same in both realms in that under certain conditions, objects assemble into an organized structure without external intervention. Thus, self-assembly is a universal concept that engineers have adopted and applied to the problem of nanoscale fabrication.

  The process of self-assembly presents an opportunity to build a deeper understanding of the factors that influence the strength and specificity of interactions. In the standards, shape is the primary factor considered to be important for creating favorable interactions. While shape is an undeniable influence on interactions, forces between the objects determine the strength and specificity of the interaction. This concept can be illustrated with shaped magnets. Both shape and polarity will play a role in the final assembly that the pieces adopt.

  - Under specific conditions, some materials can spontaneously assemble into organized structures. This process provides a useful means for manipulating matter at the nanoscale.
  - The traditional approach to manufacturing has been top-down, which involves removing pieces of an object in order to reach the final product. This process is similar to creating a sculpture from a block of material. Etching and dissolving are examples in the manufacturing process. However, as the scale gets smaller, it is more difficult to purposefully manipulate matter efficiently, thus creating a need for new approaches to fabrication. An alternate approach is to manufacture from the bottom up, combining smaller building blocks to make larger products. On the nanoscale, these building blocks are atoms and molecules or nanoscale structures, which are brought together such that every atom lies in a precise, designed location. The building blocks can be chosen or designed, and conditions created such that the blocks assemble without further external intervention. This process is called *self-assembly.* Self-assembly provides a means for building nanoscale materials that may possess unique and useful properties. This process is also crucial for applications that require the synthesis of many nano-structures simultaneously.

- The process of self-assembly involves mobile components that reorient into a structure that is both predictable and organized. In order for this to occur, the components must be in an environment ("certain conditions"), which will induce the desired interaction(s). Once components are introduced into the self-assembly environment, they will organize through attractive or repulsive forces between the components. When objects self-assemble to create stable, bound structures, there must be net attractive forces bringing and holding them together. On the nanoscale, the forces will be electrical in nature. The process of self-assembly occurs spontaneously once certain conditions are set. Thus, the free energy of final state of the *system* is lower than the initial state. Only some materials are capable of self-assembling. They must possess specific characteristics (shape, charge, etc.) in order to be viable. The components of self-assembly retain the physical identity through the self-assembly process and after self-assembly. Therefore, the initial components can be isolated from the assembled structure by providing the right conditions.
- While self-assembly is a crucial technique for the advancement of nanotechnology, it is not a new process. Self-assembly occurs in Nature to build structures on every scale. The canonical example would be the process of assembling the DNA double helix, which proceeds with a specificity that has yet to be duplicated by scientists. In addition, some of the molecular machines that carry out crucial functions within all living organisms are built through a process of self-assembly. Thus, self-assembly is a universal concept that engineers have adopted and applied to nanoscale fabrication.
- The formation of membranes is another example of nanoscale self-assembly. In this case, the building blocks (e.g., phospholipids) have a hydrophilic end and a hydrophobic end. The hydrophilic end can participate in hydrogen bonding with water, so the interaction with that end is favored over the weaker interactions (dipole-induced dipole) that occur with the hydrophobic end. Therefore in an aqueous environment, the hydrophilic ends all align such that they are exposed to the water and the hydrophobic ends are buried within. In Nature, this process creates the tissues known as biological membranes, an example of which is the cell wall. These membranes are important because they create a barrier that allows cells to maintain different chemical or biochemical environments than those of the outside.
- Engineers have adopted the process of self-assembly as a way to overcome the challenging problem of building nanoscale objects with accuracy and precision. The building blocks and the environment are designed such that the blocks assemble themselves without external intervention. This is an example of bottoms-up fabrication. Self-assembly is currently being used to extend the possibilities of synthetic chemistry and to build new nanoscale structures. Chemists combine large, structured groups of atoms that assemble in an ordered, symmetric manner to form ever larger (often snowflake-like) molecules called dendrimers. Synthesis of carbon nanotubes utilizes self-assembly in two ways. The synthesis of the individual nanotubes occurs via self-assembly. Once formed, the nanotubes tend to aggregate through van der Waals forces, aligning to form rope-like structures that are one of the

strongest and stiffest materials known. Because of the small scale, bottoms-up fabrication is an important aspect of nanotechnology and promises to play an important role in the efforts to exploit the novel properties of matter on this scale.

- **Tools & Instrumentation**

Much of the grade 7-12 science curriculum requires students to learn about objects and phenomena that are too small to be seen with the naked eye. Beginning in elementary school, students learn about the abstract concept *electricity*. In addition, they are often introduced to atoms and atomic structure. As they learn about living organisms, they study cells and even smaller things that govern the function of the cells (mitochondria, proteins, DNA). Using tools to observe and measure these things that are otherwise not visible may facilitate students' conceptions of such abstract concepts. For example, the change in voltage with resistance is predicted by the equation $V = IR$. Using a voltmeter to observe the effect that changing the resistance in a circuit has in the voltage output provides an experience that may enable students to derive the mathematical equation that explains the phenomenon.

While theory may have predicted the existence of atoms, experimental evidence provided proof of their existence. Unfortunately, the historical experiments themselves are somewhat abstract and may be less than convincing to students. The scanning probe microscopes provide new, more accessible evidence for the existence of atoms. In addition, the images provide evidence for the arrangement of atoms in a solid. The tools that are available determine what scientists are able to observe and measure. In the past, a need for a new tool was created by the desire to observe or measure a predicted phenomenon. Thus for scientists, developing new tools or instruments is often part of the experimental design. Therefore, this relationship between development of tools and addressing a hypothesis is a key part of the scientific process.

