2006-839: NANOSCIENCE & NANOTECHNOLOGY CONCEPTS FOR HIGH SCHOOL STUDENTS: THE SCANNING PROBE MICROSCOPE

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Nanoscience & Nanotechnology Concepts for High School Students: Scanning Probe Microscopy

Abstract

While nanoscience and nanotechnology are not typically thought of as topics for the high school classroom, introducing such cutting-edge research provides a means to motivate student interest in science and engineering. The interdisciplinary nature of nanoscience & engineering allows for a wide range of topics including physics, chemistry, biology and mathematics to be taught within the exciting context of cutting-edge research. As part of the National Center for Learning and Teaching (NCLT) in Nanoscale Science and Engineering, Northwestern University is developing and testing concepts in nanoscience and nanotechnology. The nano-concept material (NCM) is based on a series of hands-on activities. The NCM are developed in close collaboration with high school teachers and are field-tested for feasibility. Learning theory is incorporated into the development of the materials with the assistance of education specialists.

One set of nano-concept materials is being developed around a key measurement technique in nanoscience, scanning probe microscopy. Scanning probe microscopy is an important measurement technique for nanoscience and engineering, and provides a platform from which to teach basic science concepts such as measurements and forces. We will discuss the “hands-on” activities developed to teach concepts in scanning probe microscopy, as well as an assessment on how the materials fit into high school and middle school science curricula. Initial findings from a prototype design project show that the design project was successful in engaging student interest, and that the macroscopic models and activities were helpful in facilitating student understanding of how a scanning probe microscope works. All of the students were able to successfully build a working atomic force microscope and acquire an image.

Introduction

The introduction of the “iPod Nano” this past year is proof enough that the word “nano” has entered into the mainstream of public awareness. The buzz about nanoscience and nanotechnology is that it may generate up to $1 trillion/year in new business in everything from pharmaceuticals to computers. To support this new business, it is estimated that we will need 3 million workers trained in nanotechnology worldwide over the next ten to fifteen years.[1] The challenge of preparing a nano-educated workforce lies largely in the hands of our educational system, and until recently has been limited mostly to graduate programs at research universities. However, within the past decade the importance of introducing concepts in nanoscience and nanotechnology at an earlier stage has surfaced.

As part of a national effort to educate students of all levels in nanoscience and nanotechnology, the National Science Foundation (NSF) has recently designated $15 million to create a National Center for Learning and Teaching (NCLT) in Nanoscale Science and Engineering.[2] The NCLT is based at Northwestern University, and involves collaboration with a wide range of universities and colleges, including the University of Michigan and Purdue, as well as high schools across the country. Our goals include using cutting-edge research to engage and inspire pre-college students to become interested in science and engineering, particularly nanoscience and nanotechnology.

Background and Approach

Traditionally, we think of "looking" at something small with a light microscope. In fact, the size of objects resolved with a light microscope is limited by diffraction to roughly 200 nm. Hence, we cannot see nano-objects because the wavelength of the visible light is simply too large to be reflected off of them. So another "touch" based technique, known as scanning probe microscopy (SPM), is used to characterize the surface of the sample. Much as a blind person scans the surface of an unknown object with his fingertips, the nanoworld can be "seen" by scanning a nanoscale "tip" over the surface of an unknown sample. SPM began in the 1980s when the scanning tunneling microscope was invented by Gerd Binnig and Heinrich Rohrer at IBM.[3] They won the Nobel Prize in Physics in 1986 for this work. Scanning probe microscopy is an important *measurement* tool in nanoscience and nanotechnology, and therefore offers a cutting-edge platform off of which to teach measurement concepts important to all scientists and engineers.

The research surrounding the use of scanning probe microscopy techniques in pre-college classrooms is most developed with respect to using remote access to microscopes.[4-6] The idea is that by giving students experience with the actual microscope, they will better appreciate and understand how one works. However, remote access is expensive, and the response time of web-based control systems can be long. Some simple activities which can be done relatively inexpensively in almost any classroom have also been developed;[7] however, the duration of these activities is often very short (3-20 minutes). Here, we present a two-week long series of nano-concept materials intended to impact student learning in a more permanent way. By highlighting the aspects of scanning probe microscopy which link to measurement and forces, we are able to link well with concepts already taught in and important to high school science classrooms (see Mapping of Nano-Concept Materials to Standards section).

A major challenge in teaching concepts in nanoscience and nanotechnology lies in the fact that the nanoworld is so small it cannot be seen even with a light microscope. Macroscopic models of the nanoworld offer an important tool for teaching nanoscience and nanotechnology. In the results section of this paper, we will discuss initial findings which seem to indicate that LEGO models are effective in helping high school students to understand in scanning probe microscopy.

