So you want to do nanoscience?

Why getting A's in your science classes is not enough.

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Rationale for NSEE

It is useful to describe educational outcomes in terms of what we expect students to be able to do.

- The goal of NSEE is to produce students who will be successful in an environment that is shaped by technology related to fundamental developments in NSE research.

Objectives for Speaker

- Provide a domain expert's insight into scaffolding (TOM)
  - How I made the curriculum work for me.
  - Where are the gaps?
- Communicate my view of collaborative NCLT activities that support NSEE (RPHC)
  - Reveals what I've learned
  - Reveals what I haven't learned

Objectives for Listeners

A learning trajectory...

- What experiences were enabling with respect to future work in NSEE?
- How can we analyze the value of these experiences and replicate them in situations that may be more resource limited?

A Learning Trajectory

Geographical

Source: www.united-states-map.com

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K-3

(Ann Arbor, Michigan)

- Sourced locally from pond
- Amoeba are visible in optical microscope
- Amoeba motion and hand motion visible.

http://www.btinternet.com/~stephen.durr/

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7-12

(Bettendorf, Iowa)

- Bad chemistry teacher (Soph)
- Great physics teacher (Jr., Sr.)
- Frustrating laboratory experiences
  - Questions were met with questions
- Lab mate who was valedictorian, top student in all science classes.

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13-16

University of Michigan, Ann Arbor, Michigan

- Physics major, interested in theory, better at experiments.
- Had junior level laboratory class in which professor had gutted the lab manual
- Lab was hard
  - Reports were not perfect
  - Left open questions
  - Got an A+.

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13-16

University of Michigan, Ann Arbor, Michigan

- Did not get straight A's.
- Did research for ~1.5 years, not considered 'nano'.
- Got into graduate school based on recommendation letters
  - detailed summative assessment of ability to *do research.*

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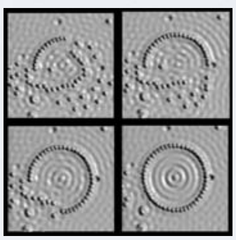
Graduate School in Physics

Cornell University, Ithaca, New York

- Not near the top of my class, academically, but successful (eventually) in research.
- First exposure to ‘nano’ (circa 1997).
- Scanning Tunneling Microscopy of atoms and molecules.

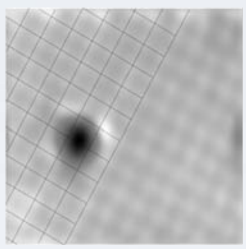
Seeing atoms

Eigler’s ‘Quantum Corral’



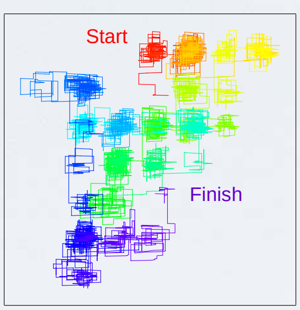
. http://www.almaden.ibm.com/vis/stm/atomo.html

A hydrogen atom



L. J. Lauhon & W. Ho

H Atom Motion



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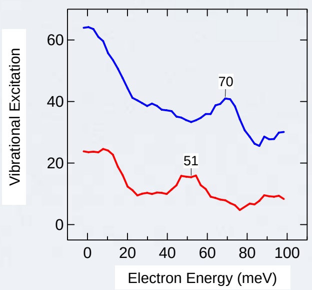
Tickling H Atoms



http://commons.wikimedia.org/wiki/Image:Hydrogen_Deuterium_Tritium_Nuclei_Schmatic-ja.png

L.J. Lauhon and W. Ho, *Phys. Rev. Lett.* **85**, 4566 (2000)

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Chemistry Postdoc

Harvard University, Cambridge, MA

- Nanotubes & Nanowires
- **Synthesis**- making new nanomaterials
- **Microscopy & Lithography**- imaging and manipulating materials

*NSE revolution is enabled by developments in both the **synthesis** of new materials and **methods** for studying them*

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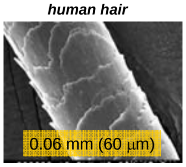
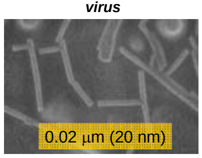
Nanomaterials

How small is NANO?

