Not Just What, but How Students Know: a Teacher-Researcher Perspective

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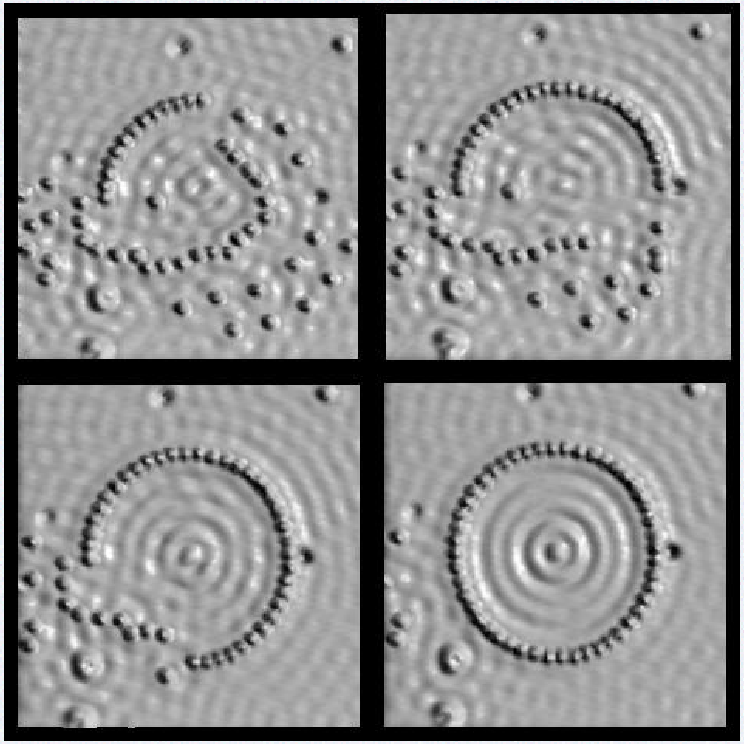
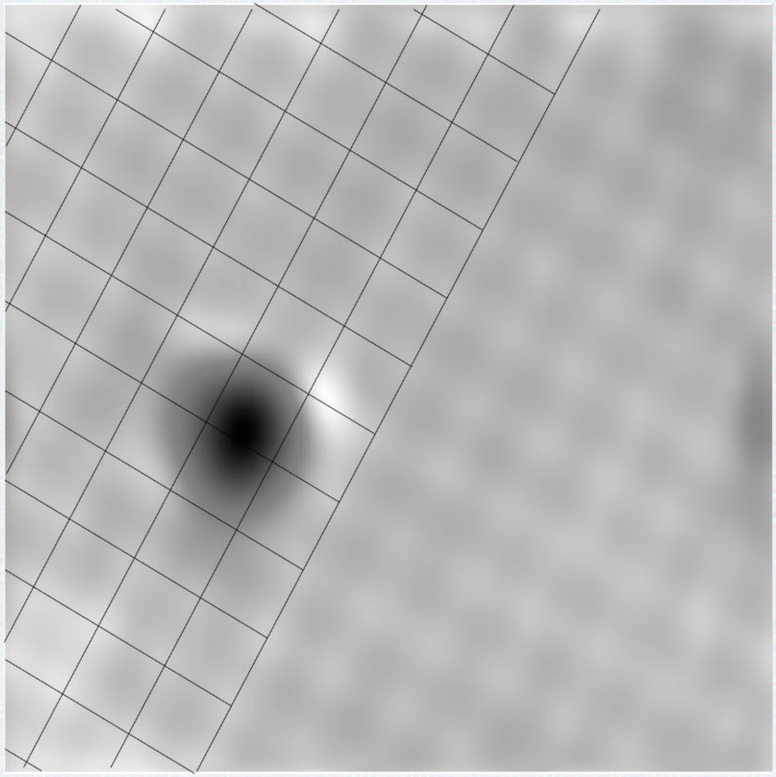
Seeing is believing

'Quantum Corral'



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

A hydrogen atom



L. J. Lauhon & W. Ho

Seeing is believing

How students know what they know influences whether the knowledge can be *used to do something rewarding*.

Predictive models of nanoscale phenomena are necessary but not sufficient for invention: *belief facilitates creativity and motivates action.*

