Nanoscale Science Informal Learning Experiences:

NISE Network Content Map

Developed by Marjorie Bequette, Rae Ostman, Kirsten Ellenbogen, Greta Zenner Petersen, Darrell Porcello, Troy Livingston, Marilyn Johnson, and Paul Martin for the NISE Network.

The NISE Network content map presents four key science content ideas for informal science education in nanoscale science, engineering, and technology:

IDEA 1:

Nanometer-sized things are very small, and often behave differently than larger things do.

IDEA 2:

Scientists and engineers have formed the interdisciplinary field of nanotechnology by investigating properties and manipulating matter at the nanoscale.

IDEA: 3

Nanoscience, nanotechnology, and nanoengineering lead to new knowledge and innovations that weren't possible before.

IDEA 4:

Nanotechnologies—and their costs, utility, risks, and benefits—are closely interconnected with society and with our values.

These four ideas represent a basic understanding of nanoscale science, technology, and engineering ("nano awareness"). For each main idea, the content map articulates supporting information and examples, allowing learners to connect different concepts and explore them more deeply ("nano understanding").

NISE Network programs, exhibits, media, and other educational experiences engage the public in these ideas. Each educational experience developed by the network focuses on different parts of the content map, as appropriate for its target audience, format, and topic. The content map is a companion to the NISE Network learning framework, which describes the kinds of learning experiences we value.

IDEA 1:

Nanometer-sized things are very small and often behave differently than larger things do.

1.1 Nanoscience is an emerging field in which scientists study and research the novel properties and behaviors of systems operating at the nanoscale.

1.2 The prefix "nano" means one thousand millionth, or one billionth. So a "nano" of something is one billionth of the whole—a very, very small fraction. A nanometer is a billionth of a meter.

1.3 Scientists and engineers think about, experiment with, and try to explain the properties of materials.

1.3.1 Physical properties are a way for scientists to describe matter. They can also use these properties to predict a material's behavior. Physical properties include size, conductivity, melting point, and density.

1.3.2 Scientists use chemical properties to describe the ways a material interacts with other matter during a chemical reaction. For example, materials react differently in the presence of oxygen or acid.

1.4 Some materials behave in a different way at a small scale than they do at a larger scale. At the nanoscale, a material may exhibit different properties that may lead to new uses.

1.4.1 Materials on the nanoscale have significantly more surface area per unit of volume than things on the micro- or macroscale. Thus, nanoscale materials often react much more quickly than they would if they were larger.

1.4.1.1 For example, aluminum is extremely reactive, but macroscale aluminum objects—like soda cans—generally remain stable unless in a severe environment, like a fire. However, nanoscale particles of aluminum can spontaneously combust and explode because the surface-area-to-volume ratio is so much greater than with a soda can. A much larger percentage of atoms lie on the surface of a nanoparticle, and surface atoms are where reactions take place.

1.4.2 Intermolecular forces cause atoms and molecules to form temporary bonds (to be "sticky"). These forces become more pronounced at the nanoscale and can also influence a material's macroscale properties (and thus how we can use it).

1.4.2.1 An example of this from nature is the gecko's foot. When humans touch a wall, the atoms in our hand bond with the atoms in the wall. But those bonds are far too few and too weak to support our weight, which means we can easily pull away. Not so with a gecko. When a gecko puts its foot on a wall, it sticks—not because of a sticky substance, but rather because of intermolecular forces. The feet of a gecko have thousands of extremely fine "hairs" called setae about 200 nanometers thick. This vastly increases the surface area of the lizard's foot. Molecules in the setae are attracted to the molecules in the wall. Because there is so much surface area, enough bonds form to overcome the force of gravity.

1.5 Some commonly-used materials can act in unexpected ways at the nanoscale.

1.5.1 A material's color can change when the particles are nanometer-sized. Light interacts differently with very small particles, and can cause them to appear a different color. Examples include titanium dioxide, zinc oxide, and gold.