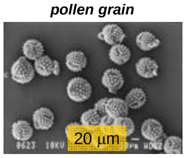
human hair



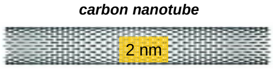
virus



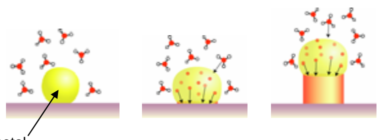
pollen grain



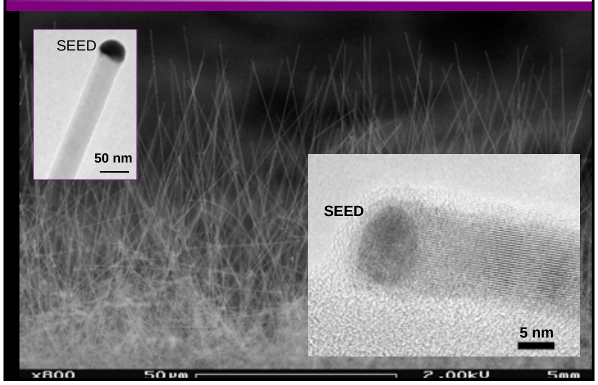
carbon nanotube



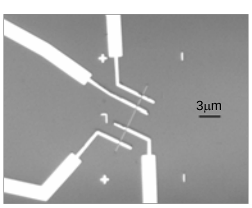
Semiconductor Nanowire Synthesis

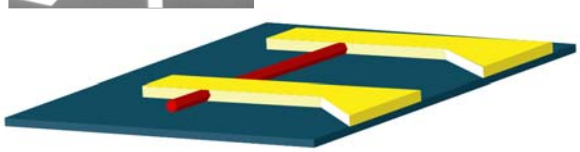


Nanowire Synthesis



Overview of Device Fabrication





Chemistry Postdoc

Harvard University, Cambridge, MA

- Harvard/MIT support a hotbed of activity in science & new tech
- Environment promoted understanding of what is new and exciting in nanoscience
- Faculty offer based on recommendations, track record in peer review publications, and ...

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MSE Faculty

Northwestern University, Evanston, IL

- Physics → Chemistry → MSE
- Responsible for NSEE at undergraduate and graduate level
- Research continues to try to push understanding of structure and properties to the smallest length-scales.

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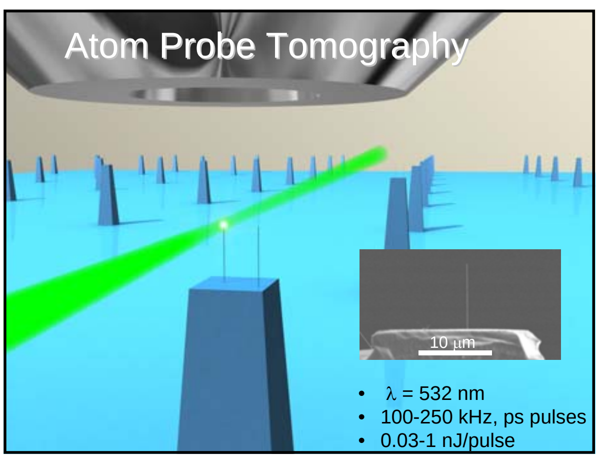
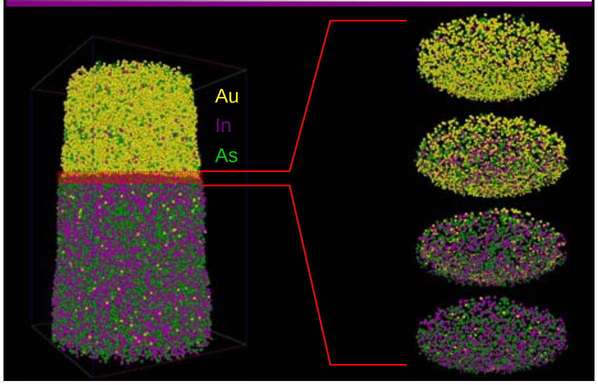
Atom Probe Tomography



