Unit Overview

Teacher Materials

Contents

For Anyone Planning to Teach Nanoscience…
Read This First!

Nanoscience Defined

Nanoscience is the name given to the wide range of interdisciplinary science that is exploring the special phenomena that occur when objects are of a size between 1 and 100 nanometers (10^{-9} m) in at least one dimension. This work is on the cutting edge of scientific research and is expanding the limits of our collective scientific knowledge.

Nanoscience is "Science-in-the-Making"

Introducing students to nanoscience is an exciting opportunity to help them experience science in the making and deepen their understanding of the nature of science. Teaching nanoscience provides opportunities for teachers to:

- Model the process scientists use when confronted with new phenomena
- Address the use of models and concepts as scientific tools for describing and predicting chemical behavior
- Involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations
- Engage and value our student knowledge beyond the area of chemistry, creating interdisciplinary connections

One of the keys to helping students experience science in action as an empowering and energizing experience and not an exercise in frustration is to take what may seem like challenges of teaching nanoscience and turn them into constructive opportunities to model the scientific process. We can also create an active student-teacher learning community to model the important process of working collaboratively in an emerging area of science.

This document outlines some of the challenges you may face as a teacher of nanoscience and describes strategies for turning these challenges into opportunities to help students learn about and experience science in action. The final page is a summary chart for quick reference.

Challenges & Opportunities

1. You will not be able to know all the answers to student (and possibly your own) questions ahead of time …

Nanoscience is new to all of us as science teachers. We can (and definitely should) prepare ahead of time using the resources provided in this curriculum as well as any others we can find on our own. However, it would be an impossible task to expect any of us to become experts in a new area in such a short period of time or to anticipate and prepare for all of the questions that students will ask.

… This provides an opportunity to model the process scientists use when confronted with new phenomena.

Since there is no way for us to become all-knowing experts in this new area, our role is analogous to the "lead explorer" in a team working to understand a very new area of science. This means that it is okay (and necessary) to acknowledge that we don't have all the answers. We can then embrace this situation to help all of our students get involved in generating and researching their own questions. This is a very important part of the scientific process that needs to occur before anyone steps foot in a lab. Each time we teach nanoscience, we will know more, feel more comfortable with the process for investigating what we don't know, and find that there is always more to learn.

One strategy that we can use in the classroom is to create a dedicated space for collecting questions. This can be a space on the board, on butcher paper on the wall, a question "box" or even an online space if we are so inclined. When students have questions, or questions arise during class, we can add them to the list. Students can be invited to choose questions to research and share with the group, we can research some questions ourselves, and the class can even try to contact a nanoscientist to help us address some of the questions. This can help students learn that conducting a literature review to find out what is already known is an important part of the scientific process.

2. Traditional chemistry and physics concepts may not be applicable at the nanoscale level …

One way in which both students and teachers try to deal with phenomena we don't understand is to go back to basic principles and use them to try to figure out what is going on. This is a great strategy as long as we are using principles and concepts that are appropriate for the given situation.

However, an exciting but challenging aspect of nanoscience is that matter acts differently when the particles are nanosized. This means that many of the macro-level chemistry and physics concepts that we are used to using (and upon which our instincts are based) may not apply. For example, students often want to apply principles of classical physics to describe the motion of nanosized objects, but at this level, we know that quantum mechanical descriptions are needed. In other situations it may not even be clear if the macroscale-level explanations are or are not applicable. For example, scientists are still exploring whether the models used to describe friction at the macroscale are useful in predicting behavior at the nanoscale (Luan & Robbins, 2005).

Because students don't have an extensive set of conceptual frameworks to draw from to explain nanophenomena, there is a tendency to rely on the set of concepts and models that they do have. Therefore, there is a potential for students to incorrectly apply macroscale-level understandings at the nanoscale level and thus inadvertently develop misconceptions.

… This provides an opportunity to explicitly address the use of models and concepts as scientific tools for describing and predicting chemical behavior.

