Participant Responses to the Nanoscience Learning Goals Registration Survey

May 31, 2006

1. What major concepts of nanoscience do you think are most crucial to teach in grades 7-12? For example, scale is often cited. What others can you suggest?

1. Decreased surface area-to-volume ratio, characteristic of nanosized particles or aggregates results in faster reaction time, and that certain properties characteristic of bulk sized materials (>10-6 nm), such as; boiling temperature, freezing temperature, vapor pressure, coefficient of friction and density (to name a few) become irrelevant for nanosized particles. 2. Nanosized materials can exhibit different properties than their bulk sized correlates. Some of the properties that tend to vary are electrical, optical, reactivity (chemical), mechanical and magnetic properties. 3. Properties can differ at the nanoscale because the Classical Mechanical model of describing the behavior of materials no longer is descriptive for such small particles. The quantum-mechanical model is a more accurate way of describing behavior for nanosized particles or aggregation of particles. 4. The dominant force at the nanoscale is the electromagnetic force, rather than gravity, which is more dominant at larger scales. 5. New technology for manipulating and gathering data, the new generation of probe microscopes, has allowed us to learn more about the behavior of small substances than ever before. This knowledge has led the way to an increase in innovation in the area of nanotechnology, though nanotechnology can be used for various applications without fully understanding the underlying mechanisms of the new products. 6. As with any new products that have a potential impact of the global ecology and life in general, they need to be thoroughly researched for any potential hazards before use.
Along with scale is size. Through the interviews we've completed so far, we've found that students have little understanding of the sizes of small things. For example, when asked how large a red blood cell is, a student might respond "really, really small!" But when pressed for a quantitative answer, they might respond .5 mm. This is not only a scale issue, but an issue of size as well.
Surface area to volume changes and their effects.
1) Macro properties may be related to intermolecular interactions and thus be meaningless at the level of an individual molecule 2) Nanoscience is at a scale that can't be detected with a light microscope. Other instruments are used to gain an understanding at this scale.
Surface area to volume ratio.
Nanoscale science is not esoteric. There are a growing number of applications all around us.
Self assembly.
1) Size and scale 2) Nature of matter (atomic and kinetic theories, etc.) 3) Electronic interactions (hydrogen bonding, ionic bonding, van der Waals interactions, etc.)
Exploring how to articulate better the link between instructional materials centered on nanoscience and nanoapplications, and more "traditional" standards in physics and chemistry (structure, properties of atoms; forces; periodic table)
1) Surface-to-volume ratio (increases on going down in size scale) 2) Why having more atoms on surfaces leads to different properties (e.g., chemical reactivity) 3) How certain properties change with size (e.g., optical) 4) How nanoscale can lead to technological advances (e.g., computer speed, memory) 5) How dominant forces are different at the nanoscale (e.g., adhesion)
Scale Surface/volume ratio Fabrication