- Development of new tools and instruments helps drive scientific progress. Recent development of specialized tools has led to new levels of understanding of matter by helping scientists detect, manipulate, isolate, measure, fabricate, and investigate nanoscale matter with unprecedented precision and accuracy.
- Technology plays an important role in scientific progress, as science and technology often drive one another. The tools and instruments available to scientists determine what is accessible for them to measure, and scientific hypotheses and theories create a need for new tools and instruments. When new tools and instruments are developed, new worlds become accessible for study. This accessibility leads scientists to new understandings and new questions, which is part of the scientific process.
- The degree to which we understand our world is limited, in part, by the tools available to investigate it. Thus, development of tools plays an important part in the progress of science. Telescopes, for example, allow for the exploration of distant portions of the universe, while optical microscopes enable the

investigation of a world that is otherwise too small to see. The development of each of these tools led to enormous gains toward understanding the systems within these worlds. Recently tools and instruments (e.g., scanning probe microscopes) have been developed that have rendered the nanoscale world accessible in ways impossible to fathom just a short time ago. These new instruments help scientists characterize nanoscale materials and objects with relative ease and to reveal their special properties. This new accessibility has lead to new understandings of matter on this scale and has aided in the development of new applications.

- In addition to visualizing the nanoscale, new tools also provide the ability to create structures on this scale. It is now possible to manipulate matter with a level of control that makes it possible to design and create nanoscale materials. SEMs can be used to create nanoscale patterns on a specially prepared surface. This technology plays an important role in the miniaturization of electronics as engineers work to create micro- and nanoelectromechanical devices (MEMS and NEMS respectively). In addition, albeit under extreme conditions, the scanning probe microscopes can be used to move individual atoms into precise positions, affording unprecedented control on the atomic level. Thus, these new tools and instruments are a critical aspect of nanotechnology.

- **Models & Simulations**

Many have argued that the process of building and refining models lies at the core of the scientific process. Indeed, the National Science Education Standards emphasize that all students should understand that " scientists formulate and test their explanations of nature using observation, experiments and theoretical and mathematical models" (NRC, 1996, p. 171). Likewise, Benchmarks identified models as a common theme, and suggests that their application is critical in fields as diverse as mathematics, education, law, business and finance, science and technology (AAAS, 1993).

Because students often have difficulty in relating models to the reality, gaining this skill in any context will help them make the connections with nanoscience concepts. This skill is critical for learning nanoscience concepts because the nanoscale is inherently inaccessible

- Because nanoscale objects and phenomena are, by their very nature, too small to see, models are needed to understand, visualize, predict, hypothesize, explain, and interpret data about them.
- Models are simplified representations of objects or systems. Some aspects of a given model are the same as the target, but others are necessarily different. Models are essential in all fields of science, helping researchers test and build their understanding of both the natural and fabricated world. Throughout history, the design and manipulation of models have been essential for the advancement of science. Models are particularly useful for making predictions about and working with objects or systems that are otherwise inaccessible. In the case of the nanoscale, the source of this inaccessibility is the size of the

structures and systems. The processes that govern the workings of the human body, micro- and nanoscale electronics, drug discovery and medical research, and the creation of highly designed and functional nanoscale materials all involve nanoscale phenomena. Progress in the understanding of these and other areas of nanoscale science has benefited from and depended on the application of modeling. For example, to aid in the design and optimization of potential drugs, pharmaceutical companies create models of structures and systems that are potential drug targets. The use of models has contributed greatly to the scientific progress in these and other areas of nanoscience and nanotechnology.

- Modeling is a critical tool for scientists. Models allow scientists to visualize aspects of objects and phenomena, to predict behaviors that can then be tested by experiment, and to organize observations and representations of data. Likewise, modeling has always played a crucial role in the design process. Many nanoscale structures that occur in nature perform functions efficiently under extremely accurate control. These structures have inspired scientists and engineers to design counterparts that duplicate nature's control and efficiency, but can be applied toward obtaining different, desirable functions. Modeling the structure and function of these natural structures plays an important role in the design of the new nanoscale assemblies.
- Much of the science that affects people's lives is not only extremely complex, but lies at a scale too small to be seen (e.g., biotechnology, nanotechnology). Models not only provide a way for scientists to make progress in these fields, but also to facilitate communication among themselves, as well as with the public at large.

- **Nano & Society**

  Part of the process of science is how the new knowledge is applied to solve the problems of current society. In order for the population to evaluate and make educated decisions about new technology, it is necessary to have some level of understanding of the science behind it. Thus, with the extent to which nanoscale science and engineering promise to impact all aspects of society, it is important to create a population that is nanotechnology literate.

We are now in the early part of what may be called the nanotechnology revolution. Nanoscale science and engineering are "science-in-the-making" and can be used to illustrate the dynamic nature of science to students. Doing so provides a way to model the process of science, in contrast with the static, content-driven way that science is traditionally taught in grades 7-12. Students can witness the processes that scientists use when confronted with new phenomena. They can see how engineers use their understandings to create new applications that address various problems and limitations, and students can participate in the debate on the usefulness and the cost-benefit ratio of these applications to society.

Student motivation, interest, and engagement are important aspects for student learning in science education. Positive student attitudes toward science have been correlated to higher performance on science assessments for the majority of students. Studies have shown that "interest is more strongly related to indicators of deep-level learning than to surface-level learning", which may explain why students with low interest in science perform poorly on exams that measure deep understanding. Based on previous research, we know that student achievement increases significantly when the science subject matter is relevant to their own lives. Participating in the dynamic nature of science and the interplay between scientific discoveries and new technologies with the greater society illustrates that science is not just some knowledge to collect, but an integral part of our lives both present and future. This presents an opportunity to use nanoscience and nanotechnology to help motivate students to learn both NSE and more traditional science.