Very often, concepts and models use a set of assumptions to simplify their descriptions. Before applying any macroscale-level concept at the nanoscale level, we should have the students identify the assumptions it is based on and the situations that it aims to describe. For example, when students learn that quantum dots fluoresce different colors based on their size, they often want to explain this using their knowledge of atomic emission. However, the standard model of atomic emission is based on the assumption that the atoms are in a gaseous form and thus so far apart that we can think about their energy levels independently. Since quantum dots are very small crystalline solids, we have to use different models that think about the energy levels of the atoms together as a group.

By helping students to examine the assumptions a model makes and the conditions under which it can be applied, we not only help students avoid incorrect application of concepts, but also guide them to become aware of the advantages and limitations of conceptual models in science. In addition, as we encounter new concepts at the nanoscale level, we can model the way in which scientists are constantly confronted with new data and need to adjust (or discard) their previous understanding to accommodate the new information. Scientists are lifelong learners and guiding students as they experience this process can help them see that it is an integral and necessary part of doing science.

3. Some questions may go beyond the boundary of our current understanding as a scientific community…

Traditional chemistry curricula primarily deal with phenomena that we have studied for many years and are relatively well understood by the scientific community. Even when a student has a particularly deep or difficult question, if we dig enough we can usually find ways to explain an answer using existing concepts. This is not so with nanoscience! Many questions involving nanoscience do not yet have commonly agreed upon answers because scientists are still in the process of developing conceptual systems and theories to explain these phenomena. For example, we have not yet reached a consensus on the level of health risk associated with applying powders of nanoparticles to human skin or using nanotubes as carriers to deliver drugs to different parts of the human body.

… This provides an opportunity to involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations.

While this may make students uncomfortable, not knowing a scientific answer to why something happens or how something works is a great opportunity to help them see science as a living and evolving field. Highlighting the uncertainties of scientific information can also be a great opportunity to engage students in a discussion of how scientific knowledge is generated. The ensuing discussion can be a chance to talk about science in action and the limitations on scientific research. Some examples that we can use to begin this discussion are: Why do we not fully understand this phenomenon? What (if any) tools limit our ability to investigate it? Is the phenomenon currently under study? Why or why not? Do different scientists have different explanations for the same phenomena? If so, how do they compare?

4. Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology, physics, and computer science…

Because of its multidisciplinary nature, nanoscience can require us to draw on knowledge in potentially unfamiliar academic fields. One day we may be dealing with nanomembranes and drug delivery systems, and the next day we may be talking about nanocomputing and semiconductors. At least some of the many areas that intersect with nanoscience are bound to be outside our areas of training and expertise.

… This provides an opportunity to engage and value our student knowledge beyond the traditional areas of chemistry.

While we may not have taken a biology or physics class in many years, chances are that at least some of our students have. We can acknowledge students' interest and expertise in these areas and take advantage of their knowledge. For example, ask a student with a strong interest in biology to connect drug delivery mechanisms to their knowledge about cell regulatory processes. In this way, we share the responsibility for learning and emphasize the value of collaborative investigation. Furthermore, this helps engage students whose primary area of interest isn't chemistry and gives them a chance to contribute to the class discussion. It also helps all students begin to integrate their knowledge from the different scientific disciplines and presents wonderful opportunities for them to see the how the different disciplines interact to explain real world phenomena.

Final Words

Nanoscience provides an exciting and challenging opportunity to engage our students in cutting edge science and help them see the dynamic and evolving nature of scientific knowledge. By embracing these challenges and using them to engage students in meaningful discussions about science in the making and how we know what we know, we are helping our students not only in their study of nanoscience, but in developing a more sophisticated understanding of the scientific process.

References

Luan, B., & Robbins, M. (2005, June). The breakdown of continuum models for mechanical contacts. *Nature 435*, 929-932.

Table 1. Challenges of teaching nanoscience and strategies for turning these challenges into learning opportunities.

