NCLT NU . UM . PU . UIC . UIUC . ANL . AAMU . FU . HU . MC . UTEP . PSS

The Big Ideas in Nanoscale Science and Engineering

Shawn Y. Stevens & Joseph S. Krajcik
University of Michigan, Ann Arbor, Michigan, USA

Overview

Every scientific domain is built upon a set of core principles or "big ideas", the understanding of which is essential to the domain. Alone or in combination, these core concepts help shape the development of a field, explain phenomena relevant to a field, and contribute to broader conceptual understanding by connecting the field to prior foundational ideas and establishing new foundations. They are critical 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* rather than more narrowly conceived of as "big ideas" in chemistry or biology. In fact, the nature of big ideas in nanoscale science and engineering (NSE) is that they are interdisciplinary. An essential question is: "What's *new* in NSE that isn't adequately articulated in existing standards?" Answers to this question can guide educators, scientists, researchers, and curriculum developers as they work to introduce NSE into the classroom. Due to the novelty of the field, core principles for NSE education had not been previously formulated.

In response to this need, a series of national workshops was held to address the challenges of bringing an emergent science such as NSE into the classroom. In June, 2006, the National Science Foundation (NSF) funded a national workshop held jointly by the NCLT and SRI International that was dedicated to identifying and reaching consensus on the big ideas for NSE that would be appropriate for grade 7-12 learners. Participants included leading scientists, engineers and science educators, chosen to represent those scientific disciplines that are involved in NSE research, learning sciences, and science education. In August 2006, at the NCLT Faculty Nanoscale Science and Engineering Education Workshop, participants considered the big ideas that would be appropriate for grade 13-16 students. The workshops resulted in a set of nine big ideas that involve content relating to: Size and Scale, Structure of Matter, Size-Dependent Properties, Forces & Interactions, Self-Assembly, Tools & Instrumentation, Models & Simulations, Quantum Effects, and Science, Technology & Society (Stevens, et al., 2007).

This poster explicates the big ideas and their primary science content (learning goals) and presents some illustrative phenomena. For further information on 'The Big Ideas of Nanoscale Science and Engineering', please visit: http://hice.org/projects/nano/index.html

A formal, more complete manuscript will be published later this year by the National Science Teachers Association Press.

References

Stevens, S. Y., Sutherland, L., Schank, P., & Krajcik, J. (2007). *The big ideas of nanoscience.*. http://hice.org/projects/nano/index.html

Defining the Construct: The Big Ideas in Nanoscale Science and Engineering

Joseph S. Krajcik & Shawn Y. Stevens
University of Michigan, Ann Arbor, Michigan, USA

What are 'big ideas'?

The core concepts and principles of the field

Big ideas may

- help learners understand a variety of concepts about field
- provide ideas/models to explain a range of phenomena
- be a key influence on explaining the major ideas in the domain
- provide insight into the development of the field

Why do we need big ideas?

- Core foundation for exploring nanoscale science and engineering (NSE) teaching and learning
- Educators, researchers and developers in the field need guidance
  - National Standards don't specifically address NSE
- Teaching NSE without a foundation of learning goals is a challenge for practitioners and teachers!

Defining the big ideas

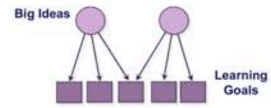
Identify, articulate

- Workshop sponsored by NCLT & SRI *(grades 7-12)*
  Over 40 participants specializing in
  - nanoscience and nanotechnology
  - formal and informal science education
- Workshop sponsored by NCLT *(grades 13-16)*
  - 32 faculty members from two-year and four-year institutions

and develop a *broad* consensus

Presented and discussed at various national meetings and workshops related to NSE education.

How do we use big ideas?



Create learning goals to align curriculum development, instruction, assessment and teacher education

THE BIG IDEAS

Structure of Matter

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.

- Atoms are the fundamental building blocks of matter. The structure of atoms affects how they interact to form organized assemblies.
- Properties inherent to the building blocks affect how they can interact with other building blocks, which affects the properties of a material.
- Thermal motion of the building blocks is essential to the formation and function of assemblies.

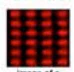
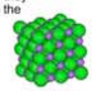
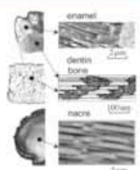


image of a silicon crystal



sodium chloride



Forces & Interactions

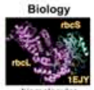
All interactions can be described by multiple types of forces, but the relative impact of these forces changes with scale. On the nanoscale, a range of electrical forces with varying strengths tends to dominate the interactions between objects.

- Small objects (e.g. atoms, molecules, nanoparticles, etc.) can interact in a variety of ways, all of which are electrical in nature. These interactions create a continuum of forces that describe all interactions within matter on that scale, the strength of which depends on the entities involved.
- Electrical forces between the building blocks at the nano- and atomic scales are essential to the formation and functioning of assemblies.
- Although electrical forces generally occur at the nano- and atomic scales, their effect can be observed at the macroscale. It is necessary to apply knowledge of electrical forces in order to explain a broad range of macroscopic phenomena.