- λ = 532 nm
- 100-250 kHz, ps pulses
- 0.03-1 nJ/pulse

Atom Mapping in 3-D



A's in Science: Necessary/Sufficient?

Necessity: what is my group doing?

- Physics
- Chemistry
- Materials Science
- Electrical Engineering

Sufficiency:

- Mastery of assessments of compartmentalized knowledge is insufficient.
- Better assessments of the *utilization* of NSE knowledge can be created.

What are 'A' students able to do?

There are gaps in scaffolding

- We expect them to make connections that they might not be making.
- Professors, who are professional learners, see connections that students don't.
- Curriculum committees aren't necessarily working from a concept map.

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Gaps in Scaffolding

Physics

- Physics is usually ‘taught’ after chemistry and biology
- Principles are abstract, and may therefore seem unrelated to ‘real life’.
- Much of what is unique about nano requires quantum mechanics.

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Gaps in Scaffolding

Chemistry

- Chemical equations are difficult to connect with what is going on in a beaker.
- Textbook understanding of bonding does not imply understanding of extended structure, *i.e.,* real materials.
- Description of electrons, bonding, energy, etc., should be consistent with what students will learn later.

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Gaps in Scaffolding

Biology

- Often taught before chemistry, encouraging us to associate biology with labeling objects rather than revealing their relationships.
- Students do not know the relative sizes of viruses, bacteria, cells. Why should they?
- Knowledge of absolute but not relational sizes reveals knowledge acquired in compartmentalized disciplines.

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Gaps in Scaffolding

Materials Science

- Materials science is not usually taught in high school
- Requires application of chemistry and physics across multiple length-scales
- Understanding of nano**materials** represents perhaps the biggest gap.

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What does it take to do nanoscience?

(Besides A's in traditional science classes)

- Connections between length-scales
- Connections between disciplines
- Consistent models of materials and phenomena

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Opportunities to Support NSEE

- Key experiences in the learning trajectory provide insight into opportunities to support NSE teaching and learning.
- These are anecdotal examples; one role of good learning science is to systematically study such experiences.

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Key Experiences & Insights

Labs without manuals (BHS, U of M)

- Growing confidence despite less structured learning environment
- Student forced to develop internal standards of excellence
- Replaces summative judgment with formative self-assessment

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NCLT Analogue

Labs without manuals

- Inquiry-based learning
- Design oriented projects
- *Nano focus:* put students in situations where they must develop consistent models across disciplinary areas
- Build formative assessment into the learning environment

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Key Experiences & Insights

Playing with Atoms (Cornell)

- Introduced the possibility of doing something that has never been done.
- Led to a new conception of nanoscale matter that was more...material.
- Novel experiences drove imagination

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Objective for NCLT Activities

Playing with Atoms

- Create defining moments and experiences that will change a student's conception of what is possible.
- Caveat: there is a danger in claiming something is interesting because it is totally novel or completely different. For scientists, the *connections* are interesting.

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Key Experiences & Insights

Bridging Length Scales (Harvard)

- Experience with materials & microscopy essential to constructing consistent models of the micro and nano world.
- Microscopies enable exploration at multiple length scales.
- Technological applications create and broaden interest.