	THE CHALLENGE…	PROVIDES THE OPPORTUNITY TO…
1	You will not be able to know all the answers to student (and possibly your own) questions ahead of time	Model the process scientists use when confronted with new phenomena: Identify and isolate questions to answer Work collectively to search for information using available resources (textbooks, scientific journals, online resources, scientist interviews) Incorporate new information and revise previous understanding as necessary Generate further questions for investigation
2	Traditional chemistry and physics concepts may not be applicable at the nanoscale level	Address the use of models and concepts as scientific tools for describing and predicting chemical behavior: Identify simplifying assumptions of the model and situations for intended use Discuss the advantages and limitations of using conceptual models in science Integrate new concepts with previous understandings
3	Some questions may go beyond the boundary of our current understanding as a scientific community	Involve students in exploring the nature of knowing: How we know what we know The limitations and uncertainties of scientific explanation How science generates new information How we use new information to change our understandings
4	Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology and physics	Engage and value our student knowledge beyond the area of chemistry: Help students create new connections to their existing knowledge from other disciplines Highlight the relationship of different kinds of individual contributions to our collective knowledge about science Explore how different disciplines interact to explain real world phenomena

Size Matters: Overview and Learning Goals

Type of Courses:	Chemistry, physics, biology, interdisciplinary science
Grade Levels:	9-12
Topic Area:	The nanoscale perspective of physical properties
Key Words:	Nanoscience, nanotechnology, nanometer, size and scale, properties
Time Frame:	5-7 class periods (assuming 50-minutes classes), with extensions

Overview

This unit provides an introduction to nanoscience, focusing on concepts related to the size and scale, unusual properties of the nanoscale, and example applications of nanoscience.

Students will participate in learning activities that are designed to help them to establish an understanding of the nature of nanoscale science, the relative size of objects, unique properties of nanosized particles, and applications of nanoscience. They will read about these issues, complete worksheets, take quizzes, conduct laboratory investigations to understand properties of nanoscale objects, and create and present a poster comparing a current technology with a related nanotechnology.

As this is an introductory unit, many new terms will be introduced as students increase their understanding of the essential features of nanoscience. References to additional readings and curricular activities are provided so that the teacher can choose to include related topics as he or she determines is appropriate.

Enduring Understandings (EU)

What enduring understandings are desired? Students will understand:

1. The study of unique phenomena at the nanoscale could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.
2. There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.
3. Nanosized materials exhibit some size-dependent effects that are not observed in bulk materials.
4. New tools for observing and manipulating matter increase our abilities to investigate and innovate.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

1. How small is a nanometer, compared with a hair, a blood cell, a virus, or an atom?

2. Why are properties of nanoscale objects sometimes different than those of the same materials at the bulk scale?
3. Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. What scientific and engineering principles will be exploited to enable nanotechnology to be the next big thing?
4. How do we see and move things that are very small?
5. Why do our scientific models change over time?
6. What are some of the ways that the discovery of a new technology can impact our lives?

Key Knowledge and Skills (KKS)

What key knowledge and skills will students acquire as a result of this unit? Students will be able to:

1. Describe, using the conventional language of science, the size of a nanometer. Make size comparisons of nanosized objects with other small objects.
2. Explain why properties of nanoscale objects sometimes differ from those of the same materials at the bulk scale.
3. Describe an application (or potential application) of nanoscience and its possible effects on society.
4. Compare a current technology solution with a related nanotechnology-enabled solution for the same problem.
5. Explain how an AFM and a STM work, and give an example of their use.

Prerequisite Knowledge

This unit assumes that students are familiar with the following concepts or topics:

1. Atoms, molecules, cells, cell organelles, and protein molecules.
2. Basic units of the metric system and knowledge of prefixes.
3. How to manipulate exponential and scientific notation.
4. Some knowledge and experience with a light microscope.

NSES Content Standards Addressed

K-12 Unifying Concepts and Process Standard

As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes: (4 of the 5 categories apply)

- Systems, order, and organization
- Evidence, models and explanation
- Constancy, change, and measurement
- Form and function

Grades 9-12 Content Standard A: Science as Inquiry

Understandings about scientific inquiry

- **Scientists usually inquire about how physical, living, or designed systems function.** Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists. (12ASI2.1)
- **Scientists rely on technology to enhance the gathering and manipulation of data.** New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used. (12ASI2.3)

Grades 9-12 Content Standard B: Physical Science

Chemical reactions

- **Catalysts, such as metal surfaces, accelerate chemical reactions**. Chemical reactions in living systems are catalyzed by protein molecules called enzymes. (12BPS3.5)

Motions and forces

- **Between any two charged particles, electric force is vastly greater than the gravitational force.** Most observable forces such as those exerted by a coiled spring or friction may be traced to electric forces acting between atoms and molecules. (12BPS4.3)

Grades 9-12 Content Standard E: Science and Technology

Understanding about science and technology

- **Scientists in different disciplines ask different questions, use different methods of investigation, and accept different types of evidence** to support their explanations**.** Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines. (12EST2.1)
- **Science often advances with the introduction of new technologies.** Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. (12EST2.2)
- **Science and technology are pursued for different purposes.** Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human inspirations.

Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people's beliefs and practical explanations concerning various aspects of the world. (12EST2.4)

Grades 9-12 Content Standard F: Science in Personal and Social Perspectives

Science and technology in local, national, and global challenges

- **Understanding basic concepts and principles of science and technology should precede active debate** about the economics, policies, politics, and ethics of various science - and technology - related challenges. However, understanding science alone will not resolve local, national or global challenges. (12FSPSP6.2)
- **Individuals and society must decide on proposals involving new research and the introduction of new technologies into society**. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions - "What can happen?" - "What are the odds?" - and "How do scientists and engineers know what will happen? (12FSPSP6.4)

Grades 9-12 Content Standard G: History and Nature of Science

Historical perspectives

- **Occasionally, there are advances in science and technology that have important and long lasting effects on science and society**. Examples of such advances include the following: Copernican revolution, Newtonian mechanics, Relativity, Geologic time scale, Plate tectonics, Atomic theory, Nuclear physics, Biological evolution, Germ theory, Industrial revolution, Molecular biology, Information and communication, Quantum theory, Galactic universe, Medical and health technology. (12GHNS3.3)

AAAS Benchmark Standards

While some of the content of this unit does not map directly to the NSES, it does address the AAAS Benchmarks. Below we list the AAAS Benchmarks that this unit addresses that are not already addressed by the NSES.

Common Themes

- **11D Scale #1.** Representing large numbers in terms of powers of ten makes it easier to think about them and to compare things that are greatly different.
- **11D Scale #2.** 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.

Unit at a Glance: Suggested Sequencing of Activities by Day for the Full Set of Size Matters Curriculum Materials

Lesson	Teaching Day	Main Activities and Materials	Learning Goals	Assessment	Homework
	(Prep Day)	(Refer to individual lesson plans for detailed breakdown)			The Personal Touch: Student Reading and Worksheet Introduction to NanoScience: Student Reading
Introduction to Nanoscience	1 day	Class discussion on Personal Touch: Student Reading, Scale Diagram Introduction to Nanoscience: PowerPoint and Student Worksheet	EU 1, 4; EQ 1, 2, 4, 5, 6; KKS 1, 3	Worksheets for The Personal Touch and Intro to Nanoscience	Visualizing the Nanoscale: Student Reading
Scale of Objects	1 day	Number Line, Scale of Objects, or Cutting It Down Activity Class discussion and Scale Diagram	EU 2; EQ 1; KKS 1	Scale Activity Worksheets Scale of Small Objects Quiz	Size-Dependent Properties: Student Reading
Unique Properties at the Nanoscale	2 days: Day 1	Unique Properties at the Nanoscale: PowerPoint Prepare for Unique Properties Lab	EU 2, 3; EQ 2, 5; KKS 2		
	Day 2	Unique Properties Lab Activities & Student Worksheet		Lab Worksheet	Seeing and Building Small Things: Student Reading
Tools of the Nanosciences	2 days: Day 1	Scanning Probe Microscopy: PowerPoint Black Box Activity	EU 4; EQ 4, 5; KKS 5	Black Box Activity Worksheet	
	Day 2	Optional Extensions for Exploring Nanoscale Modeling	EU 4; EQ 4, 5	Unique Properties Quiz	
Applications of Nanoscience	4 days: Day 1	Applications of Nanoscience: PowerPoint	EU 1; EQ 3, 6;		Prepare for What's New Nanocat? Poster Session

Lesson	Teaching Day	Main Activities and Materials	Learning Goals	Assessment	Homework
		Assign What's New Nanocat Poster Session topics and groups	KKS 3, 4		
Applications of Nanoscience	Days 2-4	Preparation for What's New NanoCat Poster Session Group presentations		Presentation Scoring Rubric and Peer Feedback Form	

What **enduring understandings (EU)** are desired? Students will understand:

1. The study of unique phenomena at the nanoscale could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.
2. There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.
3. Nanosized materials exhibit some size-dependent effects that are not observed in bulk materials.
4. New tools for observing and manipulating matter increase our abilities to investigate and innovate.