1.5.1.1 Titanium dioxide in its macroscale form is the white sunblock that lifeguards used to put on their noses: great at UV protection, but not very attractive. Nanoscale particles of titanium dioxide offer the same UV protection, but the sunblock appears clear because the particles interact differently with light. This makes for a much more appealing sunblock. Nanoscale titanium dioxide is frequently used in cosmetics with SPF (such as foundation and powders) and sunscreens. Zinc oxide has similar properties and is used the same way.

1.5.1.2 Similarly, nanoscale particles of gold look nothing like the yellowish, shiny material used in jewelry. Nanoparticles of gold are so small that they interact differently with light. Thus, solutions of nanoscale gold can appear red, blue, purple, or other colors, depending on the size of the particle and the amount of space between them. The color change that results from the spacing of the gold nanoparticles can be helpful in detecting DNA. When researchers and investigators are testing for the presence of a specific disease or investigating DNA samples from a crime scene, they can attach nanoparticles of gold to strands of DNA that complement the DNA in question. If that DNA is indeed present, the strands of DNA will combine. This brings the particles of gold closer together and consequently changes the color of the solution, indicating the presence of the DNA in question.

IDEA 2:

Scientists and engineers have formed the interdisciplinary field of nanotechnology by investigating properties and manipulating matter at the nanoscale.

2.1 All matter consists of atoms, which are particles much too small to see even with light microscopes. Atoms can link together to make molecules. The arrangement of atoms and molecules is a major factor in determining the properties of a material.

2.1.1 Carbon and its different forms are a clear example of the relationship between the properties of a material on the macroscale and the arrangement of its atoms.

2.1.1.1 Two familiar forms of carbon atoms are diamond and graphite. Both consist solely of carbon atoms, yet they have very different properties. Diamonds are clear, extremely hard, and electrically insulating. In contrast, graphite is black, soft, slippery, and electrically conductive. The very different properties of diamond and graphite result from the ways in which the carbon atoms are put together. The carbon atoms in diamond are arranged in a very strong tetrahedral shape, making the material hard. In graphite, the carbon atoms are arranged in layers of hexagons, which look like sheets of chicken wire stacked on top of one another. The layers can slip past each other, making the material soft.

2.1.1.2 Scientists have recently discovered two new forms of carbon that we didn't know about before: carbon nanotubes and buckyballs (also called "fullerenes" or "C60"). Again, these materials have very different properties because of their atomic structure. Carbon nanotubes are hollow, tubular molecules that look like sheets of rolled-up chicken wire. They have very high tensile strength (the strength of something when pulled at both ends), and they can be conducting or semi-conducting. Buckyballs are hollow soccer-ball shaped molecules. They are slippery (they roll easily over one another), and attractive for drug delivery (drugs or other molecules can be put inside the spheres).

2.2 Nano researchers have developed new ways to manipulate matter at the nanoscale. These techniques fall into two broad categories, known as "bottom-up" and "top-down" approaches.

2.2.1 "Bottom-up" approaches involve building structures from smaller building blocks, similar to building things out of Lego bricks. The building blocks for nanoscale materials include individual atoms and molecules. An important bottom-up approach is self-assembly, a process by which certain materials, under a certain set of conditions, spontaneously assemble themselves into organized structures.

2.2.1.1 A snowflake is a familiar, naturally-occurring example of self-assembly. The complex structure of snowflakes results from the nanoscale arrangement of water molecules in an ice crystal. Under the right conditions, water molecules form an ice crystal, and as additional water molecules join on the crystal grows into a snowflake. Snowflakes have six sides because molecules of water freeze into a hexagonal shape. The spontaneous self-assembly of seemingly perfect snowflakes can happen because each snowflake is so small. The larger something self-assembled is, the more chance there is for something to go wrong in the process. (In nature, you would never expect to see a human-size snowflake: before it could grow that large, it would fall to the ground.)