- The field of nanotechnology is driven by the aim to advance broad societal goals. As with other technological advances, the products of nanotechnology may impact our lives in both positive and negative ways.
- The many interrelationships between science, technology, and the global economy impact society in important ways. Economics and policy can drive science, as was the case with President John F. Kennedy's challenge to put a man on the moon by the end of the 1960's. Much funding and focused effort in science and technology were directed toward meeting this goal. Many of the scientific and engineering advances that were developed to meet that challenge found applications that impacted the greater society (e.g., electronic communications, computer technology, materials development).
- The aim to advance broad societal goals such as improved healthcare, increased productivity, and sustainable resources, is a major factor driving the nanotechnology revolution. But, the advancement of nanotechnology does not depend solely on successful research and development; an array of societal factors including the education and preparation of skilled workers and researchers, state and federal policies, and economic demands are also contributing factors. Thus there is a complex interdependent relationship between society and the advancement of nanotechnology.
- Nanotechnology promises to affect our quality of life because new nanoscale applications are being developed to solve problems as diverse as water quality, sustainable energy, and improved healthcare. While these goals are positive, any technological advance carries with it the risk of negative impacts, as well. For example, nanoscale objects are small enough to permeate the biological barriers that protect all living organisms. This means that nanoscale materials present different health risks than the same material at a larger scale. It becomes important then to direct research toward the potential risks as well as the potential benefits of nanotechnology.
- From the discovery of fire and the wheel, science and technology have been employed to improve our quality of life. The Industrial Revolution shifted an economy driven by manual labor and agriculture to one dominated by industry and mechanization. Thus, it changed not only technological conditions, but socioeconomic ones as well. More recently, computers have revolutionized

the way people work and communicate, and the Internet has equalized the accessibility of information.

- Nanotechnology promises to have a broad effect on society. Already, it impacts applications as diverse as data storage, electronics, and cosmetics, and promises to improve healthcare and the sustainability of agriculture, energy, and the environment. For example, although enough energy from the sun hits the earth every day to meet all energy needs on the planet, we have not yet found an adequate way to harness it. Changing to solar energy from nonrenewable, polluting fossil fuels would have tremendous impact on both environmental and energy concerns. Chemists are developing a nanotechnology application to produce a material that directly converts light to electricity by means of an array of nanoscale solar cells. The cells might be incorporated into a material that could cover a surface like plastic wrap or paint. In this way, nanoscale solar cells could be integrated with other building materials, and could offer the promise of inexpensive production costs that could finally make solar power a widely used alternative to electricity.
- In terms of potentially negative consequences, science is frequently ahead of society's ability to deal with it. For example, scientists' ability to split the atom to control nuclear fission changed the world. This technology led to the development of a weapon of mass destruction used to end WWII. From that moment forward, scientists have focused on controlling the use and proliferation of such technology. Currently, nuclear energy accounts for approximately 20 percent of U.S. energy production. While it is clean source of energy that it does not contribute to air pollution, the nuclear waste created by the process poses a problem that will have to be dealt with for generations. Likewise, in addition to new understandings and treatments of human disease, biotechnology also brought with it ethical questions about practices such as cloning.

Course Outline

Unit 1: Introduction to Nanoscale Science and Technology (9 wks)

Module 1—Apples to Atoms

Introduction
- Background: At the Nanoscale
- LEGOs and Oven Mitts
- A History of Nanoscience

Activity 1: Size and Scale
- Apple Analogy
- Exponents and Scientific Notation
- Powers of 10
- Orders of Magnitude
- Taking it to the Field
- Dominate Forces at the Nanoscale
- The Strong Nuclear and the Weak Nuclear Force

- Brownian Motion

- Activity 2: Measurements
    - Units—SI vs. Imperial
    - Unit Conversion
    - Measurement Activity
    - Significant Figures and Precision
    - Ideal Tools: Pen and Box
    - Ideal Tools: Pick It Up
    - Measuring in the Dark
    - Make Your Own Ruler Design
    - Tools and Methods for Measuring Extreme Distances
- Activity 3: Microscopy
    - How Light Works
    - Light Microscope
    - Scanning Electron Microscope (SEM)
    - Advanced SEM Understanding
    - Atomic Force Microscope (AFM)
    - Map It
- Activity 4: Surface Area to Volume Ratios in Nanoscience
    - Surface Area and Volume Computations
    - Ratios
    - Comparing Surface Area to Volume as Radius Changes
    - Reaction Rates and Surface Area to Volume Ratio
    - SA/V Computer Simulation
    - Roughness in Fractals and Nature
- Activity 5: Nano-Webquest

Module 2—Intro to Nano: Surface Area to Volume Ratio

- Activity 1: Same Materials Different Behavior
    - It's Not Just What's Inside that Counts
    - Will It Burn
    - Disappearing Water
    - Different Forms of Sugar
- Activity 2: Powers of 10 and Scale
    - A Journey through Size
    - Growing Creatures
    - Expression a Large Span of Distances
    - Jumping a Common Ratio
    - It's All Relative: Expressing Scale
    - Scaling from Macro to Nano
- Activity 3: Surface Area and Volume
    - Hot or Cold: Comfort or Even Survival
    - Ideal Two Dimensional Objects
    - Properties of Three Dimensional Objects
- Activity 4: NanoConcept Card Game
- Design Project: Designing a Liquid Geyser

Alternate DP: Designing a Water Cleaning System for Space Vehicles

Module 3—Nanotechnology

Activity 1: Changing the Properties of Materials by Changing Their Size
- Size-Dependent Properties
- Effect of Particle Size on the Rates of Chemical Reactions
- Effect of Particle Size on the Color of Gold Colloid

Activity 2: Searching for Nanoscale Objects
- Nano Applications Are Already Around Us

Activity 3: Nanopatterning with Lithography
- Fabricating Nano-Size Objects
- Modeling a Microsphere Mask to Make a Pattern of Nanoparticles
- Making "Nanoparticles" of Various Shapes and Sizes

Activity 4: Amplifying the Nanoscale to the Macroscale
- Imaging Nano-Sized Objects
- Amplifying Movement Using Reflected Light
- Calibration
- Finding Force Using Reflected Light

Activity 5: Vibration Isolation

Design Project 1: Designing a Nanometer-Scale Imaging Apparatus

Alternate DP: Designing a Cardboard AFM: Seeing the Unseen

Alternate DP: Designing a LEGO AFM

Design Project 2: Modeling a Nanoscience Application

Minipedia
- A Brief History of Nanotechnology
- Physics of Nanoscience
  - Atomic Force Microscopy: "Seeing" Nanoparticles on a Surface
  - Spectroscopy: "Seeing" Nanoparticles in Solution
- Chemistry of Nanoscience
  - Self-Assembly
  - Carbon Nanoscience
- Biology of Nanoscience
  - Nanoparticles Made by Biological Processes
  - Nanotechnology in Medicine