Structure and Progression of the Nano-Concept Materials

The structure of our nano-concept materials is based in part on a format developed as part of the Materials World Modules Program at Northwestern University[8, 9]. In this format, a series of activities lead up to a final project in an "inquiry through design" scheme.[10] The NCM are designed to take up two weeks of classroom time, with approximately one hour a day devoted to the class. The design project, the culmination of the series of activities, is intended to take between three to four class periods.

Each Activity consists of two to three sub-activities, which set the stage and introduce the students to the concepts in question, followed by a section called "Expanding on the Concepts" (EOTC) which helps to broaden student knowledge about the concepts introduced in the activity, as well as highlighting the connection to nanoscience and nanotechnology. When stacked together, the activities are intended to progressively prepare students for the very open-ended design project. This is shown in Figure 1.

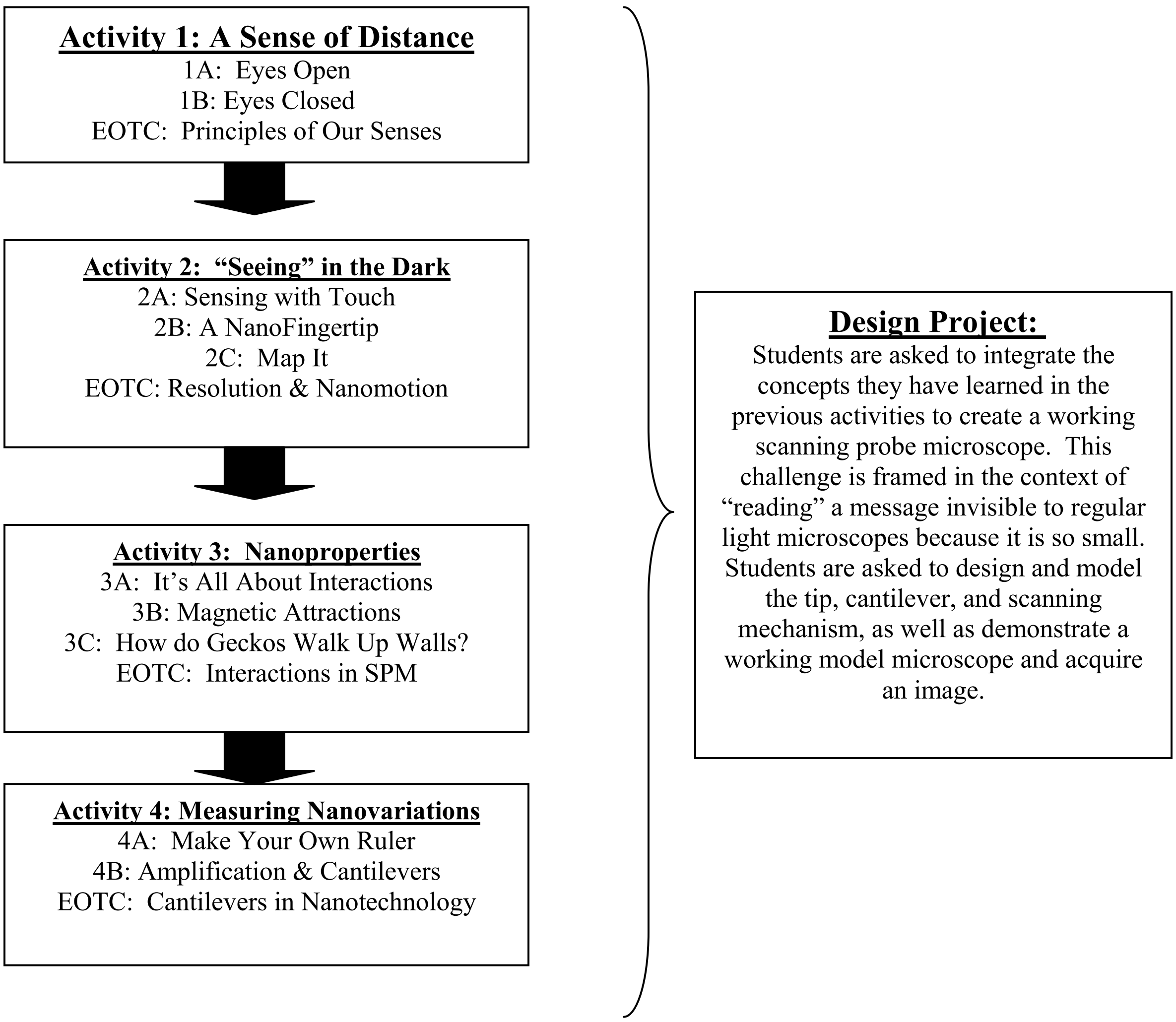

Figure 1: Progression of the Activities & Design Project

The entire NCM series is framed around teaching concepts in measurement. Activity 1, "A Sense of Distance," is intended to engage student interest and encourage students to begin thinking about measuring the world around them with senses other than sight. Sub-activity 1A, "Eyes Open," asks students to estimate the size of and distance to various objects around the room. Sub-activity 1B, "Eyes Closed," encourages students to explore measurement with their remaining sense of smell, sound, and touch. To directly connect this to the nanoworld, students "listen" to a yeast cell wall vibrating, an activity developed as an extension of work done by Professor James Gimzewski at UCLA.[11]

