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ACKNOWLEDGEMENTS
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Our special appreciation goes to the National Science Foundation for supporting our nanoscale science research, our research into how students learn nanoscale science, and the development of new courses that focus on nanotechnology for undergraduates.

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DEDICATION
This book is dedicated to Toby and Davis and all children who remind us that the smallest things can be the most important.
Introduction

Imagine you could build something from scratch atom by atom. What would you build? Would you build a robot that would move through your body gobbling up diseased cells or create a new molecule that when sprinkled on an oil spill would break down the oil, eliminating any risk to the environment? For the first time in human history we have the ability to manipulate and build materials from the atom up. New tools such as the atomic force microscope allow us to not only image atoms, but also move atoms into new arrangements that have never been attempted before. What makes all this particularly remarkable is that all this takes place at the nanoscale—one-billionth of the size of a meter. Futurists predict that nanotechnology will be the next major scientific revolution and will have greater impact on our lives than the industrial revolution or the great advances that have been made in genomics.

This book examines nanoscale science with an eye toward understanding nanotechnology. Geared toward middle and high school teachers, these investigations are designed to teach students about the unique properties and behaviors of materials at the nanoscale. The investigations were developed as a result of three National Science Foundation grants given to the authors for research examining effective ways to teach and learn nanoscale science. The investigations are designed as guided inquiry with open-ended exploration where possible. The goal of the book is to introduce the essential concepts that students need to understand nanoscale science while maintaining a broad inquiry approach. The activities of this introductory book may serve to whet the students’ appetites to know more. The book is organized around five themes: scale, tools and techniques, unique properties and behaviors, nanotechnology applications, and societal implications (see key concepts listed in Table 1).
Table 1: Key NanoScience and Engineering Concepts.

<table>
<thead>
<tr>
<th>Size and Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanoscale</td>
<td>The unique placement of the nanoworld between atomic and micro/macro scales allows exploration of the regime where properties transition from atomic behavior to familiar macro behavior.</td>
</tr>
<tr>
<td>Relative Scale</td>
<td>How large objects are in relation to each other. (Which is bigger an atom, molecule, or a virus?)</td>
</tr>
<tr>
<td>Powers of Ten</td>
<td>What is a nanometer? How much smaller is a nanometer than a micrometer?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tools and Techniques</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic Force Microscopy</td>
<td>Probing microscopes use a scanning tip to detect physical properties of materials.</td>
</tr>
<tr>
<td>Nanoimaging</td>
<td>The ability to detect the arrangement of matter at the nanoscale allows for the design of new materials.</td>
</tr>
<tr>
<td>Nanomanipulation</td>
<td>Manipulating matter at the nanoscale opens up whole new possibilities building new objects.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unique Properties and Behavior</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stickiness</td>
<td>Intermolecular forces dominate familiar forces such as gravity (van der Waals bonding, hydrogen bonding...) at this scale.</td>
</tr>
<tr>
<td>Shakiness</td>
<td>Thermal energy produces strong effects (Brownian motion, thermally activated processes).</td>
</tr>
<tr>
<td>Bumpiness</td>
<td>Graininess of matter (atoms/molecules) and properties (quantization, quantum confinement) makes working at this scale bumpy.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nanotechnology Applications</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanomaterials</td>
<td>The ability to synthesize small materials means new functionality, improved materials properties, and revolutionary technology.</td>
</tr>
<tr>
<td>Textiles</td>
<td>Nano construction allows for the creation of new fabrics that resist staining or have antibacterial properties.</td>
</tr>
<tr>
<td>Building Materials</td>
<td>The ability to mimic nature at the nanoscale allows the lotus effect to be applied to objects such as windows.</td>
</tr>
<tr>
<td>Medicine</td>
<td>Medical applications include nanoshells that target cancers and tumors for detection and treatment.</td>
</tr>
<tr>
<td>Water Quality</td>
<td>Nanoparticles that can detect and combine with pollutants may provide more efficient ways to clean water.</td>
</tr>
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<table>
<thead>
<tr>
<th>Societal Implications</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>What are the unknown dangers of generating new nanoparticles that may be released in the environment?</td>
</tr>
<tr>
<td>Ethical</td>
<td>What are the ethics of creating new materials and rearranging matter?</td>
</tr>
<tr>
<td>Social</td>
<td>How will society change as a result of using nanolabels to track the movement of people, animals, and materials throughout the globe?</td>
</tr>
</tbody>
</table>