UNIT 2: NANOMATERIALS BY DESIGN (9 WKS)

Module 4—Nanocomposite Materials

Activity 1: Testing Different Kinds of Ice: Ice Composites

Activity 2: Hunting for Composite Materials
- Composite Materials Identification

Activity 3: Exploring the Difference between Strength and Stiffness
- Testing Materials for Strength and Stiffness
- Ranking Materials for Strength and Stiffness
- Placing Materials on a Strength/Stiffness Grid

Activity 4: Testing a Foam Composite for Strength and Stiffness
- Composites in Sports Equipment

Production of Building Materials
Using Wastes to Make Concrete
Recyclability
Nuclear Waste Disposal
Hydroelectric Power
Biological Materials Similar to Cement and Concrete
Mollusks
Corals
From Shell to Limestone to Portland Cement
Termites
Nanoconcrete
Cellular Nanoconcrete
Mechanical Properties of Nanoconcrete
Nanoconcrete for Low CO_2 Emission

Module 6—Nano in Sports Materials

Activity 1: Exploring Ball Design and Materials
Compare Size, Mass, Distribution of Mass, Surface Texture, Construction, etc. of Variety of Sports Balls
Activity 2: Measuring Rebound of Sports Balls
The Importance of Rebound
Using the Coefficient of Restitution (COR)
Testing COR as a function of temperature, pressure, and humidity
Activity 3: Investigating Energy Absorption of Materials
Impact Surfaces
Energy Absorption in the Human Body
Testing Different Impact Surfaces
Measuring Deformation Caused in the Impact Surface
Activity 4: Comparing Rolling Friction of Different Surfaces
Friction in Sports
Measuring the Speed of a Green on a Grass Lawn Using a Home-made Stimpmeter
Measuring the Rolling Friction of a Variety of Sports Balls
Measuring the Sliding Friction of a Variety of Sports Shoes
Activity 5: Researching Nanomaterials in Sports Equipment
Design Project 1: Designing a Mini-Golf Game
Design Project 2: Designing a New Nano Sports Equipment
Minipedia:
Nano Bowling Balls
Nanomaterials Used in Golf Clubs
Stealth Carbon Nanotube Baseball Bats
Nanosized SiO_2 in Tennis Racquets
Long Lasting Nanoclay Tennis Balls
Nanowax on Skis and Snowboards

UNIT 3: NANOSENSORS (9 WKS)

Module 7—Smart Nanosensors

- Activity 1: Evading Motion Detection
  - Determine Active Sensor Region
  - Identify Stimulus Response of Sensor
  - Design and Conduct Evasion Experiment
  - Infrared Heat Detectors
- Activity 2: Taking a Tour of Some Sensors
  - Surrounded by Sensors
  - Search for Passive and Active Sensors at Home
  - Describe Physical and Chemical Changes in Sensor Materials
  - Stimulus/Response Mechanisms in a Sensor
  - Biological Sensors
- Activity 3: Making a Microphone
  - Sensing Sound
  - Test a Piezoelectric Film's Response to Sound
  - Compare the Test Different Piezoelectric Film
  - Testing the Effect of Substrate Material on Sound Generation
  - Human Auditory System
  - Understanding Signal Amplification
- Activity 4: Exploring the Piezo Effect: The Inside Story
  - The Physics of the Piezoelectric Response
  - Building the PVDF Monomer
  - Constructing a Molecular Model of PVDF Piezo Polymer
  - Understanding Electric Dipole and Electric Signal Generation in PVDF
  - Effect of Bending Stress on a PVDF Film
  - Electrical Signal Measurement and Resolution
- Activity 5: Measuring Piezoelectric and Pyroelectric Response
  - Pyroelectric Thermometers
  - Measure Voltage Output of PVDF in Response to Applied Force and Heat
  - Determine Relationship of Impact Force and Temperature Changes to Voltage Response of PVDF
  - Electric Polarization Changes to Thermal and Mechanical Stress
- Activity 6: Modeling a Nano Active Sensor
  - Sensing Nanoscale Dimensional Changes
  - Applications in the Atomic Force Microscope and Scanning Tunneling Microscope
- Design Project 1: Designing a Coin Counter
- Design Project 2: Designing a New Nanosensor
- Minipedia:
  - How a Motion Detector Works
  - Everyday Uses of Piezoelectric Film
    - Transportation
    - Sports and Recreation
    - Coin Counters
    - Future Applications
  - The Physics of Smart Sensors

Adhesives
Fibers
Elastomers
Plastics
Polymers and Physics
Conducting Polymers
Light-Emitting Polymers
Holographics Polymers
Inetlligent Gels
The Chemistry of Polymers
Condensation or Step-Growth Polymerization
Addition or Chain-Growth Polymerization
Copolymers
Polymers in Medicine
Biodegradable Polymers
Prosthetics
Polymeric Nanosensors
Conducting Polymer Nanosensors
Polymer Nanosensors for Measuring Radiation and Oxygen Detection
Ionic Polymer Conductor Nano-Composites (IPCNC) as Biomimetic Distributed Nanosensors
Low-Cost Humidity Nanosensors Using Nanoporous Polymer Membranes

UNIT 4: IMPACT ON THE ENVIRONMENT (9 WKS)