2.2.1.2 Another example of self-assembly at the nanoscale is the bilipid cell membrane. A bilipid membrane consists of two layers of molecules. The hydrophobic ("water-hating") ends of the molecules point toward each other, while the hydrophilic ("water-loving") parts of the molecules line the two sides of the membrane, on the outside of the cell and the inside.

2.2.2 "Top-down" approaches involve paring down larger blocks of material into smaller, nanoscale structures. A macroscale analogy to the top-down down approach is sculpture or carving. When artists create sculptures, they start with a large piece of stone or wood and cut away the extra material to create the figure or shape they want. A benefit of this approach is that it's well-known and understood. A drawback is that it wastes material and isn't extremely precise.

2.2.2.1 A technical example of this is creating a computer chip out of a chunk of silicon. Technicians (and others) accomplish this through lithography, a process frequently used in electronics manufacturing. There are several different lithographic techniques, but the general idea is similar to sculpting: take a relatively large sample of silicon and etch it away to create small features and components.

2.3 Nanoscale effects occur in a wide range of materials and objects.

2.3.1 Nanoscale effects can be found in nature, such as the super-hydrophobic properties of some leaves, including lotus leaves and the iridescence on some insect wings or bird feathers.

2.3.1.1 The lotus effect, first observed in the leaves of the lotus plant, is a dirt- and water-repelling property of some plants. Despite constant exposure to dust, dirt, and rain, the leaves of the lotus plant remain clean and dry. Scientists have learned that this is because the surface of each leaf contains waxy, nanoscale bumps that prevent dirt and water from adhering.

2.3.1.2 Similarly, the iridescence on some butterflies, insects, and birds also results from nanoscale structures. For example, the beautiful colors you see in a peacock feather or a blue morpho butterfly wing do not come from pigments, but rather from the size and spacing of nanoscale structures.

2.3.2 Scientists and engineers have recreated some of these effects in commercial products. Stain- and water-resistant fabrics mimic the lotus effect. Security images on currency, credit cards, sensors, and fabrics mimic naturally occurring iridescence.

2.4 The dramatic growth of the fields of nanoscience and nanotechnology has been made possible by the recent development of specialized tools by scientists and engineers.

2.4.1 A group of microscopes called scanning probe microscopes (SPMs) illustrates the importance of tools to nanoscience and nanotechnology.

2.4.1.1 Nanoscale objects, including atoms, are smaller than the wavelengths of visible light. Thus, light does not bounce off them; it is literally impossible to see something so small. This means that we can't use traditional light microscopes to see things at the nanoscale.

2.4.1.2 A scanning probe microscope gathers information about a surface by detecting different kinds of information. You can think about the tool as "feeling" the topography of a material's surface—its hills, valleys, and contours. Similar to a person running their finger over a page of Braille, an SPM gathers information by running the tip of a probe back and forth over a sample. And, just like the nerve stimulation in the person's finger that must be processed by the brain, the SPM sends the information about the tip movement to a computer, which turns the information into an image. Before the development of scanning probe microscopy, researchers were limited in their ability to learn what is happening in the nanoscale and atomic world. SPMs changed that, opening up new areas for more thorough exploration.

IDEA 3:

Nanoscience, nanotechnology, and nanoengineering lead to new knowledge and innovations that weren't possible before.

3.1 In the field of nanotechnology, researchers and engineers take advantage of the change in properties at the nanoscale to produce new and/or improved materials and devices in areas such as computing, medicine, energy, the environment, and manufacturing.

3.2 The interdisciplinary nature of the field of nanotechnology has helped scientists and engineers develop new innovations. People from a diverse disciplines work together and share their knowledge and approaches with each other. By approaching scientific and engineering questions from new, interdisciplinary angles, researchers can come up with and pursue new ideas.

3.3 Nanotechnology includes a wide range of research and applications. It's important that everyone—scientists, citizens, media, government officials—be specific when talking about each kind of nanotechnology and not assume they are all the same.