Nanoscale science uniquely ties together all the science domains because it focuses on the raw materials—atoms and molecules—that are the building blocks of physics, chemistry, biology, and Earth and space sciences (Table 2). In unprecedented ways, scientists from different departments are collaborating in nanoscale research to explore science from multiple perspectives. For example, physicists are interested in the unusual properties of gold nanoshells. These tiny nanoparticles begin as glass beads that are then covered with gold. The nanoshell behaves differently depending on the size of the gold shell. Different-sized shells have different melting temperatures, different electrical conductivity behaviors, and are even different colors. These properties make it an ideal tool for use in medical testing and treatment.
**Table 2**

**Nano Investigations and the Science Domains.**

<table>
<thead>
<tr>
<th>Investigations</th>
<th>Biology</th>
<th>Physics</th>
<th>Chemistry</th>
<th>Mathematics</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td></td>
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<tr>
<td>Fact or Fiction? Exploring the Myths and Realities of Nanotechnology</td>
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<tr>
<td><strong>Size and Scale</strong></td>
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<tr>
<td>That’s Huge!</td>
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<td>One in a Billion</td>
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<tr>
<td>Nano Shapes: Tiny Geometry</td>
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<tr>
<td>Biological Nanoshells: Viruses</td>
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<tr>
<td><strong>Tools and Techniques</strong></td>
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<td>What’s in Your Bag? Investigating the Unknown</td>
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<tr>
<td>NanoMagnets: Fun With Ferrofluid</td>
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<tr>
<td>Scanning Probe Microscopy</td>
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<tr>
<td><strong>Unique Properties of Nano Materials</strong></td>
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<tr>
<td>It’s a Small World After All: Nanofabric</td>
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<tr>
<td>Biomimicry: The Mystery of the Lotus Effect</td>
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<td>How Nature Builds Itself: Self-Assembly</td>
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<tr>
<td>Physics Changes With Scale</td>
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<td>Shrinking Cups: Changes in the Behavior of Materials at the Nanoscale</td>
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<td>Limits to Size: Could King Kong Exist?</td>
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<tr>
<td><strong>Nanotechnology Applications</strong></td>
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<td>NanoMaterials: Memory Wire</td>
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<tr>
<td>Nanotech, Inc.</td>
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<tr>
<td>NanoMedicine</td>
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<tr>
<td>Building Small: Nano Inventions</td>
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<tr>
<td><strong>Societal Implications</strong></td>
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<tr>
<td>Too Little Privacy: Ethics of Nanotechnology</td>
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<tr>
<td>Promise or Peril: Nanotechnology and the Environment</td>
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The gold that coats the nanoshell is an inert metal that easily absorbs light and the rate of absorption and reflection depends on the thickness of the gold layer. This differential rate of absorption means the nanoshell can be used for locating and treating cancer. When nanoshells are coated with antibodies and injected into the body, they are delivered by the body to a specific cancer where antibodies on the nanoshell attach to antigens on cancer cells. When a laser is shown on the cancerous area, the gold nanoshells heat up—essentially cooking the cancer while the surrounding healthy cells are unharmed. In addition to treating the cancer, a similar process is used to attach florescent dyes to nanoshells. When the florescent dyes...
are injected into the body the nanoshells glow in areas where there are cancer cells, which makes the nanoshells a remarkable tool that allows doctors to very specifically locate cancers and target specific areas for treatment. Not only is nanotechnology being innovatively used in medicine but also in environmental science. Scientists are exploring the use of nanoshells as a way to target and filter specific pollutants in water. The goal is to have a highly efficient way to provide clean water to countries around the Earth. As this example shows, a single application such as a nanoshell can be used in chemistry, physics, biology, and Earth and space sciences. By exploring science at the tiniest of scales, students can begin to understand the building blocks of materials and the properties of atoms and molecules that make up our world.