Module 10— Biodegradable Nanopolymers
Activity 1: Comparing Packing Materials
Design a Test to Compare the Properties of Biodegradable and Nonbiodegradable Packing Materials
Test the Degradation of Packaging Materials in Water
Construction of Cellular Packing Materials
Activity 2: Hunting for Biodegradable Products
The Need for Biodegradable Products
Search for the Variety and Availability of Biodegradable Materials
What's in a Landfill?
UV Degradation of Polymer
Activity 3: Processing Biodegradable Materials
Gelatin—A Biodegradable Polymer
Making Different Forms of Biodegradabel Materials from Gelatin
Comparing the Strengths of Gelatin Films
Correlate Strength of Biodegradable Materials with Concentration of Gelatin Solutions
Structure of Polymer Gels and Films
Cross-Linked Bonding in Polymer Materials
Activity 4: Measuring the Degradation Rates of Biodegradable Materials

Determine the Purposes of Materials Used in a Food Package
Examining the Electromagnetic Fields in a Microwave Oven
Mechanism of Popping Popcorn Kernels in a Microwave

Activity 2: Analyzing Food Packaging Materials

Tracing the History of Food Preservation and Packaging Technology
Examine a Variety of Different Types of Food Packaging
Identify and Categorize the Purposes of the Packaging and the Materials Used
Analyzing the Properties of Food Packaging Materials
Recycling Food Packaging Materials
Plastic Recycling Code

Activity 3: Evaluating the Impact of Food Packaging on the Environment

Understanding Food Packaging and the Environment
Efficiency of Biodegradation in Landfills
Evaluate the Environmental Impacts of Food Packaging Alternatives
Determine the Recycling Rate of Various Packages
Calculate Packaging-to-Product-Ratios to Determine Packaging Efficiency of a Variety of Solid and Liquid Packages
Source Reduction and Recycling

Activity 4: Researching Food Packaging Materials: Paper or Plastic?

Trace the Life Cycle of Food Packaging Materials
Evaluate the Overall Impact of Packaging Bags on the Environment

Activity 5: Designing a Protective Package

Investigate the Ability of Different Packaging Materials to Protect Package Content
Energy Transfer, Work, and Newton's 2nd Law of Motion
Generate Criteria for Evaluating Protective Packaging
Test Different Packaging Materials
Design, Construct, and Test a Protective Package

Activity 6: Testing the Effectiveness of Food Preservation via Nanotechnology

Design a Test for Nanosilver Food Packaging

Design Project 1: Designing a Potato Chip Package

Design Project 2: Designing a New Nanotech Food Package

Minipedia:

Nanopackaging Using Polymer–Silicate Nanocomposites
Ultra High Humidity/Moisture Barrier Nylon-6 Nanocomposites
Nanotechnology in Food Microbiology
Active Packaging—Incorporation of Nanomaterials to Inhibit Pathogen Growth in Fresh Produce or Meat

Module 12— Nanotechnology and the Environment

Activity 1: Catalyzing with Platinum Black

Chemiluminescence and Luminol
Reactivity of Methanol and Oxygen in the Presence of Pt. Catalyst
Oxidation of Methanol
The Effect of Activation Energy on the Rates of Reaction

- Activity 2: Searching for Catalysts
  - Catalysts Used in Natural Processes, Industrial Processes, and Pollution Treatment
  - The Green Chemistry Challenge
  - Selectivity vs. Specificity
  - Catalysis of Natural and Synthetic Rubber
  - Papain: The Natural Catalyst in Meat Tenderizers, Cleaning Solutions, and Skin Treatments
  - Catalysts for Removing Heavy Metals from Wastewater
- Activity 3: Using a Heterogeneous Acid Catalysis
  - Homogeneous and Heterogeneous Catalysts
  - Heterogeneous Acid Catalysis of the Hydrolysis of Methyl Acetate
  - Specific vs. General Acid Catalysis
  - Comparing the Rates of Reactions
  - Recycling Heterogeneous Catalysts
  - Organic and Inorganic Acid Catalysts
  - Calculating the Surface Area-to-Volume Ratios of Solid Catalyst Particles
- Activity 4: Using a Metal Catalyst to Degrade an Air Pollutant
  - Breathing Easier: Catalytic Air Treatment
  - VOCs (Volatile Organic Compounds)
  - Ozone and Photochemical Smog
  - Degrading Ammonia via Thermal Catalysis of Different Metals
  - Comparing the Rate of Poisoning of Different Metal Catalysts
  - Recycling Catalytic Coverters
  - Increasing Reaction Rate Using Nanoscale Catalysts
  - Enhancing Catalysts Specificity and Selectivity
- Activity 5: Using Photocatalysis with TiO_2 Nanoparticles to Degrade Air and Water Pollutants
  - Understanding How Photocatalysis Work
  - Determine the Photocatalytic Degradation Rate of Methylene Blue
  - Examine the Effects of Catalyst Concentration, UV Light Intensity, and pH on MB Degradation
  - Photoactivity and Electronic Properties of Titanium Dioxide
  - Efficiency of Photocatalysis
  - Comparing Photosynthetic and Photocatalytic Processes
- Activity 6: Testing the Effects of Self-Cleaning Nanostructures
  - Lotus Effect and Nanostructure
  - Making a Self-Cleaning Filter
  - Testing Self-Cleaning of Local Plant Leaves and Other Surfaces
- Design Project 1: Designing a Catalytic System to Degrade a Pollutant
- Design Project 2: Designing a Nano-based Catalysis for Environmental Cleanup
- Minipedia:
  - Environmental Impact of Cars
    - Ethyl: The Rise of Lead
    - Catalytic Converters: The Fall of Ethyl
    - New Challenges for Environmental Catalysis

Photochemical Smog
Degradation of Ammonia by Copper and Iron Transitional Metal Catalysts
Effects of the Environment on the Performance of PEM Nanocatalysts

Texts & Supplemental Instructional Materials

- Instructional Modules developed by the Materials World Module, Northwestern University
  - Apples to Atoms
  - Introduction to the Nanoscale: Surface Area to Volume Ratio
  - Nanotechnology
  - Composite Materials
  - Infrastructure Materials
  - Sports Materials
  - Smart Sensors
  - Biosensors
  - Ceramics
  - Biodegradable Materials
  - Polymers
  - Food Packaging Materials
  - Environmental Catalysis
- Nanotechnology: a gentle introduction to the next big idea, by Mark and Daniel Ratner
- Vision: how science will revolutionize the 21st century, by Michio Kaku
- Interactive simulations/animations
- Journal articles and reference materials
- Guest speakers

Key Assignments

A primary goal of the **i-Nano** course is the implementation of a technological design at the end of each set of module activities to help students apply and reinforce science and mathematical content knowledge in the given module topic. The course defines technological design as a series of six major activities each creating laboratory opportunities that encourage students (a) to express themselves individually as well as in a group (b) to better observe and communicate their activities, and (c) to engage in iterative trials that improve understanding and thinking. The course places a special emphasis on iterative trials because redesign can best cement an understanding of the scientific concepts and focus attention on the practical considerations that affect the success of a design. By doing so, students experience the reinforcement of content knowledge, process skills, and technological reasoning.

