Teacher's Preparatory Guide

Learning about the nanoscale and the SI system of measurement

Purpose: To help students understand the size of the nanoscale. To relate the size of a nanometer to everyday objects. To refresh students on the SI system of measurement.

Time required: 2-50 minute class periods.

Level: upper middle to lower high school

Teacher Background:

This is an article from the National Nanotechnology Infrastructure Network's education portal. It can be accessed from http://www.nnin.org/nnin_what.html.

Nanotechnology is the science and technology of small things – in particular things that are less than 100nm in size. One nanometer is 10^{-9} meters or about 3 atoms long. For comparison, a human hair is about 60-80,000 nanometers wide. Scientists have discovered that materials at small dimensions—small particles, thin films, etc- can have significantly different properties than the same materials at larger scale. There are thus endless possibilities for improved devices, structures, and materials if we can understand these differences, and learn how to control the assembly of small structures.

There are many different views of precisely what is included in nanotechnology. In general , however, most agree that three things are important:

1. Small size, measured in 100s of nanometers or less
2. Unique properties because of the small size
3. Control the structure and composition on the nm scale in order to control the properties.

Nanostructures--- objects with nanometer scale features-- are not new nor were they first created by man. There are many examples of nanostructures in nature in the way that plants and animals have evolved. Similarly there are many natural nanoscale materials….. catalysts, porous materials, certain minerals, soot particles, etc that have unique properties particularly because of the nanoscale features. What is new about nanotechnology is that we can now, at least partially, understand and control these structures and properties to make new functional materials and devices. We have entered the era of engineered nanomaterials and devices.

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One area of nanotechnology has been evolving for the last 40 years and is the source of the great microelectronics revolution- the techniques of micro- and nano-lithography and etching. This is sometimes call "top-down" nanotechnology. Here, small features are made by starting with larger materials and patterning and "carving down" to make nanoscale structure in precise patterns. Complex structures including microprocessors containing 100s of millions of precisely positioned nanostructures can be fabricated. Of all forms of nanotechnology, this is the most well established. Production machines for these techniques can cost millions of dollars and a full scale microprocessor factory can cost one billion dollars. In recent years, the same "top down" nanoprocessing techniques have enabled many non-electronic applications, including micromechanical. Microptical, and microfluidic devices.

The other fundamentally different area of nanotechnology results from starting at the atomic scale and building up materials an structures , atom by atom. It is essentially molecular engineering- often called molecular or chemical nanotechnology. Here we are using the forces of nature to assemble nanostructures – the term "self assembly" is often used. Here, the forces of chemistry are in control and we have, at least to date, somewhat less flexibility in making arbitrary structures. The nanomaterials created this way, however, have resulted in a number of consumer products. Significant advances are expected in the next decade in this area as we understand more completely the area of chemical nanotechnology.

And there are many exciting applications that combine both bottom up and top down processing- to create for example single molecule transistors that have large (macroscopic) leads fabricated by top-down and single molecule assembled from bottom up.

Elsewhere on this site are highlighted some of the current applications of nanotechnology as well as those that we can reasonably forecast.

These materials have unique properties because of their small size. At the nanoscale, properties of materials behave differently and are said to behave under atomic and molecular rules. Researchers are using these unique properties of materials at this small scale to create new and exciting tools and products in all areas of science and engineering.

Nanotechnology combines solid state physics, chemistry, electrical engineering, chemical engineering, biochemistry and biophysics, and materials science. It is a highly interdisciplinary area – meaning that it involves ideas integrated from many traditional disciplines. Some universities have begun to issue degrees in nanotechnology; others view it as a portion of existing academic areas. Either way many trained scientists, engineers, and technicians in these areas will be required in the next 30 years.

The federal government believes that nanotechnology is one of the most important research endeavors for our country. In 2001 it established the National Nanotechnology Initiative (NNI) as an umbrella organization to promote and organize nanotechnology research across the government. Under NNI, ten federal agencies fund nanotechnology research with a current budget of approximately $1 billion per year. An aggressive set of technology milestones and grand challenges have been set by NNI. In 2004, President Bush signed into law the 21st Century Nanotechnology Research and Development Act which further promoted nanotechnology research. Other countries around the world have followed with significant programs in Nanotechnology.