This book begins the study of nanotechnology for students by getting them to think about the very small size of a nanometer. Understanding size and scale at this very tiny level is difficult because we cannot easily experience things this small. Most students have trouble understanding the small sizes of things like cells or bacteria, and even more difficulty understanding the size of atoms, molecules, or viruses. The investigation of scale begins with a focus on relative size (understanding which is bigger, a virus or a cell) and moves to investigating the powers of ten, which are the foundation of the metric system. Students explore just how tiny one part in a billion really is through a series of investigations with dilutions (One in a Billion). Students explore the size and geometry of nanomaterials such as buckyballs, carbon nanotubes, and even viruses (Nano Shapes: Tiny Geometry). Next students take a look at viruses as self-assembling nanomachines (Biological Nanomachines: Viruses). These activities lay the foundation for later concepts that focus on molecular self-assembly and the introduction of unique properties of nanotubes.

**TOOLS AND TECHNIQUES**

Just as the microscope and the telescope opened up new worlds that had never been seen before, the atomic force microscope and other new nanoscale tools have enabled significant advancements in nanoscale science. But unlike the telescope and microscope, the nanoscale world is too small to be seen and can only be detected through other more indirect means. Students explore what it is like to try to detect unknown materials bound inside a black bag (What’s in Your Bag: Investigating the Unknown). They must think like scientists to detect the properties and shape of their unknown materials. Next, students explore how an atomic force microscope (AFM) works to probe these tiny materials. Using a pen flashlight they model how an AFM scans back and forth to detect shape (Scanning Probe Microscopy). Next, students use magnets to shape ferrofluid into new forms and explore how magnetism can be a tool for detection and manipulation (NanoMagnets: Fun With Ferrofluid).

**Unique Properties and Behaviors**

The section on unique properties and behaviors of nanoscale materials introduces students to the structure of these materials. They begin their investigations exploring how nanofabrics are able to repel a range of stains and liquids (It’s a Small World After All: Nanofabric). This effect is explored further with living materials as students explore biomimicry of the lotus effect using plant leaves. This remarkable activity shows how the structure of some leaves makes them highly resistant to dirt, giving them a self-cleaning mechanism. Using magnifying glasses, students can see water bead up on leaves like cabbage and then watch as water droplets pick up other solid materials and as it rolls off the leaf (Biomimicry: The Mystery of the Lotus Effect). This macroscale investigation models the behavior of new self-cleaning glass that is used in skyscraper windows.

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**Table 3: INTERDISCIPLINARY NANO SCIENCE**

**Links to the Science and Mathematics Education Standards.**

<table>
<thead>
<tr>
<th>Physical Sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motions and forces</td>
</tr>
<tr>
<td>Interactions of energy and matter</td>
</tr>
<tr>
<td>Entropy and conservation of energy</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Life Science</th>
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</thead>
<tbody>
<tr>
<td>The cell</td>
</tr>
<tr>
<td>Molecular basis of heredity</td>
</tr>
<tr>
<td>Matter, energy, organization in living systems</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Earth Science</th>
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<tbody>
<tr>
<td>Properties of Earth materials</td>
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<tr>
<td>Geochemical cycles</td>
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<table>
<thead>
<tr>
<th>Science and Technology</th>
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<tbody>
<tr>
<td>Abilities of technological design</td>
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<tr>
<td>Understandings about science and technology</td>
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<table>
<thead>
<tr>
<th>Mathematics</th>
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</thead>
<tbody>
<tr>
<td>Measurement</td>
</tr>
<tr>
<td>Proportionality</td>
</tr>
<tr>
<td>Mathematical modeling and representaions</td>
</tr>
<tr>
<td>Problem solving</td>
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<table>
<thead>
<tr>
<th>Unifying Concepts and Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constancy, change, and measurement</td>
</tr>
<tr>
<td>Systems, order, and organization</td>
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<table>
<thead>
<tr>
<th>Science in Personal and Social Perspectives</th>
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<tbody>
<tr>
<td>Health</td>
</tr>
<tr>
<td>Risks and benefits</td>
</tr>
</tbody>
</table>
Materials behave very differently at the nanoscale than they do at the macroscale that we usually experience. The investigations Physics Changes With Scale, How Nature Builds Itself, and Shrinking Cups are designed to explore the shaky, bumpy, and sticky nanoworld. At this tiny scale materials are very bumpy and are highly influenced by changes in thermal energy. Students model this behavior through a self-assembly activity using Legos and magnets. After placing pieces of magnets and Legos into a box and shaking the box repeatedly, uniform structures form. This investigation models self-assembly that occurs with structures such as virus capsids at the nanoscale. The magnets in this activity model the intermolecular forces that dominate other forces such as gravity. Students explore how different scales influence each other by looking at the relationships of surface area to volume (Limits to Size: Could King Kong Exist?). By measuring different sized cubes and examining how the volume differs when surface area decreases, students are encouraged to think about why friction and heat play major roles in nanoscale manipulation.