The six major components emphasized in the **i-Nano** course are aligned with the National Science Education Standards (NRC, 1996) and the Standards For Technological Literacy of the International Technology Education Association (ITEA, 2000). **i-Nano**, however, goes beyond the standards by including the component of *"Redesign"* as seen below. The six major components with targeted learning objectives are:

The Problem Focus

- Define the specific problem or consumer need
- Gather background scientific information, design constraints and impact issues

Design Implementation

- Brainstorm ideas
- Propose prototype(s)
- Design the prototype(s)
- Construct the prototype(s)

Test

- Devise and conduct tests of the prototype (s)
- Reflect on the feasibility of the prototype design (s)

Redesign

- Propose alternate design for prototypes (if needed)
- Implement the redesigned prototype(s)
- Test the redesigned prototype(s)
- Reflect on the feasibility of the newly designed prototype(s)

Evaluation

- Develop evaluation criteria
- Choose the best design
- Evaluate the design solution and its consequences using the criteria
- Identify the pros and cons for each design
- Decide why the design that was chosen was the best choice

Communication - using verbal, written, portfolio, or dimensional models,

- Communicate the problem
- Describe the processes/ procedures used
- Visually display the test results
- Identify the "best" solution and tell why
- Discuss the feasibility of the design in the real world e.g. a marketing or business plan
- Reflect on what was learned from technological design

Instructional Methods and/or Strategies

The **i-Nano** course will be taught using a modular approach, consisting of 3-week long modules. The learning experiences planned for the modules consist of a series of hands-on activities that culminate in a final design project. Thus the traditional lecture by the instructor will not be a significant part of the course; instead, the instructor will act more as a facilitator than a teacher. Students will be active in their own learning by participating in module activities designed to promote self-directed, cooperative, and collaborative learning opportunities. As an example of how a typical module is conducted is described as follows: An introductory activity involving reaction chemistry and the synthesis and characterization of nanometer-sized particles teaches students about the concept of scale. It also helps students explore nanoscale versus macroscale and think about how materials at these scales can be fundamentally different. Activity 2 is a library research project that encourages students to explore a wide variety of nanoscale objects being developed, such as buckyballs, DNA wires or hairpins, molecular motors, nanowires, etc. in the fields of medicine, electronics, and pharmaceuticals. Activity 3 guides students to investigate a method that is used to control the size and shape of nanoparticles using lithography. Students are introduced to the concept of nanoscale surfaces, similar to DNA and proteins, and the difficulty in characterization of these surfaces. Activity 4 helps students simulate mapping of the topographical features of a nanoscale surface by amplifying nanoscopic surface structure to a macroscopic scale, like that of an atomic force microscope (AFM). Activity 5 helps students learn about the wild oscillations that are magnified on a nanometer scale and how to damp such oscillations to allow accurate determination of surface topography. In the **final design project**, students are challenged to propose a new application for their chosen nanoscale object or design a model AFM.

The working philosophy in developing the course content will be to (1) explain how nano-world phenomena and principles are linked to those in the macroscopic world, and (2) consider how these can be applied to improve our quality of life. Each module will link the latest research topics in nanotechnology to basic science concepts, learning goals, and national science education standards. Modules will be based on design principles rooted in literature on how people learn, and knowing what students know, including recent research on student learning in higher education. The course material will be designed based on the following principles:

Structuring Modules around Learning Goals: We begin by identifying the content standards, inquiry habits of mind, the nature of science standards and the prerequisite knowledge that students need for a particular module or curriculum. We then go on to redefine the student learning goals in terms of expected performance. Based on expected performance, we design a range of assessments including embedded assessments. It is important for teachers / instructors to work from a framework in which they know what students already understand and believe about the scientific world.

Contextualizing the Inquiry: To contextualize the learning and engage students, we start with a driving question or challenge – a rich open-ended situation that connects with curiosities students have about the real world. We use various activities and investigations to help students apply their scientific understanding to real-world situations.

Supporting Inquiry: Because inquiry is complex, we use several strategies to support it: (1) elicitation of students' prior understandings and predictions, (2) elicitation of students' ideas; (3) use of scaffolds (teacher prompts) to help students engage in otherwise difficult tasks such as writing explanations, and (4) use of learning technologies to help students explore phenomena.

Anchoring in Multiple and Varied Phenomena and Representations: Students need a concrete experience or model in which to anchor abstract concepts; therefore the course materials will allow students to experience varied phenomena and representations either first hand or vicariously.

Designing for Diversity: Students bring unique perspectives and communication skills to their learning that reflect their cultural, ethnic, and socio-economic backgrounds. The previously mentioned strategies can also support learners from diverse backgrounds.

Advanced Learning Technologies: The course will help students visualize the unseen nanoworld using remote computer simulation and modeling. Remote controlled nanoscopic scanning probes will also be applied wherever applicable to enable students to "touch, feel, and see" nanoworld phenomena. Students will see the relevance of nano-structured materials to everyday applications and to the future needs of our society by connecting the material structures, properties and phenomena of the nanoworld to those in the macroscopic world. Students will learn how nano research ultimately leads to new technology and product developments.