What **essential questions (EQ)** will guide this unit and focus teaching and learning?

1. How small is a nanometer, compared with a hair, a blood cell, a virus, or an atom?
2. Why are properties of nanoscale objects sometimes different than those of the same materials at the bulk scale?
3. Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. What scientific and engineering principles will be exploited to enable nanotechnology to be the next big thing?
4. How do we see and move things that are very small?
5. Why do our scientific models change over time?
6. What are some ways that the discovery of a new technology can impact our lives?

What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:

1. Describe, using the conventional language of science, the size of a nanometer. Make size comparisons of nanosized objects with other small objects.
2. Explain why properties of nanoscale objects sometimes differ from those of the same materials at the bulk scale.
3. Describe an application (or potential application) of nanoscience and it's possible effects on society.
4. Compare a current technology solution with a related nanotechnology-enabled solution for the same problem.
5. Explain how an AFM and a STM work; give an example of their use.

Alignment of Unit Activities with Learning Goals

Learning Goals	*Lesson 1: Intro to Nanoscience*	*Lesson 2: Scale of Objects*	*Lesson 3: Unique Properties*	*Lesson 4: Tools of the Nanosciences*	*Lesson 5: Applic. of Nanoscience*
Students will understand…					
EU 1. The study of unique phenomena at the nanoscale could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.	•				•
EU 2. There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.		•	•		
EU 3. Nanosized materials exhibit some size-dependent effects that are not observed in bulk materials.			•		
EU 4. New tools for observing and manipulating matter increase our abilities to investigate and innovate.	•			•	
Students will be able to…					
KKS1. Describe, using the conventional language of science, the size of a nanometer. Make size comparisons of nanosized objects with other small objects.	•	•			
KKS2. Explain why properties of nanoscale objects sometimes differ from those of the same materials at the bulk scale.			•		
KKS3. Describe an application (or potential application) of nanoscience and its possible effects on society.	•				•
KKS4. Compare a current technology solution with a related nanotechnology-enabled solution for the same problem.					•
KKS5. Explain how an AFM and a STM work; give an example of their use.				•	

Alignment of Unit Activities with Curriculum Topics

Chemistry

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
Nature of Chemistry	Tools of Science	Units & Measurement (size & scale)	• Lesson 1 (L1): Intro to Nanoscience • Lesson 2 (L2): Scale of Objects • Lesson 6 (L6): One Day Introduction	**Slides** • L1: 1-4 • L6: 1-8 **Activity/Handout** • L1 ○ Student Reading: Intro to Nanoscience ○ Worksheet: Intro to Nanoscience ○ Handout: scale diagram • L2 ○ Reading: Visualizing the Nanoscale ○ Card Sort/Number Line Activity ○ Scale of Objects Activity ○ Cutting it down activity ○ Quiz: Scale of small Objects
Structure of Matter	Electron Configuration	Quantum Theory	• Lesson 3 (L3): Unique Properties at the nanoscale	**Slides** • L3: 5, 6, 12, 14
Structure of Matter	Atomic Interactions	Chemical Reactions (precipitate formation, self-assembly)	• Lesson 1 (L1): Intro to Nanoscience	**Slides** • L1: 17-19 **Activity/Handout** • Reading: Intro to Nanoscience • Worksheet: Intro to Nanoscience
Nature of Chemistry	Tools of Science	Units & Measurement (size & scale)	• Lesson 1 (L1): Intro to Nanoscience • Lesson 2 (L2): Scale of Objects • Lesson 6 (L6): One Day Introduction	**Slides** • L1: 1-4 • L6: 1-8 **Activity/Handout** • L1 ○ Reading: Intro to Nanoscience ○ Worksheet: Intro to Nanoscience ○ Handout: Scale Diagram • L2 ○ Reading: Visualizing the Nanoscale ○ Card Sort/Number Line Activity ○ Scale of Objects Activity