This website is part of the National Nanotechnology Infrastructure Network (NNIN). The National Nanotechnology Infrastructure Network (NNIN) which consists of specialized nanotechnology laboratories at 13universities across the nation was funded in 2004 by the National Science Foundation as part of the NNI program. The NNIN provides researchers from across the nation with economical access to state-of-the art nanotechnology facilities.

Many are predicting that nanotechnology is the next technical revolution and products resulting from it will affect all areas of our economy and lifestyle. It is estimated that by 2015 this exciting field will need 7 million workers worldwide. The workforce will come from all areas of science and engineering and will include those with two-year technical degrees up to PhD researchers in universities and industry.

Materials:

- Metric ruler
- NanoRuler (available at http://www.nanozone.org/nanoruler_print.htm)
- candy in various sizes (M&M'S, Skittles, pepermint, minature bars) or other small objects for measuring
- Coins: pennies, nickels, dimes, quarters
- For Nanoproducts poster: Paper, pencil, metric ruler, NanoRuler, construction paper, magazines, colored pencils, glue, markers, scissors

Advance Preparation:

Before beginning this lesson, review metric measurement with students. A good overview can be found at http://physics.nist.gov/cuu/Units/index.html as well resources at the U.S. Metric Association (http://lamar.colostate.edu/~hillger/)

Have the students bring in magazines to cut out pictures of various products that have been developed with nanotechnology or could be altered by nanotechnology. Alternatively, you could allow students to use the Internet to research examples of nanoproducts. An excellent resource on nanoproducts is *The Project on Emerging Technologies' Consumer Product Inventory* (http://www.wilsoncenter.org/index.cfm?fuseaction=topics.home&topic_id=166192).

Download the NanoRuler and make enough copies for students working in pairs.

Safety Information: Remind students to be careful when using scissors.

Directions for the Activity:

1) Place students in pairs.
2) Lead students in a discussion of the SI prefixes including the 7 basic units.
3) Ask the following questions:
   a) How many of you have heard the word nano?
   b) In, what ways have you heard the term nano used?
   c) What do you think nano means?
4) Today, we will discuss the SI prefix Nano

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5) Distribute the NanoRulers and metric rulers to each student. Have students identify the metric markings, such as millimeters(mm) centimeters (cm) decimeters (dm). They should also examine the NanoRuler to see the units of measurement.
6) Have students make estimates of the size of a variety of objects. The direct them to carefully measure the objects using the metric ruler and the NanoRuler.
7) Have them enter their results in the measurement tables.
8) Lead a class discussion about their estimates and actual sizes. Discuss the measurements using the NanoRuler. Ask them what they noticed about the NanoRuler measurements (they should indicate that there are a lot of nanometers in an object because the scale is so small $1x10^{-9}$).
9) Direct students to create a poster on nanoproducts. Somewhere on each poster they should use an SI measurement (preferably nano). Provide them with three options for their poster:
   a) They should choose products that are currently available and indicate what is nano about them;
   b) Choose a non nanoproduct and think of ways it could be changed with nanotechnology; or
   c) Think of a product they would like to see developed using nanotechnology.
10) Students will present their posters during a class period.

Procedure (from Student Activity Guide)

Part I. Measuring at the nanoscale --

1. Read the article "What is Nanotechnology?"
2. Complete the worksheet for the article "What is Nanotechnology?"
3. Gather the materials to be measured for the activity from your teacher.
4. Estimate the diameter of your objects in centimeters and millimeters. Record your estimates in the table provided.
5. Obtain a metric ruler and NanoRuler from your teacher and carefully measure your object using both rulers. Record your answers in the table provided.
6. Make a nanoposter using the pictures on this page/internet search/or use magazines.

