Pilot program to integrate nanotechnology in Utah’s high schools

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How big is the World Nanotech Market?

- US$1 trillion in 2010 - UK firm "Evolution Capital Resources"

2004 to 2005

- US$30 billion in manufactured goods in 2005 – more than double the previous year.
- Governments, corporations, and venture capitalists spent $9.6 billion on nanotech research and development (R&D) worldwide in 2005, up 10% from 2004.

In 2014, 15% of manufacturing output — $2.6 trillion — will incorporate nanotech.

Source: October 2004 Lux Research Report “Sizing Nanotechnology’s Value Chain”
Why Nanotech at K12?

Present school students are the 21st century workforce for the nation.

Introduction of nanoscience and technology in grades K-12 will be necessary to create interest among students.

Nanotech Workforce Pipeline

K-12 → 2 years college → Univ MS → Ph.D

40,000 US scientists
800,000 US workers needed to support $1T in 2015 (NSF)
Workforce Development & Job Generation

- Education & Training
- Professional
- Graduate
- Undergraduate
- Technical Institutes
- Community Colleges
- K-12

Adolfo Nemirovsky, nanoEducation and Training Forum™ (nETF™)
Nano at K12 – Big Challenge

Observations from the NanoUtah’03 conference

Student’s comments

- Do we need to learn chemistry, physics, biology, math, computer science and engineering to be a Nanotechnologist or Nanoscientist? – That’s tough!
- If someone likes physics but not biology or other subjects, how will he/she consider higher education in this exciting area?

Teacher’s Comments

Who will teach nanotechnology course?
New faculty with Nanotech degree?
Introducing Nano at K12 curriculum

• How?
  – Isolated stand-alone sections?
  – Integrated part in appropriate places?

  Integrated parts in :
  ➢ Chemistry
  ➢ Physics
  ➢ Biology
What to include?

1. Introduction to micro and nano scale.
2. History of Nanotechnology
4. Limitation of the human eye and optical microscope.
5. Introduction to electron microscope.
6. Bottom-up and Top-down technology
7. Introduction to Fullerenes and Carbon nanotubes
8. Structure-property relation
9. Synthetic methods, such as CVD, MBE etc
10. Size-dependence of properties.
11. Applications of Nanotechnology
12. Nanotechnology products
Understanding Size: Step-by-step magnification

1 meter
(=1,000 mm)

10 cm = 0.1 m
=100 mm

1 cm = 0.01 m
=10 mm

100 µm = 0.0001 m
=0.1 mm

Eye limit

100 nanometers (nm)
=0.000 000 1 m
=0.1 µm =0.0001 mm

Microscope limit

1 µm = 0.000 001 m
(=0.001 mm)

10 µm = 0.000 01 m
=0.01 mm

source:  http://microcosm.web.cern.ch/microcosm/P10/english/P0.html
How small is one nanometer (nm)?

1 nanometer (nm) = \( \frac{1}{1,000,000,000} \) meter; One-billionth \((10^{-9})\) of a meter
= \( \frac{1}{1,000,000} \) millimeter
= \( \frac{1}{1,000} \) micrometers

The typical width of a **human hair** is 50-60 micrometers. We can see hair in naked eyes.

If you could **split** that hair into 50,000/60,000 separate strands, each would be a **nanometer** wide.

To see nanometer scale objects, we need **Electron Microscope**, where **electron** is used instead of **light**.

Electron microscope can resolve objects about **1000 times smaller** than an optical microscope, enabling magnifications of **1,000,000x** without loss of detail.
Is it possible to work on such small things?

Examples of hair:

Photo: just to show how cutting edge they are, Thinktank have had their logo printed on a human hair using nanotechnology!

Caption: Human hair engraved using an excimer laser;

credit: Lambda Physik

Courtesy of Thinktank.
The smallest unit of matter. There are 92 natural atoms – See Periodic Table.

Everything in the world is made of different combinations of these atoms.

source: http://microcosm.web.cern.ch/microcosm/P10/english/P0.html
How Small is nano?

- Milky Way Galaxy (>10^{16} m)
- Nanoscale
  - New phenomena
  - New tools
- Bulk Solids, Fluids, Gases
- Clusters & Macromolecules
- Small Molecules
- Atoms
- Genetic Code
- Proteins & Complexes
- Single Virus
- Bacteria
- Human Cell
- Multicellular Tissue
- Human Chromosomes
- Complex Organisms

1 Å: 1 billionth of a meter
Biological Structure

- Tissues, chromosomes, human hair
- Cells (bacteria)
-Viruses
-Protein complexes
-Proteins
-Atoms & Mols.

Scales:
- 10 µm
- 1 µm
- 100 nm
- 10 nm
- 1 nm
- 1 Å

Courtesy: Jordan Gerton, University of Utah
In 1956 IBM invented the first computer disk storage system. This system could store five MBytes. It had fifty, 24-inch diameter disks!

1960 - 1980s Hard Disk Drive for Main frame computers

Weight 650 pounds

Hard Disk (5-200 Mbytes)

In 1980, Seagate Technology introduced the first hard disk drive for microcomputers. It was 5 1/4" drive and held 5 MB

Microtechnology

Current Hard disk (100 – 400 GB)

2.5 inch

Thumb Drive

128 MB – 14 GB
Electron Microscopes

- Scanning Electron Microscope (SEM)
- Transmission Electron microscope (TEM)
- Scanning Transmission Electron Microscope (STEM)
- Scanning prove microscopes: Scanning tunneling microscope (STM)/Atomic Force Microscope (AFM)
Human vision spans from 720 nm in the red wavelengths of light to 400 nm in the blue violet wavelengths.