				○ Cutting it down activity ○ Quiz: Scale of Small Objects
		Units & Measurement (Instruments)	• Lesson 1 (L1): Intro to Nanoscience • Lesson 2 (L2): Scale of Objects • Lesson 4 (L4): Tools of Nanoscience • Lesson 6 (L6): One Day Introduction	**Slides** • L1: 5-9 • L6: 11-14 **Activity/Handout** • L1 ○ Student Reading: Intro to Nanoscience ○ Worksheet: Intro to Nanoscience ○ Handout: Scale Diagram • L2 ○ Reading: Visualizing the Nanoscale ○ Cutting it down activity • L4 ○ Black Box Activity ○ Reading: Seeing & Building Small Things ○ Quiz

Biology

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
Nature of Life	Science of Biology	How Scientists Work	• Lesson 1 (L1): Introduction to Nanoscience	**Slides** • L1: 1-4 **Activity/Handout** • Scale Diagram: Discuss using question 1-2 from Intro to Nanoscience worksheet
		Studying Life	• Lesson 2 (L2): Scale of Objects	**Slides** • L1: 3 **Activity/Handout** • Number Line • Student Quiz • Reading: Visualizing the Nanoscale
		Tools and Procedure	• Lesson 4 (L4): Tools	**Slides** • L4: 1-11, 12 (optional) **Activity/Handout** • Black Box Lab Activity • Reading: Seeing and Building Small Things • Quiz
Nature of Life	The Chemistry of Life	The Nature of Matter; Properties of Water; Carbon Compounds	• Lesson 3 (L3): Unique Properties at the Nanoscale	**Slides** • L3: 1-17 **Activity/Handout** • Reading: Size-Dependent Properties • Unique Properties Labs • Student Quiz • Reading: The Personal Touch • Reading: Intro to Nanoscience
The Human Body	Nervous System	The Senses Drugs and the Nervous System	• Lesson 5 (L5): Applications of Nanoscience	**Slides** L5: 1-2, 9
The Human Body	Circulatory and Respiratory Systems	The Circulatory System	• Lesson 5 (L5): Applications of Nanoscience	**Slides** L5: 1-2, 11
	The Immune System and Disease	Infectious Disease		**Slides** L5: 1-2, 12
		Cancer		**Slides** L5: 1-2, 10

Extensions	Bioethics	Use of Nanotechnology in the Human Arena	**Size Matters** • Lesson 5 (L5): Applications of Nanoscience	Any topics covered in L5 or any students may have considered

Physics

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
Mechanics	Measurement	Length/mass/time Units/order of magnitude	• Lesson 1 (L1): Intro to Nano • Lesson 2 (L2): Scale of Objects • Lesson 6 (L6): One Day Introduction	**Slides** • L1: 2-3 • L6: 2-3 **Activity/Handout** • L2 ○ Card Sort/Number Line ○ Scale Diagram ○ Cutting it Down
		Electrostatic forces	• Lesson 4 (L4): Tools of the Nanosciences • Lesson 6 (L6): One Day Introduction	**Slides** • L4: 2, 8 • L6: 24
Electricity and Magnetism	Current and Resistance	Classical vs. Modern Physics (e.g., different dominant forces, different “rules” at nano/atomic scale)	• Lesson 3 (L3): Unique Properties at the Nanoscale	**Slides** • L3: (most)

Environmental Science

Unit Topic	Chapter Topic	Subtopic	Size Matters Lessons	Specific Materials
Water	Using Science to Solve Environmental Problems	What is Science	• Lesson 1 (L1): Intro to Nanoscience • Lesson 2 (L2): Scale of Objects • Lesson 3 (L3): Unique Properties at the Nanoscale	**Slides** • L1: 1-4 • L3: 1-17 **Activity/Handout** • L1 ○ Scale Diagram •Have students discuss and question diagram using questions 1-2 from student worksheet • L2 ○ Number Line ○ Student Quiz ○ Reading: Visualizing the Nanoscale ○ Student Quiz • L3 ○ Reading: Size-Dependent Properties ○ Labs A-H, any combination of labs as instructor sees fit ○ Student Quiz ○ Reading: The Personal Touch ○ Reading: Intro to Nanoscience

Size Matters Pretest/Posttest: Teacher Answer Sheet

20 points total

1. How big is a nanometer compared to a meter? List one object that is nanosized, one that is smaller, and one that is larger but still not visible to the naked eye. (1 point each, total of 4 points)

A nanometer is one billionth of a meter (or 10^{-9} m in scientific notation).