3.4 The products enabled by nanotechnology include applications that are on our shelves every day.

3.4.1 There are likely many more applications ahead of us, but several current examples are included here. All of these examples were found on the Project for Emerging Nanotechnologies (PEN) Consumer Products Inventory website, **http://www.nanotechproject.org/inventories/consumer/**.

3.4.1.1 The glue in cardboard laminates, including McDonald's food packaging: Starch-based adhesives are commonly used to laminate graphics onto cardboard packaging, but traditional starch-based adhesives need high temperatures and lots of water to hold the cardboard layers together. A company called EcoSynthetix has made a new adhesive that they claim uses nanoparticles of starch between 50 and 150nm across. The smaller particles have more surface area per volume than larger starch molecules, which means they need less heat and water—and therefore less energy—to activate the adhesive and laminate graphics onto cardboard. McDonald's was the first major company to take advantage of this technology in their cardboard packaging.

3.4.1.2 Sunblock, including Burt's Bees Chemical-Free Sunscreen SPF 15: Titanium dioxide ($TiO2$) has long been used as a sunscreen because it reflects, refracts, and absorbs the sun's rays and therefore prevents them from reaching your skin. However, naturally occurring titanium dioxide is opaque white and, when used in a sunscreen, leaves a visible white film on the skin. Nanoscale titanium dioxide, in contrast, is transparent because light interacts differently with particles that small, but it is still effective at protecting skin from UV rays. This Burt's Bees sunscreen, as well as many other skin products, takes advantage of this property of nanoscale titanium dioxide.

3.4.1.3 Health and diet supplements, such as NanoTrim and Revive Health: These companies claim that they have "nanoized" certain nutrients (made them smaller), thereby increasing their reactivity and efficacy within the body (because of the increased surface area), as well as the body's likelihood of accepting the synthetic nutrients.

3.4.1.4 Plastic beer bottles, including Corona, Miller Lite, Miller Genuine Draft, and Ice House: "Imperm" technology, used by Miller Brewing, is a plastic composite that includes nanoparticles of clay. The clay nanoparticles make the plastic stronger than glass and help prevent air exchange between the inside and outside of the bottle, keeping the beer fresher longer.

3.4.2 Nanotechnology allows us to rework existing applications, making things work in new ways as those products are reengineered at the nanoscale.

3.5 Nano-based research into areas like food supply, clean water, energy, climate change, and disease detection, prevention and treatment may also lead to unprecedented developments and entirely new applications.

3.5.1 Examples of potential applications include targeted cancer treatments; inexpensive and easy-to-use drinking water filters; and more efficient and less expensive solar cells.

3.5.1.1 Medicine: Much of the current research in nanotechnology is dedicated to the ultimate goal of detecting or curing cancer. Current methods of cancer screening have trouble detecting tumors smaller than one million cells. Diagnostics based on nanotechnology research, however, have much higher specificity and are more sensitive, holding the promise of detecting tumors smaller than 1,000 cells. The earlier a doctor can detect cancer, the higher the person's chance of survival. Furthermore, current cancer treatments take a systemic approach: radiation and chemotherapy treatments are directed at a person's entire body, and often the treatment side effects can be as debilitating as the cancer itself. With the extremely small size and increased specificity offered by nanotechnology-enabled approaches, researchers hope to change this. Targeted drug delivery and targeted attacks on tumors would make cancer treatment much easier on the patient. Professor Naomi Halas at Rice University conducts promising research on using gold nanoshells to fight cancer. This targeted therapy focuses only on the tumors, rather than the entire body.

3.5.1.2 Water: Nanofilters offer hope for a cheaper and more effective method of cleaning water to make it safe for drinking. These filters have extremely small pores, or holes, some even as small as 15nm across. In comparison, the smallest water-borne poliovirus is 25 nm. Filters with such small pores allow water to pass through, while unwanted bacteria, chemicals, and viruses stay on the other side. No single type filter has yet emerged as a clear success, but scientists and engineers are experimenting with ceramic filters, carbon nanotube filters, and more. Many companies are developing nano-based water treatments. Dais Analytic Corporation in Florida has developed a reverse-osmosis treatment using a "NanoClear" process. Seldon Technologies in Vermont has created the Seldon WaterBox, which filters water using a carbon nanotube membrane.