Based on these curricular design principles, the i-Nano course will:

- Support students in learning based on national science education goals
- Engage students with inquiry-based learning challenges and hands-on design activities
- Incorporate the latest cutting-edge research in NSE and learning science
- Enable students to make logical connections between the nano and macroscopic worlds
- Make extensive use of 3-D visualization, touch, feel, & sound effects
- Offer challenge-based materials at various levels of difficulty between grades 9 and 12
- Align with California state learning standards and goals
- Develop a nanoliterate workforce able to participate in nano-related career paths in the state of California

Assessment Methods and/or Tools

- At the midpoint of each 3 week module, i.e., after completing all the module activities, a **performance task** will serve as evidence of the enduring understanding. A suitable performance task might be to design an instrument to characterize the surface features of a "nanoscale" structure, as posed by the following sample scenario: You are a research consultant for Nanoscalers, Inc. A new client brings you a prototype nanoscale sensor array for the detection of bacteria levels in lakes and ponds. The performance of this device is intimately tied to the nanosized features patterned onto a surface. The manufacturing process of these devices relies heavily on accurate quality control feedback in order for the device to operate correctly. Your team at Nanoscalers, Inc. has been chosen to design an apparatus and technique capable of characterizing the nanoscale features utilized by this device. The apparatus/technique must also meet the following criteria specified by Nanoscalers, Inc.: 1) the macroscale model must scale to a nanoscale apparatus; 2) the apparatus must be reusable; 3) the apparatus cannot damage or change the structure being imaged; 4) the apparatus must be able to characterize an area that is 10 μm x 10 μm in lateral dimension. The dynamic range must be at least 0-3 nm in height; 5) the measured data must be quantitative and used to recreate an image of the analyzed structure; and 6) all measurement and data processing must occur in a single class period.

  This performance task will ask students to demonstrate their understanding of nanometer size scale and properties by scaling from macro-dimensions. They will realize that not all macroscale functionality can be converted directly to nanoscale functionality. Both electrical and optical properties will have size-dependent behavior. On a nanometer scale, very small forces can cause dramatic structural changes, which will lead to properties changes. Students will also need to consider how many data points and how wide an area are required to yield meaningful data to gain an understanding of the surface being investigated and be able to graphically represent the minute "biological" surface features.

- Oral presentation and written report of the culminating design project
- Additional paper-and-pencil assessment items will be developed for quizzes and tests to serve as check points and assessment of their understanding of size-dependent properties and structural imaging techniques.
- Reading and homework assignments
- Classroom participation

Optional Background Information

"The emerging fields of nanoscience and nanoengineering - the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization - are ...likely to change the way almost everything - from vaccines to computers to automobile tires to objects not yet imagined- is designed and made." (from the July 2000 NSTC/NSET National Nanotechnology Initiative report, www.nano.gov)

Nano Labs

C-1 'Metric Measures' Los Angeles Southwest Community College (LASWCC) lab explores linear measures, weight, liquid volume and temperature in a hands on manner. Common items used are such as pennies, pins, table tops, microscope slides etc. Clay balls allows students to predict volume, by a graduated cylinder. Weighing object individually and collectively determines student accuracy in using a beam balance. Temperature readings of boiling water, and ice cubes at room temperature reflects students ability to use appropriate lab equipment. Pre-lab activity includes meteric (factor label) conversions pre and posttests in the lab. Process abilities and source references from student texts insure proper scientific methodologies.

C-2 Nano scale science: paper cube construction to determines volume to surface area geometry instructions unit to size (i.e., "King Kong" exists) NSTA press pp 95-109.

E. In a controlled experiment lab 'Pendulum Swings' students construct a simple pendulum using tape, string, rubber stoppers. They record the number of swings for 10 seconds using a stopwatch. They record the swings for only one variable at a time holding the other two constant. The variables are string length, height. Stoppers are dropped, and the number of stoppers. The three graphs are plotted to determine if there is any relationships between variables. Students also note Potential and Kinetic energy maximums, and minimums along the pendulum's trajectory cycle.

II.

B-1 Density lab: Question is which floats or sinks-Diet or regular coke? Students are asked to predict. Using overflow cans, students can measure displaced water when observing the density of a golf ball versus a tennis ball. Students also test Boernoull and Achimedes buoyancy rules.

C-1 Periodic Table activities: coloring families are a PT looking up family properties. Noting metalloids, across metal/non metal boarders, plotting periodicity trends across rows. Students will also plot density melting points distributions across the PT Trends includes relative reactivity in alkaline and alkali earth metals, atomic size, ionization energies, etc.

II.

E-1 Particle Size/Flame Test Demos: Demonstration arranges items according to volume to surface area from smallest item (low surface area to volume) to largest ratio. Items include a nail, steel wool, iron filings, nondairy creamer. They are placed over the Bunsen burner and heated or burned. Students observe rates of combustion from just getting hot to spectacular explosions students plot particle versus reaction spontaneity. Flame Test Demo allows students to observe sight, smell, and reaction color in developing items into a Bunsen burning, such items are old and new pennies, copper sulfate, iron, salt, sugar, magnesium strip, sulfur, iron fillings, etc.

II.

E---- Sulfur Clock Lab (Kukla et al pp588-589) allows students to time the reaction of various molar concentrations of sodium thiosulfate with IM HCL. Students plot the reaction curve and derive the reaction rate constant. They write reaction equations from their data.

II.

G-1 Scanning Probe Instruments- to simulate the unknown in nano microscopy, students are given opaque black plastic baas containing common everyday objects. By feel only, students will discern the objects and draw a 3D representation. Other 'black box' probes using wooden dowels to probe heights and locations of object surface structure given more realistic dimensionality (UCLA- CSN I Lab). NSTA and Atomic Force microscope construction using a pen laser as the light source. 'NanoScience" pp44-47.

III.

A 1-a Electric Force and Charge- Rub a balloon on a shirt, sweater (wool) to remove electrons. Place near stream of running water to show deflections of the stream near rubbed balloon demonstrates coulomb forces.