Nanotechnology Applications
An examination of new applications in nanotechnology challenges students to think about the tremendous potential nanoscale engineering may offer to our society. Students conduct investigations with memory wire (NanoMaterials: Memory Wire) and nanofabricated socks that are antibacterial (Nanotech, Inc.). Using gelatin and gel, students explore how gold nanocapsids are able to kill tumors without damaging the surrounding healthy tissue (Nano Medicine). This section ends by challenging students to think of their own inventions that could be created with nanotechnology. Students imagine a world where nanobots can reshape their eyes so they don’t need glasses or a world where nanomachines move around their mouths mopping up bacteria. This futuristic writing activity places them in the shoes of modern engineers who apply nanoscale science to human problems (Building Small: Nano Inventions).

Societal Implications
One of the greatest changes that nanotechnology may bring is the use of tiny labels and tracking devices that will allow us to monitor the movement of most materials around the globe. The changes in our privacy may be dramatic, from diamond rings that can have nanosized names and addresses tagged in them, to explosive materials that are embedded with distinctive markers (Too Little Privacy). What are the ethical implications of engineering new and totally different materials that are released into the environment? Should we build self-assembling robots just because the technology is available? Furthermore, what are the potential problems that can occur from this type of invisible engineering (Promise or Peril)? The last section of this book examines the ethical and societal implications of nanotechnology. Students consider how this remarkable technology could alter the way we live and imagine a new world where we can build nearly anything from the bottom up.
Too Little Privacy: 
ETHICS OF NANOTECHNOLOGY

Overview
Advances in nanotechnology allow us to create unique and tiny labels for manufactured materials, create tiny sensors that can detect the presence of specific molecules, and make machines that are so small they can work invisibly. Through a series of scenarios students confront the potential threats to our privacy as well as the ethics of nanotechnology.

Objectives
- To be able to describe potential threats to privacy that can emerge with nanoscale technology.
- To be able to explain ethical uses of technology.

Process Skills
- Predicting
- Inferring
- Analyzing

Activity Duration
40–60 minutes

Background
In 2003, the Gillette Company reported it was purchasing hundreds of millions of tiny NanoBlock circuits and putting them on its razors (Fitzgerald). These tiny circuits use radio waves to transmit information. The size of these tags is about the size of a dust mote (some NanoBlock circuits are as small as 70 microns across) and the tags transmit information reliably up to a distance of about three feet. The goal was for stores to use the tags to identify thieves stealing the razors, but customers were concerned that these types of tags could be used to invade their privacy. What if someone driving by your house could detect the tags? What if everything you bought could be detected and monitored by different stores? Would you care if your neighbors or the government knew which brands of toothpaste, clothing, or shoes you owned? What if these tiny tags were used to monitor more than things you buy and instead monitored your health, your diet, or the places you go during the day?

Recent advances in nanotechnology are resulting in smaller and smaller electronic devices, new forms of sensors, and the ability to add molecular nametags to products. These new technologies present us with ethical challenges in ways we have only imagined. Some futurists have argued that nanotechnology’s greatest impact will be the loss of our privacy as a society. This investigation uses four scenarios to encourage students to think about the ethics and consequences of nanotechnology.

Procedures
Engage Invite your students to name significant technological advances that have occurred in human history. Generate a quick list of technological advances and record these on the board.

Using this list, ask them, How have each of these technologies changed the lives of people? Encourage students to share both positive and negative consequences of technology and record these on the board. Discuss how new technologies have removed our privacy. Already we live in a world where our food selections are monitored by grocery stores, our cars are tracked on highways with video monitors, our keys are electronically coded so that our employers know when we enter and leave the building, our conversations are monitored on city streets by police, and our movements are tracked as we shop in the mall.

Continue the discussion by asking students to think about the following:
- How does this electronic surveillance make our lives safer?
- Are there times when this monitoring is not in our best interest but serves to help someone else make money?