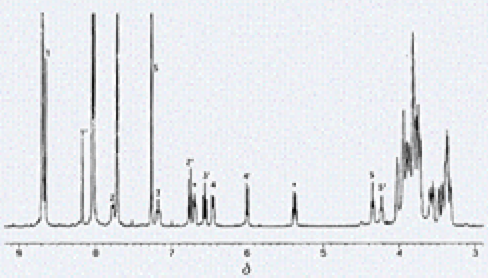
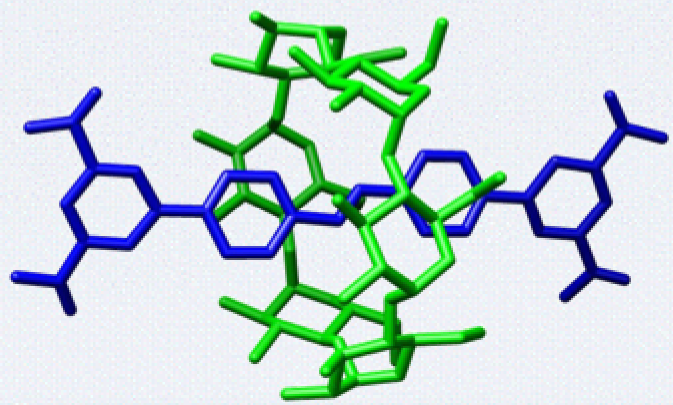
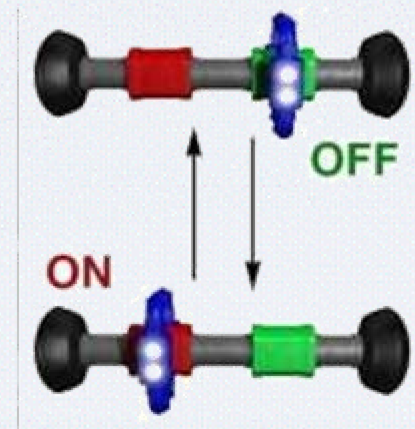


Image source: wikipedia





Outline

Not Just What, but *How* Students Know

- Motivation and Objectives
- Approach to Nanoconcept Inventory research
- Selected findings
- Perspective and prescriptions

Caveat: education research teaches us many things we already know.

An audience pre-test

A student orders metal rods for an electron beam evaporator from a chemical supply catalog. The rods arrive with documentation of the purity of the metal, but no MSDS.

Another student orders the same metal from the same company, but in nanoparticle form. The package arrives with an MSDS that warns that the material may spontaneously ignite (and is toxic).

- *Why would the particles spontaneously ignite?*
- *Why are the particles toxic, but not the rod?*

A learning objective for nanoscience

- **Students should be able to formulate hypotheses based on predictive models of nanoscale materials and systems.**
- These general skills are transferable to many disciplines, including failure analysis, internal medicine, and motorcycle repair.
- *In context of nano, these skills are thought to be important to the future of our research enterprise and economic well being.*

What is my responsibility as a teacher?

- My nanoengineering students need to be able to do things that are useful and rewarding.
- The nation needs a well-trained workforce to lead the world in scientific discoveries, drive innovation in engineering, and sustain or improve our standards of living.
- The funding that fuels nano research carries obligations to promote these broader impacts.

Motivation for nano education research

*The promotion of **nano** has created a conflict of interest and a related pedagogical challenge*

- We need funding to do **new**, exciting research.
- Nano is a hot **new** area that attracts students.
- The student asks:
  - *Is nano so revolutionary that it is unrelated to boring subjects like physics and chemistry?*
- The teacher needs to know:
  - *Is nanoscience so different that we need to adopt new pedagogical methods?*

Motivation for studying higher-ed preparation

How do we exploit the novelty of nano while emphasizing the unity of foundational concepts and disciplines?

***How** students learn foundational concepts influences the utility of those concepts in further study and disciplinary practice.*

Objectives of NanoEd Research

- Evaluate secondary ed student preparation for nano curricula at the higher ed level.
  - Assess depth and breadth of student understanding.
  - Understand how they learned what they know.
- Prepare higher ed teachers for the students.
  - Identify misconceptions that inhibit further nano learning and determine their prevalences.
  - Speculate on gaps in knowledge, particularly understandings that lie between or span disciplines.

Approach : NanoConcept Inventory

- Define foundational concepts (Big Ideas).
  - *e.g.* Particulate Nature of Matter
- Elaborate more specific concepts and provide examples of their manifestation in observable phenomena.
- Select for study concepts linked to national and state standards for secondary education.
- Develop assessment items to probe student understanding and misunderstanding of key concepts and/or models.

Approach : NanoConcept Inventory

- Examine:
  - Origin of models/conceptions: situational or compartmentalized knowledge?
  - Prevalence of misconceptions
  - Resistance to instructional correction
- Consider implications for teaching and learning of nanoscience and engineering.

Student Population

- North suburban Chicago high school
- Junior level physics students or
- Sophomore honors chemistry students
- Pre/post test with and without interventions to counter misconceptions.
- 447/500 went to 4-year colleges in 2008.

Students show basic limitations in engaging the physical world through measurement

Which of the following units of measure may be used to describe a sample of water in a drinking glass?

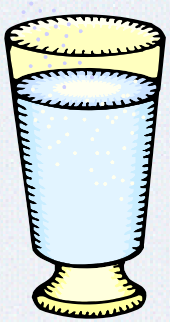
I. cubic centimeters

II. grams

23% III. milliliters

II + III: 26%

I + II + III: 33%



Intervention: Here is a scale and an unmarked plastic cup. Pour me 100 ml of water.