Engineering & Design

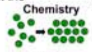
Building and controlling nanoscale structures and machines

Biology



biomolecular recognition

Chemistry



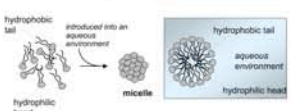
assemblies bonding

gecko

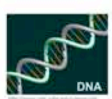
Self-Assembly

Under specific conditions, some materials can spontaneously assemble into organized structures. This process provides a useful means for manipulating matter at the nanoscale.

- Many factors affect the process of self-assembly. These include the structure, composition and properties of the materials to be assembled and the environment in which the assembly will take place.
- The process of self-assembly can be described in terms of forces and energy.



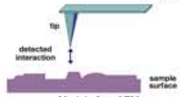
dendrimer



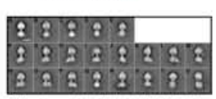
Tools & Instrumentation

Development of new tools and instruments helps drive scientific progress. The recent development of specialized tools has led to new levels of understanding of matter by helping us detect, manipulate, isolate, measure, fabricate, and investigate nanoscale matter with unprecedented precision and accuracy.

- Specialized tools are required to detect, measure, and investigate the nanoscale world because structures on this scale are too small to be seen with optical microscopes.
- Although nanostructures have always existed in nature, scientists and engineers were unable to study them, or to manufacture new nanostructures until advances in technology allowed highly specialized and sensitive tools to be developed.
- Many of the primary tools used to study and/or manipulate nanoscale structures (e.g., AFM and STM) interact with individual atoms or nanoscale objects by means of electric forces.



Model of an AFM

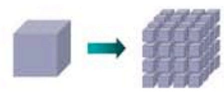


SEM micrographs of individual F_1F_0-ATPase

Size & Scale

Factors relating to size and geometry (e.g., size, scale, shape, proportionality, dimensionality) help describe matter and predict its behavior.

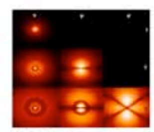
- There are worlds that are too small to be seen with the naked eye. These include the micro-, nano-, and atomic/molecular worlds. Each of these worlds contains unique representative objects.
- Changes in scale can change the way things work and behave.
- The surface area-to-volume ratio depends on the size and shape of an object.



Quantum Effects

Scientists may choose to use different models to help explain and predict the behavior of matter depending on the scale and conditions of the system. In particular, as the size or mass of an object becomes smaller and approaches the nanoscale, quantum mechanics becomes necessary to explain its behavior.

- All matter behaves both with particle-like and wave-like character.
- Only discrete amounts of energy can enter or exit certain systems (e.g., atomic and sub-atomic, many nanoscale systems).
- It is impossible to know *exactly* what did, or will happen to matter on the nano-, atomic, and sub-atomic scales.



Size-Dependent Properties

The properties of matter can change with scale. In particular, as the size of a material transitions from the bulk to atomic scale, it often exhibits unexpected properties that lead to new functionality.

- Properties of matter can change with size, particularly as the size of the sample decreases and approaches the nanoscale.
- The surface area-to-volume ratio increases as objects become smaller. As the size of an object approaches the nanoscale, the fraction of the atoms that are on the surface increases, and surface-related properties become more important.
- The shapes of structures formed at the nanoscale can lead to unique properties.

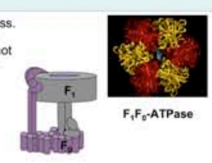
Colloidal solutions of different-sized gold nanoparticles

transmitted light reflected light

Models & Simulations

Scientists use models and simulations to help them visualize, explain, and make predictions and hypotheses about the structure, properties and behavior of objects, processes, systems and phenomena. The complexity and extremely small size of nanoscale targets make models and simulations useful for the study and design of nanoscale materials and phenomena.

- Every model has limitations to its accuracy and usefulness. Specific models are designed to make certain aspects of atoms, molecules, or nanostructures apparent and may not accurately represent other properties of these structures.
- Various types of models (e.g., physical, mechanical, computer, mathematical) are used to represent, explain, make predictions and generate questions about the structure and behavior of matter at the macro-, micro-, and nanoscales.



F_1F_0-ATPase

Science, Technology & Society

The advancement of science involves developing explanations for how and why things work, and technology applies that knowledge to meet objectives, solve practical problems or answer questions of interest. At each step, people make decisions that affect scientific progress and its effects on society and the environment. Because nanotechnology is an emergent science, it provides an opportunity to witness and actively participate in scientific progress and the decisions about how to use the new technologies

- Nanocale structures must be evaluated in terms of their risk and benefits to human health and the environment. Because these are new materials, their effect on humans and the environment may not be apparent for some time.

NSF
NCLT National Center for Learning and Teaching in Nanoscale Science and Engineering
University of Michigan School of Education
hi-ce Center for Highly Interactive Computing in Education