Materials
Each group will need:
- Case scenarios
(Student Sheet 1)
EXPLORE Launch this lesson by sharing the news report that Gillette razors will be made with tiny radio wave transmitters embedded inside the razor. Ask your students to brainstorm the pros and cons of this new technology. Encourage them to think about the issues from the standpoint of the store, the razor company, the buyer, and the government. Do different people have different perspectives on the value and ethics of using these tiny tags? Divide students into groups of 2–4 and provide each group with a scenario from Student Sheet 1 to discuss. Ask them to decide the following:

1. What aspects of our society are affected by this new nanoscale technology?
2. Who is affected by the use of the technology?
3. Who profits and who loses if this technology is adopted?
4. Who should decide if the technology is used or not?

You may want to use an ethical decision-making model to frame the discussion. The Jennings, Campbell, Donnelly, and Nolan (1990) framework invites students to identify the stakeholders, establish the relevant facts, identify unanswered questions, determine the values of each stakeholder, and consider possible solutions.

EXPLAIN Discuss why these new technologies are now appearing, enabled by the development of new tools and techniques that miniaturize conventional surveillance and sensing technology down to the micro- and nanoscale. Define ethics for students, emphasizing the ideas of morality. Encourage students to think about all the “shades of gray” that may influence our decisions to use or not use new technology. For example, in the case of technology that enables tracking of individuals, we may not want to monitor the movement of all visitors to our country, but we may want to monitor a patient with Alzheimer’s disease. Ask students to consider how attitudes toward a particular technology (especially those that may affect privacy) may differ for people living in a democratic society versus those that live under a dictatorship. What responsibilities do we have as citizens to participate in the decision-making process about uses of new technologies?

EXTEND New applications of nanotechnology appear almost daily in the media, and these new products and materials can provide an ongoing discussion of ethics and privacy.

Invite a nanoscience researcher to come to your class (or visit virtually through web conferencing or e-mail) to share his or her research. This interaction can also stimulate students to think about new career opportunities in nanoscience. One interesting way to introduce the guest is to tell students that they are talking to a scientist who is visiting, and they get 20 questions to figure out what the scientist does in his or her job. They can only ask yes or no questions until they are ready to guess the exact type of job. If they guess incorrectly, that student is no longer allowed to continue to ask questions of the guest. This approach to guest speakers makes the students think hard about the types of work that scientists do while also highlighting the diversity of different fields.

This investigation can be extended into thinking about futuristic potential applications of nanotechnology. Have students brainstorm and write about new ways nanotechnology could be used in our lives. Launch the lesson by sharing an idea developed by Robert Freitas (Institute for Molecular Manufacturing) for creating a programmable dermal display that would display health information directly on the hand. This display (a pixelbot) would be made of tiny robots that are implanted under the skin that detect information from an array of other medical robots that circulate in the body monitoring different components of health.

An interesting animation of this pixelbot can be found at www.nanogirl.com/museumfuture/dermaldisplay.htm.

EVALUATE Check for understanding:

1. What makes nanotechnology different from other types of technology?
2. How are issues of privacy different for nanotechnology when compared to the technologies that are common in our world today?
3. In a democratic society, how should people decide which technologies should be used?

References
Nano Labels

Researchers are developing tiny nano-sized bar codes that can be used to invisibly tag almost anything that is manufactured. These tags have the potential to monitor sales, track sales by types of customers or geographic regions, indicate thefts, and signal inventories held by stores and warehouses.

- What do you think about this idea to label manufactured goods?
- Do you care if people know what brand of underwear you buy?
- What if the labels were put in bullets or explosives so that police could track and locate murderers or terrorists?
- If you could track food from the farm to your mouth, what are the advantages and disadvantages?
- Would it be a good idea to put nano tags in compact discs so that manufacturers could make sure CDs are legal? Are there any negative concerns about having the music industry track the music that you buy?
- If we could label and monitor money flow, how could this be used in beneficial and harmful ways?

Nano Health

A growing area within nanotechnology is development of sensors that can be used to monitor your health. The goal is to produce tiny sensors that could be injected into your blood stream that can monitor a wide range of health indicators including your heart rate, blood pressure, blood glucose levels, cholesterol, as well as the presence of pathogenic viruses or bacteria.