Human eyes cannot see at **electron wavelengths** so we need a **television type screen** or special photographic film to make electron microscope images visible to human eyes.

The **wavelength of electrons** used in electron microscopes is usually **1.0 to 0.1 nm**.

Since electrons are easily scattered by air molecules, the interior of an electron microscope must be sealed at a very **high vacuum**.
How SEM works

SEM Setup

Electron/Specimen Interactions

When the electron beam strikes the sample, both photon and electron signals are emitted.

Incident Beam

Primary Backscattered Electrons
Atomic Number and Topographical Information

Cathodoluminescence
Electrical Information

Secondary Electrons
Topographical Information

Sample

Auger Electrons
Surface Sensitive Compositional Information

X-rays
Through Thickness Composition Information

http://mse.iastate.edu/microscopy/choice.html
Below are five different SEM images of the same mosquito.

Because the SEM illuminates them with electrons, they also have to be made to conduct electricity.

Gold coated mosquito sample
For SEM

Source: http://www.mos.org/sln/sem/intro.html
Individual electronic components were soldered on to printed circuit boards.

Integrated circuits placed all components in one chip, drastically reducing the size of the circuit and its components.

Clockwise from the top: 1941 vacuum tube used for telephone communications; the point-contact transistor as it was introduced June 30, 1948 to the world, six months after its invention; 1955 transistor which replaced vacuum tubes in network communications equipment; 1957 diffused base high frequency broadband amplifier; 1967 microchip, used to produce the tones in a touch-tone telephone set, contained two transistors; and (center) a Lucent Technologies digital signal processor chip, which can contain as many as 5 million transistors, used in modems and cellular communications.

Imagine a carbon atom sitting at each of these points, and you have a model of the C60 molecule.

If the C60 molecule were the size of a soccer ball, then the soccer ball in turn would be roughly the size of the earth. Fullerenes have been found to exist in interstellar dust as well as in geological formations on Earth. They are only new to us.

Fullerene or Bucky ball; After the American architect Richard Buckminster Fuller (1895 - 1993).
Different chemical transformations of C\textsubscript{60}

The chemical transformations that are possible with C\textsubscript{60} could be classified in five main groups.

**Addition reactions.** Formation of exohedral compounds by addition of nucleophiles or radicals, cycloadditions, complexations with transition metals and others

**Electron transfer reactions.** Chemical reduction of fullerenes can easily be achieved by reaction with electropositive alkali and alkaline earth metals or organic donor molecules.

**Heterofullerenes.** (Substitutional doping): Substitution of a carbon atom of the fullerene skeleton for a heteroatom, for example nitrogen or boron

**Formation of endohedrals.** Introducing and trapping of atoms inside the spherical carbon cage

**Ring opening reactions.** Producing a hole in the C60 skeleton while breaking a discrete number of bonds

http://www2.chemie.uni-erlangen.de/services/dissonline/data/dissertation/Francesc_Camprubi/html/chapter1.html
Top-down process
Bottom-up: Build materials atom by atom

Molecular Beam Epitaxy (MBE)

Sources

substrate

Heater

GaAs thin-film

substrate
A novel data storage system capable of $10^{15}$ bytes/cm$^2$ is being explored. In this system, H atoms would be designated as 0 and F atoms as 1. A tip that can distinguish between 0 and 1 rapidly and unambiguously is being investigated.

http://www.ipt.arc.nasa.gov/gallery.html
A small gold dot rests on a silicon cantilever. The dot is a test mass for studying how the cantilever can be used to measure the masses of tiny particles, including viruses, with atto-gram precision.

With lithographically fabricated nanoelectromechanical (NEMS) device, the Cornell researchers can measure the mass of a particle with a sensitivity of $10^{-18}$ grams, far exceeding the precision of a comparable device with femtogram ($10^{-15}$ g) sensitivity reported last year. To get any better measurement of mass you would have to vaporize the particle and shoot its constituent molecules through a mass spectrometer.
A nanoguitar, devised at Cornell years ago, has been "played" for the first time by shooting laser light at the silicon "strings." A newer version of the guitar.

Reported by: Lidija Sekaric at the Fall 2003 AVS meeting

Researchers at Cornell University used laser light to set the 10-micron-long silicon "strings" of the guitar in motion. There is no practical microphone available for picking up the guitar sounds, but the reflected laser light could be computer processed to provide an equivalent acoustic trace at a much lower frequency.

The Chandra x-ray telescope recently saw concentric circles in the inter-galactic gas cloud surrounding the cluster core; some astronomers interpret the ripples as being sound waves (with a frequency some 57 octaves below human hearing, and possibly "the deepest note ever detected from an object in the universe").

http://www.aip.org/png/cat9.html
Dip-pen lithography
Conclusions

• Isolated and stand-alone sections on nanotech seems hard for student’s understanding and teachers had to provide backgrounds to correlate with new section and that kills class-hours.

• If these newly added sections are considered as an integrated part of regular curriculum in appropriate places, the lesson was very well received, and easily understood by most of the students.

• Advantages of integrated lessons:
  – students will get lessons regularly over the year which is related to their regular class work, thus the word nano and its importance will insinuate more thoroughly into their awareness.
  – teachers will avoid extra class-load for the additional isolated parts.