3.5.1.3 Energy: Solar cells hold great potential for capturing the sun's energy and transforming it into electricity that we can use to fulfill our various energy needs. However, current solar cells are expensive, bulky, and not very efficient, making them unrealistic for widespread use. Researchers hope that nanotechnology can help address these issues by making thinner, less-expensive, flexible, and/or higher efficiency solar panels. Current research focuses on a range of approaches, including zinc oxide (ZnO), titanium dioxide (TiO2), carbon nanotubes, buckyballs, and quantum dots. Professor Bob Hamers from the University of Wisconsin-Madison conducts research on the use of carbon nanofibers, titanium dioxide, and zinc oxide for renewable energy purposes. InnovaLight is a California-based company that specializes in silicon nanoparticle-based inks, which they hope to modify and use to design novel solar cells.

IDEA 4:

Nanotechnologies—and their costs, utility, risks, and benefits—are closely interconnected with society and with our values.

4.1 Technologies are part of larger systems that include technological, social, environmental, economic, and political components.

4.1.1 In order to understand the role that technologies play and the effects they have, we need to think about the ways that nanotechnologies are connected to larger systems. Using nanotechnologies can represent tradeoffs across many dimensions in society.

4.1.2 A nanotechnology that benefits one person or group may put others at risk.

4.1.3 Technologies and their production, distribution, and use have a complex connection to the natural environment. Some nanomaterials may interact in surprising new ways with complex biological systems, creating new environmental and health impacts (both positive and negative).

4.1.3.1 Nanoparticle silver is increasingly common in fabrics as an antibacterial agent. Research shows that silver nanoparticles leach out of the fabrics and into laundry wash water, which could become a concern for water sources, aquatic animals, and perhaps people.

4.1.4 As with any technological innovation, the presence of nanotechnologies and use of nanomaterials could have secondary economic impacts across the globe. One potential secondary impact is the obsolescence of current practices, processes, and industries.

4.1.4.1 If new materials reduce the need for catalysts like platinum, the mining industry in South Africa could decline. Similarly, replacing copper in electronics with new conductive nanomaterials could impact the economy of Brazil, a major copper producer.

4.1.4.2 Manufacturers of thin film photovoltaics, the next generation of solar technologies, will likely have a market advantage over companies that produce older solar energy technologies.

4.2 Technologies and society are closely interconnected. Change in one influences change in the other.

4.2.1 Throughout history, changes in technologies have gone hand-in-hand with changes in the broad organization of society.

4.2.1.1 The Industrial Revolution radically changed people's lives. Instead of working at home on the family farm, most people now commute to offices and factories, and structure their lives around 9-to-5 business hours, weekends and two-week vacations. Societies also changed dramatically with the widespread use of the automobile, and again with the adoption of the personal computer and the Internet.

4.2.1.2 Similarly, nanotechnologies could also have dramatic effects on our society. For example, researchers are testing a new device designed for public spaces like malls, airports, and even public schools to signal the presence of flu viruses, including swine flu and influenza A (H1N1), and perhaps even HIV.

Some sensors could be sophisticated enough to detect illness even before an individual shows symptoms. These kinds of sensors could be vital to preventing broad outbreaks of deadly illnesses in schools and workplaces. However, we currently have strict protections on individual health records, which these sensor data could violate.

4.2.2 Technologies often affect social relationships. By offering us new ways to interact with family members, people in our community, and people around the world, technologies change the ways we interact with others.