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ISP Work Circle: Inside the iPod

Apple

Hard Disk Drive

http://electronics.howstuffworks.com/ipod.htm

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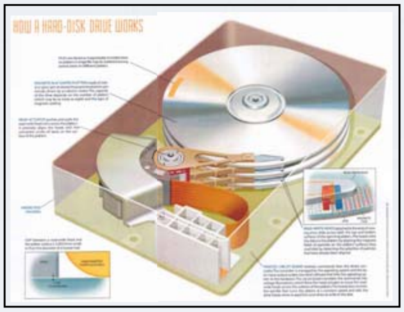
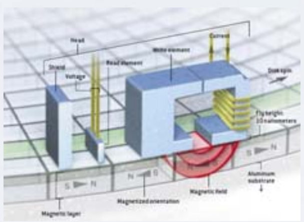
How a Hard Disk Drive Works



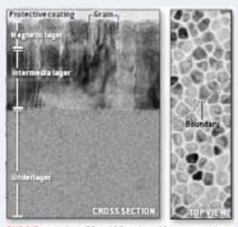
J. W. Toigo, *Scientific American*, **282**, 58 (2000).

Close-Up of a Hard Disk Drive

Hard Disk Drives rely on nanotechnology



Sci. Am. **295** (2), 90 (2006).



ONE BIT comprises 50 to 100 grains of ferromagnetic material magnetized in a roughly rectangular zone (*left*). The boundary is a nonmagnetized zone, a jagged plane along grain lines (*right*).

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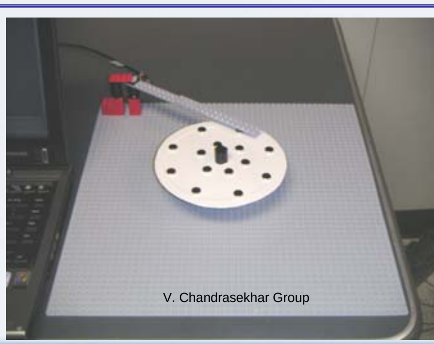
Macroscale Model of HDD



V. Chandrasekhar Group

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Key Experiences & Insights

Teaching Tests Learning

- We learn how much we know when we have to explain it to others.
- Communication between cultures is of the utmost importance to success in business and science.

A skill not particular to nano, but is essential to doing nano.

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NCLT Relevance

Teaching Tests Learning

- Communication between cultures is of the utmost importance to our success.
- Kids should be teaching each other throughout the curriculum.
- Represents an opportunity for formative assessment.

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Key Experiences & Insights

Roles of Assessment

- Ability to do research (self-directed learning) was recognized by mentors.
- This was not evident on transcript, and infrequently 'tested' in classroom.
- Generic assessments are not available to gauge proficiency in nanoscience.

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NCLT Relevance

Roles of Assessment

- It is possible to develop generic assessments of whether models developed in stovepiped disciplines are being connected in a consistent manner.
- A grand concept map of the NSE learning trajectory will be very useful in developing such an assessment.

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Review of Objectives

- Provide a domain expert's insight into scaffolding (TOM)
  - How I made the curriculum work for me.
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Center Goals & NSEE Objectives

What can we do together?

- **NanoConcept Inventory:** assessment tools can provide formative feedback for teachers and data for learning scientists.
- **'Content' Work Circles:** studying NSE learning and reducing findings to practice are not the same thing, but are mutually supportive.

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NCLT Goals

What can we do together?

1. Develop fundamental research about prior knowledge, learning trajectories, and learning experiences to support students in learning the challenging subject matter of NSE.
2. Develop fundamental knowledge and models of how to prepare 7-16 instructors in teaching NSE and using NSE materials.
3. Develop courses & programs (grades 13-16) to serve as models to other universities & colleges.
4. Develop a cadre of individuals who can pursue research on the teaching and learning of NSE.
5. Develop 7-16 Teachers/Instructors in NSE sensitive to the learning and teaching of NSE and understanding NSE.
6. Through research and leadership capacity building, impact minority institutions & at-risk populations in understanding and teaching of NSE throughout the US.
7. Establish NCLT as a national leader, building an NSE clearinghouse of information in NSE & NSEE.

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