Self assembly The world of the atom Basic quantum concepts Networks: energy networks, chemical networks, biological networks, biogeochemical networks
Nanoscience is about molecules Nanoscientists build machines so small that you can never see them
The roles that nanoscience plays in one's everyday life and the science behind it, designed at the appropriate level and science standards. I think what we are working on with Nanosense is in the right direction.
The other nanoscience concepts I am familiar with are: Nanoscale particles have different properties than macroscale particles; Self assembly; and Different forces dominate at nanoscale and macroscale. It is also important to relate nanoscience to standard concepts such as energy, forces, chemical reactions, and to life and geo sciences.
At the nanoscale, the world is bumpy, shaky, and sticky. Bumpy because of the discrete nature of matter at atomic scales. Shaky because of themodynamics effects resulting in molecules & atoms in constant motion. Sticky because of electromagnetic forces (like van der Waals intermolecular forces) dominating at that scale and forces more familiar to 7-12 students such as gravitational forces being negligible. Helping students understand these three major changes from human scale to nanoscale would provide a solid beginning to understanding the uniqueness of the nanoscale that excites nanoscientists with possibilities. And this doesn't rely on quantum mechanical effects which are also exciting but likely beyond nearly all 7-12 students. Another aspect I'd like to explore is the interdisciplinary nature of nanoscience. At that scale, the traditional distinctions of biology, chemistry, physics are so blurred as to be essentially meaningless. Nanoscience may prove to be context to help 7-12 students integrate the learning they've had in discrete science classes into more of a conceptual whole by seeing relationships among these separate science disciplines.
(1) Relationship to natural biomolecular structure and function and (2) Designs for nanoparticle drug delivery systems
1. All things are made of atoms 2. Molecules have size and shape 3. At the nanoscale, everything is in constant motion 4. The properties of things at the nanoscale is a function of the molecules and their environment.
Scale Structure of matter
NanoLeap Big Ideas 1. Properties of Matter 2. Forces 3. Energy 4. Measurement and size 5. Interdisciplinary Nature of Nanoscale Science 6. Ethical and Social Issues of Nanoscale Science
The issue of gravitational forces vs. electromagnetic forces—doing estimation calculations to show which dominates at that scale, but also thinking about what quantum phenomena we need to be careful about at that scale.
Scale is clearly the most important but this includes two major ideas. One is simply size and understanding how small is the nanoscale. The other idea is that not all properties scale. What constitutes a lubricant is different at the nanoscale. New properties arise as things get small enough (quantum effects.) As a general science concept I would also stress electrical conductivity (metals, insulators, and semiconductors.) This concept is key to periodic properties and semiconductor devices and lab-on-chip medical diagnostics.
1) Impact of surface to volume ratio 2) Impact of particle size on environment of electrons (i.e., quantum confinement effects) 3) Impact of particle size on interaction with light
The different chemical and physical behavior of a material at the nanoscale level (compare with the same

property at the bulk level)
I think it is important at an early age to allow children to explore beyond the established boundaries of traditional disciplines. Nanoscience shifts the emphasis of traditional disciplines that focus on “content” to "”form”. Nanoscience also focuses on the importance of surfaces and interfaces between objects. This is analogous to teaching a system of math based on 8 instead of 10 because we count the spaces between our fingers, rather than our fingers.
Forces Comparison of thermal energy with other energies
Industrial Applications—examples of what have already been used around the world. There should also be some kind of fundamental understanding of the safety and risks of nanotechnology and nanoscience.
From a physics point of view, things happening at the nano scale boils down to quantum mechanics, which is quite difficult to teach at the pre-college level. Linking the abstract concepts in quantum mechanics to real nano systems is another challenge.
Why nanotechnology...why now, why is it important.
Inter/multidisciplinary Properties of matter Measurement and size Forces Energy Social/ethical implications
In the following, I've identified two topics for each discipline (phys, chem, bio) in each of four areas. 1) Motion and Energy: Conservation of energy at the atomic scale, temperature, states of matter, the gas laws from an atomic perspective, diffusion, biological energy. 2) E&M: The Coulomb force, dipoles, forces between atoms and molecules, properties of materials from an atomic perspective, protein folding, molecular recognition. 3) Atoms & molecules: atomic structure, electron orbitals, chemical bonds, reaction rates and catalysis, macromoleucles, DNA and proteins. 4) Light: Photons-atom interactions, Light waves and interference, photochemistry, spectroscopy, photosynthesis, fluorescense.
• Science has developed ways of understanding the structure of atoms and molecules that cannot be seen with the naked eye. • Richard Smalley was right; matter on the atomic scale behaves differently from matter on the macroscopic scale. • Many of the properties of matter depend on the size of the sample. The concept of color, melting point, boiling point, etc., have a very different meaning at this level. • Nanoscience isn'tnew; chemists have been manipulating atoms and molecules on the nanoscale for more than 100 years. What is new is our ability to use nanoscale science for technology. • The term "nano" doesn't mean the same thing when applied by Apple to describe one of their IPods and scientists and engineers.
1. Nano products 2. Potential societal and economic impacts of nano 3. Manipulating materials at the nanoscale to show new phenomena 4. Physical, electrical, and chemical properties at the nanoscale 5. The human story of behind nano
1. Surface area to volume ratio 2. Properties are very different at the nanoscale 3. Potential for exciting new technologies
Particulate Nature of Matter
The change in dominant forces. The importance of surface effects. The drastic change or lack thereof of intensive properties. Structure-property relationships.