Part II. Exploring NanoProducts

7. You will create a poster on nanoproducts to be presented in class.
8. You have three options to choose from for your poster:
   a. Choose products that are currently available and indicate what is nano about them;
   b. Choose a non nanoproduct and think of ways it could be changed with nanotechnology; or
   c. Think of a product you would like to see developed using nanotechnology.
9. Your teacher will direct you on what resources you may use to create your poster. You must include an SI measurement in your poster.
10. Be creative!

Data Table

Object	Estimated Diameter	Diameter in Centimeters (cm)	Diameter in Millimeters (mm)	Diameter in Nanometers (nm)
Penny				
Nickel				
Dime				
Quarter				
Textbook				
Notebook				
Pencil				
M&M				
Mint				
Miniature Candy Bar				
Stick of Gum				

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Assessment
Student Worksheet (with answers)

1) What are the basic units of measurement in the SI system? Meter, kilogram, second, ampere, Kelvin, mole, candela

2) Why are metric measurements important? Easy to use; based on units of 10 so no conversion like with fractions; used in science and engineering; used around the world; etc.

3) What did you learn about metric units? Easy to use, based on ten, etc.

4) Were your estimated measurements similar to your actual measurements? Responses will vary

5) If not, how did your estimates differ from the actual measurements? Responses will vary

6) How did the NanoRuler measurements compare to the metric measurements? There were a lot more nanometers for an objects measurement

- What does this make you think about the nanoscale? Students should understand that the nanoscale is very small and that it requires many nanometers to equal a millimeter or centimeter.

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"What is Nanotechnology?" Worksheet

1. Define nanotechnology. Nanotechnology is the science and technology of small things – in particular things that are less than 100nm in size

2. What is the diameter of a human hair? 60-80,000nm

3. One nanometer is equal to 10^{-9} meters

4. List the three important factors included in nanotechnology.

   a. Small size, measured in 100s of nanometers or less

   b. Unique properties because of the small size

   c. Control the structure and composition on the nm scale in order to control the properties.

5. What is new about nanotechnology? Scientists and engineers can understand (practically) and control atoms and molecules and their properties to make new functional materials and devices

6. What is meant by top-down nanotechnology? Give an example. It is when small features are made by starting with larger materials and patterning and "carving down" to make nanoscale structure in precise patterns. Example – microprocessor.

7. What are the branches of science involved in the study of nanotechnology? physics, chemistry, electrical engineering, chemical engineering, biochemistry and biophysics, and materials science

8. In reading the article, the term "highly interdisciplinary area" was used. Explain what is meant by highly interdisciplinary. It involves ideas integrated from many traditional disciplines.

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Resources:
To learn more about units of measurement, scale and nanotechnology, here are some web sites with educational resources:

- *The Si System* – http://physics.nist.gov/cuu/Units/indez.html
- *Powers of Ten* explores the relative size of things from the microscopic to cosmic – http://powersof10.com
- Teaching resources on the metric system can be found at the U.S. Metric Association – http://lamar.colostate.edu/~hillger/
- *Scale of Objects* by NanoSense offers a series of units designed for high school students – http://www.nanosense.org
- *How Small is Nanotechnology?* offers activities to explore the size of the nanoscale including the Nanometer Ruler - http://nanozone.org/How.htm
- *How Big is a?* is an interactive size comparison found at – http://www.cellsalive.com/howbig.htm
- *The Scale of Things* poster from the Office of Basic Energy Science is available at - http://www.er.doe.gov/bes/scale_of_things.html
- National Nanotechnology Initiative teacher resources – http://www.nano.gov/html/edu/home_edu.html
- National Nanotechnology Infrastructure Network education portal – http://www.nnin.org/nnin_edu.html.

National Science Education Standards

- Content Standard A
  - Understandings about scientific inquiry
- Content Standard E
  - Understanding about science and technology

Principles and Standards for School Mathematics

- Numbers and Operations
  - Understand numbers, ways of representing numbers, relationships among numbers, and number system

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