- What are the advantages and disadvantages of nano-sized monitors that would be injected into your body?
- How could this type of monitoring system be useful to diabetics or people with a history of heart problems?
- What if the monitor could send an alarm if you ate high-fat foods like cookies or cake—would this be a useful tool to help you watch your nutrition?
- Would it be helpful to have a monitor that could signal if you haven’t eaten enough protein or are missing essential vitamins?
- Are there groups of people that would benefit more from these types of monitors than others?
- If the monitors were expensive, would you be in favor of allowing wealthy people to purchase them if they were not available for the poor?
- If large numbers of monitors from different people could be networked, the data could be used to monitor large-scale health issues. What privacy issues might arise from this type of application? If it could signal a sudden rise in the flu or colds, would this change your view of this type of monitoring?
Scenario 3: Nano Environment
Environmental researchers are currently using remote sensors to monitor the health of water, soil, and air. Researchers are finding new ways to make these sensors smaller and smaller with a goal of creating invisible sensors that could be networked to provide data on the health of whole ecosystems.

- Would you want sensors in your watershed keeping track of pollutants, pH, and oxygen levels?
- If networks of sensors could be created, how would you feel about having the forest near your house filled with tiny sensors that could detect movement, changes in temperature, and the presence of pollutants?
- Would you want clouds of sensors released that could monitor global warming?
- Should we track endangered species by placing a sensor in each animal and monitoring its movement and health over its lifespan?
- Would you purchase building sensors that could monitor your house, apartment, or workplace to ensure that the air quality is good?

Scenario 4: Nano Travel
One idea that has been proposed is to create smart dust that could be put in paints, sidewalks, or ceilings that could monitor the movement of people. Already we monitor movement in stores, airports, train stations, streets, and hotels.

- Should we monitor the movement of people on a large-scale basis?
- If this monitoring allowed us to identify terrorists, would it be more ethical?
- Is it more acceptable to monitor the movement of children as a way to keep them safe?
- If your grandfather had Alzheimer’s disease, would you want him monitored to make sure he didn’t wander off into unsafe situations?
- Would you want this type of sensor put in your pet so that if the pet were lost or stolen it could be retrieved? (Some pet owners already put chips in their pets that can be detected by animal shelters so the owner can be notified. Other pet owners use radio collars on their dogs to be able to track them when the dog is running free.)
- What rules should be in place to ensure that people have safety, privacy, and freedom?
- When is monitoring people without their knowledge acceptable? Are there already situations where you are monitored without your explicit knowledge?
Promise or Peril: Nanotechnology and the Environment

Overview
Nanoscience research has made great strides in recent years in areas such as nanomaterials and drug delivery. This success has kindled hope for exciting technological breakthroughs in the near future in areas ranging from new cures for cancer therapies to new materials that gobble up toxic waste in the environment. The nanosized particles utilized in these proposed technologies products have beneficial results, but at what cost? Do we really know the effect these particles have on our environment or even our health?

Objectives
- To explore the advantages and disadvantages of nanotechnology on the health of living things.
- To simulate the use of nanosensors in pollution remediation.

Process Skills
- Observing
- Predicting

Activity Duration
90 minutes

Background
Nanoparticles naturally exist in our world. Viruses, pollen, sea spray, and ash are all tiny natural particles that affect our environment and our health. Now that nanoscience allows scientists to build products atom by atom, many human-made nano-sized particles are utilized in industry, laboratories, and medicine. Along with being engineered with specific chemical and biological functionality, nanoparticles are particularly reactive simply because of their size. Since they are so small, an ensemble of billions of nanoparticles has an enormous surface area exposed to the environment and they can diffuse quickly throughout a system into which they are introduced. The benefits of these new nano products are evident, but questions lie in the fate of these particles. Where will free particles such as nanosensors made for detecting contaminants in water end up after their job is done? Or what about decomposing products that consist of nano-sized particles? Where do these particles go? Because these particles behave in novel ways, their impact on the environment is an unanswered question. Proper management of these particles is necessary for the protection of environment and human health. To fully realize nanotechnology’s promise, the risks must be weighed against the benefits.

Imagine cleaning a contaminated waterway with nanoparticles that can detect and destroy pollution or using tiny sensors to warn a soldier of potentially harmful chemicals. Wei-zian Zhang, a scientist at Lehigh University, has shown that iron nanoparticles from 100–200nm in size can be beneficial in cleaning toxic organic wastes such as trichloroethylene (TCE) in ground water. In a demonstration study in a manufacturing plant, the particles were shown to reduce TCE levels significantly and show real promise as a tool to clean up toxic contamination sites. Even with those benefits, many unknown risks are evident. One particular study investigated the harmful effects of the synthetically produced buckyballs on fish. This study found that these particles can destroy lipid cells, a major component of brain tissue.