As part of scale, the physical quantaties that vary with length, area, or volume.
The atomic and molecular structure of matter.
Kinetic model of heat and temperature.
Qualitative understanding of quantum effects at the nanometer scale.
Modeling; particularly, models at the nano-scale.
Reasoning by inference to determine what nanoscale measurements mean.

2. A candidate learning goal related to scale might be: The scale of matter determines its nature and properties. If you have candidate learning goal(s) for any of the concepts above, please list them here.

Students will understand how matter can have different sizes, and that all small objects are not approximately the same size.

1) Some physical characteristics such as density and melting point have no meaning when talking about a single molecule
2) Principles behind scanning electron and atomic force microscopes.

- The properties of matter differ between the macro-, nano-, and atomic scale. (need to go beyond intensive and extensive properties-- some properties DO change depending on the amount of substance)
- Forces and interactions change with scale (e.g. dominant force no longer gravity at nanoscale).
- The properties of a substance change as the surface area to volume ratio changes (already in the standards I think)

The dominant forces of matter depend upon size at the nanoregime.

Self assembly is integral to the formation of natural systems (viruses, cells) and the fractal nature of many structures underscores the importance of understanding emergence of patterns at scale.

At the macro-scale, engineers assemble devices and machines. At the nanoscale, things can assemble themselves.

At the macro-scale, the behavior of systems and objects is deterministic. At the nanoscale, the behavior of systems and objecs is probabilistic.

Nanoscale science is interesting because its phenomena are surprising, different from the behavior of atoms and molecules, and from macroscopic matter. Can the new phenomena be understood with existing concepts and theories, or will truly new science be needed? We don't know yet.

The goals I include below have not been carefully crafted as precise learning goals, but rather suggest the directions that eventual learning goals may take. Note that many of these are subsets of the "scale" learning goal given above as an example, suggesting that we might have broader learning goals and more targeted learning goals that provide more detail of the broad goal.

1) Bumpy: Matter consists of discrete components that interact in complex ways to produce material that we perceive to be continuous. (Perhaps appropriate for middle school years when they begin studying atomic structure and molecules).
2) Shaky: All matter is in constant motion - we measure and experience this motion at human scale as 'temperature'. (For more advanced high school students, would be able to expand this to include more thermodynamics concepts)
3) Sticky: There are only a few known basic forces that govern our universe. Different forces are dominant at different scales.
4) Interdisciplinary nature of nanoscience: Don't know how to word this exactly, but the focus on unifying themes throughout science education suggests that helping students make connections and see larger patterns and trends might lead to a number of related learning goals.

Natural biomolecular machinery provides important models for understanding key concepts in nano-scale science.

1. All things are made of atoms
2. Molecules have size and shape
3. At the nanoscale, everything is in constant motion
4. The properties of things at the nanoscale is a function of the molecules and their environment.

For Benchmarks listed below, the first number and letter refer to the chapter and section (e.g., 11D = Chapter 11: Common Themes), the next letter after the / refers to the grade level (e.g., /M = middle school, /H = high school), and the final number refers to the sequence number of the benchmark at that grade level.