Sample nanosized objects:

- Virus, DNA strand (diameter), Ribosome, Hemoglobin, Sucrose molecule
- Carbon nanotube (diameter), Buckyballs
- Some enzymes (e.g. ATP synthase), some "molecular motors" (e.g. kinesin)
- Photosynthetic machinery in plants and bacteria,

Sample objects that are smaller:

- Water molecule
- Atoms
- Sub-atomic particles (protons, neutrons, electrons)

Sample objects that are larger than but still not visible to the naked eye:

- Bacteria, Ameoba
- Human egg cell, Human sperm cell
- Red blood cell

2. Name two properties that can differ for nanosized objects and much larger objects of the same substance. For each property, give a specific example. (2 points each, total of 4 points)

Optical properties (such as color and transparency):

- Bulk gold appears yellow in color, nanosized gold appears red in color.
- Regular zinc oxide appear white on the skin, the nano-version appears clear.

Electrical properties (such as conductivity):

- Carbon nanotubes conductivity change with diameter, "twist," and number of walls.
- Physical properties (such as density and boiling point).
- Nanoparticles have lower melting and boiling points b/c there is a greater percentage of atoms at the surface (require less energy to overcome intermolecular attractions).

Chemical properties (such as reactivities and reaction rates):

- Nanoparticles have a greater percentage of atoms at the surface and thus greater reactivities (students may mention any of the examples of this done in the labs).

3. Describe two reasons why properties of nanosized objects are sometimes different than those of the same substance at the bulk scale. (2 points each, 4 points total)

Dominance of electromagnetic forces:

- Gravitational force is a function of mass and distance and is weak between (low-mass) nanosized particles.
- Electromagnetic force is a function of charge and distance is not affected by mass, so it can be very strong even when we have nanosized particles.

Quantum effects:

- At very small scale, the classical mechanical models that we use to understand matter at the macroscale don't work.
- The quantum mechanical model that does help us understand matter is based on probability, not certainty and unusual results such as quantum tunneling (when an electron can "pass through" an energy barrier) may occur.

Surface to volume ratio:

- As surface area to volume ratio increases, a greater amount of a substance comes in contact with surrounding material, this increase reaction rates.

Random molecular motion:

- While random molecular motion (molecules moving around in space, rotating around their bonds, and vibrating along their bonds) is present for all particles, at the macroscale this motion is very small compared to the sizes of the objects and thus is not very influential in how object behave.
- At the nanoscale however, these motions can be on the same scale as the size of the particles and thus have an important influence on how particles behave.

4. What do we mean when we talk about "seeing" at the nanoscale? (2 points)

- "Seeing" an object means using a tool that interacts with the object to produce some representation of it (often an image).
- While many common tools use the interaction between visible light and an object to create a representation, at the nanoscale the objects we want to "see" are smaller than the wavelengths of visible light so this approach is not useful.
- To "see" at the nanoscale, we need to use tools that leverage other kinds of interactions with the surface of the object (like electrical and magnetic forces) to create a representation of the object.

5. Choose one technology for seeing at the nanoscale and briefly explain how it works. (3 points)

Atomic Force Microscope (AFM)

- Uses a tiny tip that moves in response to the electromagnetic forces between the atoms of the surface and the tip.
- Either measures the tiny upward and downward movement of the tip necessary to remain in close contact with the surface or makes the tip vibrate to tap the surface and senses when contacts is made.
- In both bases, the signals (forces or contact) change based on the features of the object's surface (height, angle etc.) and are used to infer a topographical image of the object.