In this activity, students will explore the advantages and disadvantages of nanotechnology. Students will also simulate the use of nanosensors to detect harmful materials in the environment.

Materials
Each group will need:
- Small plastic container with tight-fitting lid (shoebox size)
- Sand to fill ¾ of plastic container
- 10 metal pellets (such as BBs)
- 10–15 small magnets
- Student Sheet 1
**Procedures**

**Engage** Ask students to name different types of water pollutants. Make a list of contaminants on the board or overhead projector. Discuss with students the different causes of water pollution and why it is harmful to humans and the environment. Students may name oil spills, sewage spills, industrial spills, and so on. For more information on different types of pollution visit [www.epa.gov](http://www.epa.gov).

Ask the students to pair up with a partner and brainstorm different methods of getting rid of pollution. Most students will probably name preventative methods such as preventing illegal dumping. Suggest that through new nanotechnology discoveries there might be a method in the near future to clean up polluted waters thought to be permanently contaminated. Give the example of nanoscientists trying to use nanoparticles to detect pollutants and destroy them.

You also want to make sure students understand that there are unknown risks of setting nanoparticles free into the environment that policy makers and scientists cannot ignore. Can these nanoparticles enter the bodies of organisms, and if so, do they affect one organ or all of them? Do possible toxic effects stem from one nanoparticle or only when they are clumped together in large numbers?

**Further Reading**


**Explore** Now that students are aware of sources of pollution and approaches that nanotechnologists are working on to remediate these problems, students will simulate what it would be like to try to detect contaminants in water or the air. Place students in groups of three and charge them with developing a strategy to “detect” pollution molecules with their nanosensors.

Each group will use the container of sand to represent their water sample. The BBs or other metal pellets represent the pollutants in the water sample. The magnets will represent the nanosensors designed to attach and possibly destroy the pollution particles. The students will drop the magnets into the container of sand and BBs. As students gently shake the container, the nanosensors (magnets) will “seek out” the pollutants (BBs) and attach. The shaking represents the natural occurrence of interaction of particles in a lake or river.

**Explain** Explain to the students that this interaction of a nanosensor and harmful particle is similar to the antibody-antigen interaction that takes place in their bodies.

Use the analogy of a foreign particle in the human body that causes an immune response to kick in. That foreign particle has “unknown” risks and the body’s systems detect this issue. How does this compare to scientists sending nanoparticles into the environment and the environment’s response to those particles? The outcomes are still not fully known.

**Extend**

- Ask students to consider the advantages and disadvantages of using nano-sized particles in our immediate surrounding.
- For an extension in this area, create a web quest for current research on the use of nanosensors to detect pollution and other harmful chemicals.

**Evaluate** Check for understanding:

1. What are the implications of using nanoparticles in our environment?
2. What are possible risks of releasing nanoparticles into the environment?
3. How could nanoparticles be gathered once they are released into a given space?
Name _______________________________________

**Problem**
How could nanoscientists detect and destroy pathogens, pollutions, or other harmful particles in our environment?

**Pros and Cons**
Discuss with your lab group the pros and cons of trying to detect pathogens and pollution in our environment.

**Materials**
- Container of sand
- Metal pellets (BBs)
- Magnets

**Process**
1. Open the container of sand. The sand represents your environment (air, water, and so on).
2. Drop the BBs or metal pellets into the container of sand. What do the BBs represent in this simulation?
3. Drop the magnets into the container of sand and metal pellets. What do the magnets represent in this simulation?
4. Note the time: __________. Close the container and gently shake it. What does the shaking of the container represent in this simulation?
5. Check every few minutes until you see that the magnets have detected all the BBs and are attached.

6. Once you have all magnets and BBs attached to each other, note time: _____.

7. Once all the BBs are captured by the magnets, how can they be removed from the environment?

Conclusion

1. What are the advantages of using nanosensors to clean up oil spills or other types of pollution?

2. What are the possible disadvantages of using nanosensors to detect or clean up pollution?

3. Why is efficient clean-up time an issue in environmental disasters?
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