7-a Electrical Circuits Lab- simple battery driven series and parallel circuit with a small light bulbs. Lab Illustrates when circuit is broken with components in series, light bulb is not lit, with parallel circuits using two light bulbs, one area of the circuit shows one bulb lit and the other bulb out. Remaining bulb is brighter as bright as series circuit. Students compares voltage, resistance, and current requirements using Ohm's Law. Power is also calculation for the light bulbs in each circuit.

III

B-2 Electro Chemistry- 'citrus' lab using orange to construct a simple spontaneous battery. Electrodes of different metals are placed in the orange and voltage recorded. Electro potential is demonstrated between copper, zinc, lead, etc. Non-spontaneous batteries are constructed using two straighten paper clips connected to a 9 volt power source. The other end of the paperclip linked by alligator clip is placed into a petri dish containing sodium sulfate. Bronthymol Blue is used as a indicator to illustrate hydrolysis in the solution. Students derive oxidation- reduction reactions or each paperclip (electrode) defined by indicator color. Hydrogen and oxygen gas is collected and flame test confirmed the gas separations from water. Students write electrode equations. Electro Plating demonstrated by a single replacement reaction of zinc nuggets or Redox in a copper (I) sulfate solution. Copper is plated on both metals due to lower electro potentials.

Electrolysis (see Redox above)

III.

D 3-b Gas Spectrum Tubes- hand held spectroscopes handed out to students to view emission lines from argon, neon, hydrogen, helium gas tubes. They then plot spectral lines for four elements giving wave lengths for each line. Students calculate frequency of observed spectral lines.

III
E-2 Nano Solar Cell- adopted from UCLA's CNSI, two glass plates are treated with SnO_2 , Ti O_2 and graphite. These plates are tested for conductivity using a muff meter plates are classified as anode or cathodes sandwiched together after. The Ti O_2 Nano crystals have been immersed in raspberry juice, which serves as the photovoltaic medium. Iodine is dropped thru the clamped sandwich acting an electrolyte. The constructed Solar cell is connected to a multimeter under a light projector. Each student team records voltage, and current and is able to compute power (P=IV) their solar cell generals.

IV.
H-7 Virus Construction Model (NSTA pp 31-37) students become familiar with basic virus construction of a paper kosahedval capsid. A pencil serves as the viral tail with pipe cleaners as tail fibers taped to the pencil xxx is used as DNA which is inserted into the constructed capsid. This simple model illustrated infection but also potential medical delivery application.

IV.
H-5a Articificial Bone (Dragon Fly-TV- episode 5) cleaning sponges represent collagen – or bone material which has been broken on served. Ordinary epoxy is used to repair damage and compared to premixed Nano materials. Strength tests are performed and materials compared.

IV.
H-2b Self Assembly Lab (CNSI/UCLA) Pre-lab 'dry' activity includes arranging pennies in circle or square to determine maximum number with out overlap and going beyond geometry boundaries. 'wet' activity employs square and round magnets floating in water containers made into a circle and movable rectangle. The repulsive or attractive nature of the magnets test Gibbs 'Free' Energy Law: $\Delta G = \Delta H - T\Delta S$.

Nanotechnology Course Outline

Nanotechnology Labs Dr. Tartaglia

1. Metric measurement labs are designed for students to be able to calculate, convert, and use the metric system for scientific measurements in contrast to English units. Students are required to: 1) measure objects, 2) weigh assorted items, 3) calculate the volume of unknown items, as well as other measurements for specific objects.

2. In the nano scaling lab, students measure the cubic volume of a sugar cube and determine how many molecules are contained within the sugar cube as well as the edge of the sugar cube.

3. The nano cutting paper lab is designed to illustrate how small a nano particle is. A 20 cm strip of paper is cut in half over and over with scissors until it is no longer possible to cut it. This lab illustrates that the student cannot cut a piece of paper down to the nano level by showing that certain tools are required to complete specific tasks in the scientific world.

4. The Area-patterns activity (MWM module Activity 3) allows students to model the process of atomic force microscopy as well as understanding the bottom-up approach of fabricating nanoscale materials.

5. The Nano entropy lab is a measure of the randomness or disorder in processes or systems. The more disordered a system, the greater its entropy. The Gibbs free energy equation is investigated which is incorporated in nanotechnology.

6. The properties of steel lab changes the properties of iron by introducing carbon. The steel is both heated and cooled to produce the desired products. Spring steel, annealed steel, hardened steel, and tempered steel are manufactured and their specific material properties are examined.

7. The conductivity lab is designed to measure the conductivity of an element; how well does an element conduct an electric current. Various elements are test to determine their overall rank order of conductivity.

8. The nano lithography lab focuses on nanopatterning with lithography. The students use a frame to produce a pattern of nanoparticles. The activity models the process of nanosphere lithography on the macroscale.

9. The atomic force lab uses lego models to actually build an atomic force microscope and understand the process of how it works.

10. The nano self-assembly lab involves the movement of magnets to align themselves in accordance to their magnetic fields. Other force besides magnetic force can also influence self-assemble in nanotechnology. Cubic and hexagonal patterning of atoms is investigated.

11. The compressive forces and nano composite ice labs show how strong composite materials are designed. Pure ice spheres are compared with ice spheres combined with paper and/or sawdust. Both samples are subject to stress and pressure tests. The composite materials are far superior to the other forms.

12. The nanostaining pants investigation allows students to explore properties of nano-treated stain resistant-fabrics. Are there common properties of materials that do stain the treated and untreated fabrics?

13. The electrolysis lab illustrates how water can be decomposed into hydrogen and oxygen. The quantities of hydrogen and oxygen produced are measured and analyzed.

14. The nano optics lab shows how reducing the size of an object to the nanometer scale affects its physical properties. Nanoparticles depend on their size. The color of light scattered from solutions containing nanoparticles of gold reveals that at 3-30 nanometers, gold is actually red.

15. In the nano solar cell lab, students prepare solar cell devices which convert light energy into chemical/electrical energy from simple materials. They measure their electrical output in the light and dark using a multimeter.