Scanning Tunneling Microscope (STM)

- Uses a fine tip that can conduct electricity; the nano-object to be imaged must also conduct electricity.
- The tip is put very near, but not touching the object surface and the "tunneling" of electrons between the tip and the atoms of the object's surface being creates a flow of electrons (a current).
- The signals (current) changes based on the features of the object's surface (height, angle etc.) and are used to infer a topographical image of the object.

6. Describe one application (or potential application) of nanoscience and its possible effects on society. (3 points)

Existing Applications Include:

- Stain Resistant Clothes: Fine-spun fibers ("nanowhiskers") are embedded into fabrics and act like peach fuzz to create a cushion of air around the fabric so that liquids bead up and roll off. This innovation will leads to less stains, less need for washing clothes (using detergent) and dry cleaning (using chemicals), and even less need to replace (and thus produce clothing). These could all have positive impacts on the environment.
- Nano Solar Cells: Traditional solar cells provide one source of clean energy but they are expensive to produce. A new kind of solar cells use nanoparticles of TiO_2 coated with dye molecules to capture the energy of visible light and convert it into electricity. These solar cells are less expensive to produce and have the potential to be used in a wide range of applications.
- Clear Sunscreen: Traditional inorganic sunscreens (ZnO and TiO_2) provide powerful protection from the full range of UV light, but are often not used or under-applied because they appear white on the skin (due to the scattering of visible light). ZnO and TiO_2 nanoparticles provide the same UV protection as their larger counterparts, but are so small that they don't scatter visible light and thus appear clear on the skin.

Existing Applications (continued)

- Building Smaller Devices and Chips: A technique called nanolithography lets us create much smaller devices than current approaches. This technique can be used to further miniaturize the electrical components of microchips. Dip pen nanolithography is a ‘direct write’ technique that uses an AFM to create patterns and to duplicate images. “Ink” is laid down atom by atom on a surface, through a solvent—often water.
- Health Monitoring: Several nano-devices are being developed to keep track of daily changes in patients’ glucose and cholesterol levels, aiding in the monitoring and management of diabetes and high cholesterol for better health. For example, some researchers have created coated nanotubes in a way that will fluoresce in the presence of glucose. Inserted into human tissue, these nanotubes can be excited with a laser pointer and provide real-time monitoring of blood glucose level.

Potential Applications Include:

- Paint That Cleans the Air: A titanic-oxide-based compound in nanosized particles has been claimed to clean the air by decomposing the major ingredients that cause air pollution such as formaldehyde and nitride. This compound could be used in paints, acting as a permanent air purifier and helping to improve the air quality in polluted areas.
- “Paint-On” Solar Cells: Scientists are trying to develop a photovoltaic material using semiconducting nanorods that can be spread like plastic wrap or paint. These nano solar cells could be integrated with other building materials, and offer the promise of cheap production costs that could finally make solar power a widely used electricity alternative.
- Drug Delivery Systems: Nanotubes and buckyballs could serve as drug delivery systems. Because they are inert and small enough to cross many membranes, including the blood-brain barrier, they could be used to carry reactive drugs to the right part of the body and “deliver” the drug inside the appropriate cell.
- Water Treatment: Advanced nanomembranes could be used for water purification, desalination, and detoxification, nanosensors could detect contaminants and pathogens, and nanoparticles could degrade water pollutants and make salt water and even sewage water easily converted into usable, drinkable water. This could help address water crises across the plant.
- Clean Energy: Hydrogen fuel is currently expensive to make, but with catalysts made from nanoclusters, it may be possible to generate hydrogen from water by photocatalytic reactions. Novel hydrogen storage systems could be based on carbon nanotubes and other lightweight nanomaterials, nanocatalysts could be used for hydrogen generation, and nanotubes could be used for energy transport.
- Detecting Disease with Quantum Dots: Quantum dots are small cadmium-based devices that contain a tiny droplet of free electrons, and emit photons when submitted to ultraviolet (UV) light. Scientists are exploring ways to seal the dots in polymer capsules to protect the body from cadmium exposure; the surface of each capsule can then be designed to attach to different harmful molecules (for example those indicating presence of cancer). As the dots collect in a tumor, they become visible in ultraviolet light under a microscope, allowing doctors to identify and locate cancer earlier.