4.2.2.1 New technologies are often accompanied by changes in cultural norms. We are all actively involved in developing acceptable behaviors related to technologies. A current example of this is cell phones. This technology is still being integrated into our daily lives, so we're still negotiating the rules for how cell phones are used in different contexts.

4.2.2.2 Emerging cultural norms related to new technologies do not reflect everyone's values equally.

4.3 Many people affect the development and adoption of nanotechnologies through our choices as consumers, citizens, voters, parents, and professionals. The choices we make are influenced by our values as individuals and members of groups.

4.3.1 People play an important role in governing new technologies, exerting their influence in many ways. Consumers influence the market through purchases. Citizens help choose the political leaders who invest in and regulate new knowledge and technologies. Scientists and engineers choose what knowledge gets pursued, elaborated, and translated into practice. Activists seek to assure that knowledge is pursued and applied in accordance with their agendas.

4.3.2 Our values shape how technologies are developed and adopted. People choose technologies based on convenience, habit, and affordability, as well as goals and aspirations for their lives. Governments fund technologies in an effort to benefit their economy and their citizens. Scientists and engineers develop technologies that reflect their values. Companies build technologies that can be sold for a profit or meet shareholders' expectations.

4.4 Governments, companies, and organizations can all be involved in guiding the development and regulation of nanotechnologies.

4.4.1 At the moment, there are few processes in place to monitor either the presence of nanoparticles or their effects in air, water, soil, ecosystems, or human bodies. Scientists are not yet sure what the long-term effects of nanotechnologies may be on human development or ecological health. This uncertainty about the effects, dangers, and benefits of nanotechnology is matched by uncertainty about how to manage such impacts.

4.4.2 While regulations and safety standards exist for other chemicals, most existing governmental regulations do not apply to nanoscale materials. Even where nanomaterials do fall under existing regulations, the question remains as to whether officials need to reevaluate those regulations. U.S. federal agencies have begun to research and consider the regulation of nanotechnology and nanomaterials.

4.4.2.1 In 2009, the USDA National Organics Standards Board (NOSB) materials committee recommended that nanoparticles be excluded from organic production, processing, and packaging, except when required by law. Public comment responding to a previously published NOSB Materials Committee discussion document on nanotechnology overwhelmingly called for the total prohibition of nanotechnology in certified organic products.

4.4.2.2 The Food and Drug Administration (FDA) has established nanotechnology regulatory science research categories for FDA-regulated products, including physico-chemical characterization, nonclinical modeling of nanomaterials, risk characterization information, risk assessment, and risk communication. In 2012, the agency issued draft guidance documents for the use of nanotechnology by the food and cosmetic industries.

Titanium dioxide is an example of a nanoscale material used in products that are regulated by the FDA. Titanium dioxide has long been used in sunblock, but now manufacturers are using nanoscale titanium dioxide, which has different properties. It is unclear whether regulations can and should treat nanoparticles in the same way as their larger-scale versions.

4.4.2.3 The Environmental Protection Agency (EPA) is applying a comprehensive environmental assessment approach to understand the health and ecological implications of engineered nanomaterials. A series of case documents is being developed to synthesize existing information related to product life cycle, environmental transport and fate, exposure-dose in receptors (humans, ecological populations, and the environment), and impacts in these receptors for particular nanomaterials in specific applications. Case studies are available on nanoscale titanium dioxide and nanoscale silver, and are under development for multi-walled carbon nanotubes.

4.4.3 Non-profits, interest groups, and other coalitions can have an impact on the regulatory regimes that govern nanotechnology.

4.4.3.1 In 2006, Friends of the Earth and the International Center for Technology Assessment organized a broad coalition of consumer, health, and environmental groups in submitting the first-ever legal petition to the Food and Drug Administration, charging that the agency has failed to address the human health and environmental risks of nanomaterials in consumer products.

4.4.3.2 The Environmental Defense Fund works in partnership with government agencies (such as the FDA) and industry (such as DuPont) to identify and manage possible health risks before new nanotechnology products are widely used.

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www.nisenet.org

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