Direct interventions are not always successful in overcoming misconceptions

A laboratory technician is looking through an optical microscope and sees a red blood cell approximately 7 µm in diameter. Which one of the following is also on the size scale of 7 µm?

I. Diameter of a single human hair 21% → 11%

II. Infectious anthrax bacillus 45% → 56%

III. Uranium atom 12% → 9%

- Gains may have resulted from repeated homework associated with Nikon "Universcale" animation (H Chem).
- After instruction in physics, number choosing uranium atom went from 13% to 23%.

Knowledge (or belief) is related to what students have observed or 'seen'.

Of the following, which can be easily compressed to a significantly smaller size?

I. block of aluminum

II. water in a vial } 15%

68% III. gas in a syringe } 15%

Rate of correct response is high, but why?

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Which one of the following statements describes compressibility of matter?

I. Gas molecules are not bound to each other. This means they can easily compress into the empty space between molecules. 48%

II. Both liquids and gasses are easily compressed. This is due to the spaces between atoms. 15%

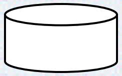
III. All matter is made of atoms and atoms are mostly empty space. Therefore, all states of matter are easily compressed.

Knowledge is not well integrated into model of particulate nature of matter.

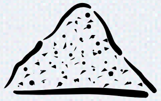
Direct intervention involving experimental activity can have a measurable impact

A student conducts two experiments reacting hydrochloric acid (HCl) with metallic zinc (Zn) to produce zinc chloride ($ZnCl_2$) and hydrogen gas (H_2).

$$Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$$



- In Experiment *I*, a 5.0 g *pellet* of zinc was used.



- In Experiment *II*, 5.0 g of *powdered* zinc was used.

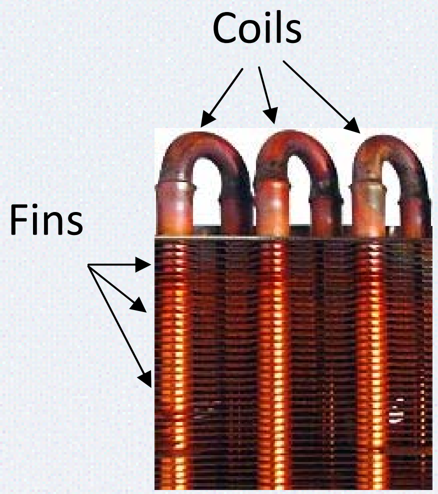
Experiment II using the *powdered* zinc was found to go faster to completion than Experiment I. The reason for this result would be best described as:

The *pellet* of zinc is less reactive than the *powdered* zinc due to stronger metallic bonding. 23% → 2%

The *powdered* zinc has a greater surface area. Therefore, more zinc can react per unit time with the hydrochloric acid present in the reaction vessel. 58% → 91%

Reasoning does not proceed from a general principle to a specific situation

Why do the heat exchange coils of an air conditioner have many fins around the coils?



20% I. The coils allow a smooth airflow to maximize the heat exchange with the air.

43% II. Since the fins are attached to the coils, the fins increase the rate of heat transfer to the air.

24% III. The additional surface area and mass of the fins are necessary for maintaining high pressure inside the coils.

Nano-relevance: nanowire battery electrodes

Summary of selected claims

- Prevalent misconceptions may inhibit nanoscience learning at higher ed level.
- Student conceptions strongly influenced by visual data and representations.
- It is possible to improve student performance and/or counter misconceptions with specific interventions.
- Nano-relevant facts or concepts are not generally incorporated into a framework or model that is consistent across disciplines.

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Prescription to address pedagogical challenges

Seeing is believing

- We should continue to promote the novelty of nano while emphasizing the unity of foundational concepts and disciplines.
- Higher ed instructors will need to focus attention on misconceptions arising from informal models strongly influenced by visual data.
- We can exploit interpretive visual faculties to instill predictive models of nanoscale phenomena that will drive research and innovation.

NanoEd pedagogy should be closely linked to what we envision as nanoengineering practice

- **Practice** in a discipline defines NanoEd outcomes: the learning environment should emulate the hands-on environment of the research or industrial laboratory.
- ***Students need to engage with the nanoworld by designing and making things. (like in shop class)***
- Misconceptions need to be challenged in practice, not just in a single course or on a single exam.
  - *Mistakes have consequences in the 'real' world.*

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Provide **framework** for students to integrate knowledge across length-scales & disciplines

- Processing-structure-properties-performance relationships define the practice of materials science and engineering.
- MSE integrates the practice of physics and chemistry, and recently biology into a unified discipline.
- This framework has been adopted for the teaching and practice of nanoscience as well.
  - *E.g.* MSE376: Nanomaterials
  - Earth and environmental sciences could also be included.

A **framework** for NanoEd is essential for educators

- A unified framework is useful in identifying gaps in traditional disciplinary training.
- Given the perceived importance of nanoscience and engineering education to future competitiveness, a systematic approach to training is warranted.
- NanoEd research informs the design of the learning process.

Acknowledgments

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