SCALE

- Properties of systems that depend on volume, such as capacity and weight, change out of proportion to properties that depend on area, such as strength or surface processes. (Benchmarks, 11D/M1)
- Because different properties are not affected to the same degree by changes in scale, large changes in scale typically change the way that things work in physical, biological, or social systems. (Benchmarks, 11D/H2)

STRUCTURE OF MATTER

1. All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances. (Benchmarks, 4D/M1)
2. Atoms are made of a positive nucleus surrounded by negative electrons. An atom's electron configuration, particularly the outermost electrons, determines how the atom can interact with other atoms. Atoms form bonds to other atoms by transferring or sharing electrons. (Benchmarks, 4D/H1)
3. Atoms often join with one another in various combinations in distinct molecules or in repeating three-dimensional crystal patterns. An enormous variety of biological, chemical, and physical phenomena can be explained by changes in the arrangement and motion of atoms and molecules. (Benchmarks, 4D/H7)
4. The configuration of atoms in a molecule determines the molecule's properties. Shapes are particularly important in how large molecules interact with others. (Benchmarks, 4D/H8)

NanoLeap Big Ideas

1) Properties of Matter--Surface interactions can dominate, and changes in properties can arise at the nanoscale size.
2) Forces--Electrical and magnetic forces are the most important of the fundamental forces at the nanoscale level.
3) Energy--The flow of energy and large part drives processes of change in biological and chemical systems.
4) Measurement and size--Imaging and measurement tools allow for detection, characterization, and manipulation of nanostructures.
5) Interdisciplinary Nature of Nanoscale Science--The nature of nanoscale science, technology and engineering is interdisciplinary.
6) Ethical and Social Issues of Nanoscale Science-- Social interactions can occur between scientific and engineering communities and society.

The interaction distance of particles determines the nature of fundamental forces we need to consider in terms of crystal structure and stability. What is the glue that holds nano-particle based materials together?

- Scale of matter can introduce new properties.
- Electrical conduction involves movement of charges and smaller distances mean charges get there sooner.
- Electrical conduction can be controlled by gates and small changes in the gate makes large changes in the conduction.

- The ratio of the number of atoms on a particle`s surface to that in its bulk becomes large at the nano-scale and can control properties at the nano-scale
- Due to electron confinement, quantum effects can become dominant at the nano-scale
- The ratio of the wavelength of light to the characteristic feature size can become large at the nano-scale, causing light wave phenomena to dominate at the nano-scale.

A learning objective would be to explain the interaction among nanoscaled material and to their environments.

The point for me is that with scale, concentration, and complexity, the properties of matter can change--not all matter scales the same. For example, what I have in mind in question 2 may be represented by comparing the flammability of a log vs. sawdust--same material different surface properties and therefore different combustibility. This is different from the scale/concentration/complexity issues associated with neurons that a sufficient densities achieve consciousness. We are approaching here the question of "emergent" properties,which I think exceeds the comprehension of grades 7-12 and everyone else for that matter.
• Intermolecular forces, for example, determine how atoms move and get organized in nano systems.
• Nanoscience crosses the boundaries of biology, chemistry and physics. • At the nanoscale, surface interactions dominate. • Instruments can be used to measure the structure and properties of objects that are too small to be seen.
Smalley: Atoms and molecules are "sticky" They are held together by weak intermolecular forces.
1. Nano (including nanoscience, nanotechnology, and nanoengineering) has led to a range of products--from the now common to the highly innovative. 2. Nano has the potential to have very big societal and economic impacts on our lives. 3. Nanoscientists work at super small size scales to manipuate materials to exhibit new phenomena. 4. At the nanoscale, physcial, electrical, and chemical properties of a material are size dependent in a way that they're not at any other scale. 5. The potential of nano is greatly broadened by its interdisciplinary nature.
Nanoscale surface images show us that matter is composed of atoms and molecules.
At the nanoscale, intermolecular interactions have a significant effect on material properties. Surface effects such as friction and dangling bonds significantly impact material properties.
Everything is made of atoms. There are only about 100 different types of atoms. Atoms and molecules are constantly in motion. Greater motion means higher temperatures. Models are useful conceptual devises but we must understand their limitations.