Activity 2, "Seeing in the Dark," focuses in on using the sense of touch to measure the world. In sub-activity 2A, "Sensing with Touch," students explore the process of reading a Braille pattern with their fingertips. Sub-activity 2B helps students to extrapolate this measurement process to the nanoscale by replacing the fingertip with ball bearings of various sizes which are traced over a pattern of LEGOs, as diagrammed in Figure 2.

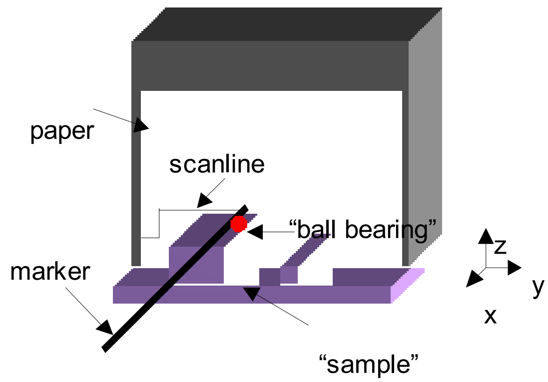

Figure 2: "Nanofingertip" Activity 2B

Finally, in sub-Activity 2C, "Map It" the students take data over a 3D LEGO sample, input and graph it in Excel, and analyze what they have created. The expanding on the concepts section describe the actual tips used in nanoscience to measure samples, as well discussing the important role that the tip plays in determining technique resolution.

In Activity 3, "Nanoproperties," students are guided through activities which help them to realize that there are many different properties that can be measured. In sub-activity 3A, "It's All About Interactions," students explore variations in texture, temperature, and elasticity of materials at the macroscale and extrapolate such variations to the nanoscale. Using their finger as a force sensor, students map out a magnetically patterned sample in sub-activity 3B. Finally, in "How Do Geckos Walk Up Walls," students explore electrostatic interactions in ZnO nanoparticles. The expanding on the concepts section of the instructional material, "Interactions in Scanning Probe Microscopy," explains the three fundamental ways a tip can be used to explore a sample: contact, intermittent contact, and non-contact.

Finally, Activity 4, "Measuring Nanovariations," introduces how the small variations in nanostructured samples are measured and amplified. First, to prompt the realization that different units are necessary for different length scales, students create their own ruler and measure the size of different objects in sub-activity 4A. In sub-activity 4B, "Amplification and Cantilevers," students measure the deflection of a styrofoam cantilever with varying masses using a laser spot deflected of the cantilever end onto the wall, depicted in Figure 3. The expanding on the concepts section discusses how a cantilever can be designed to meet specific sample measurement requirements.

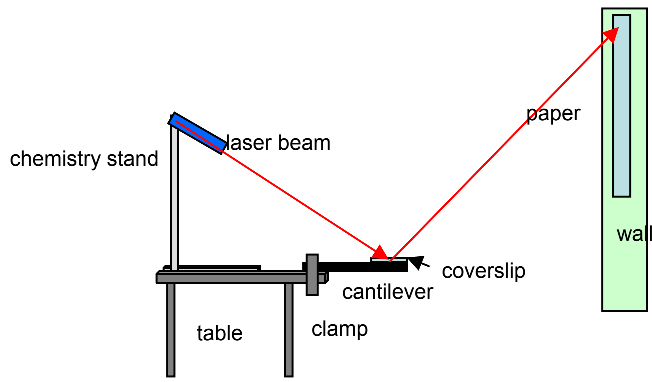

Figure 3: Set-up for measurement of cantilever deflection

The final design project is by far the most challenging, and most engaging portion of the instructional material, as it challenges students to integrate the concepts they have learned in the previous sections and create a working model of a microscope that can read an "invisible" magnetic message sent to them. Students are given this magnetic message and challenged to read it by developing a scanning probe microscopy technique that can detect what it says. Students are provided with a variety of tools including LEGOs, lasers, magnets, popsicle sticks, ball bearings, soda cans and scissors. By designing a cantilever, tip, and scanning and amplification mechanism, students are able to plot the data they acquire on Excel and read the hidden message.

Initial Results

We present some preliminary findings of a test of the design project below. The NCM in its entirety will be tested in high school classrooms in mid-February/early March 2006 at Schaumburg High School, and in May at Palatine High School, both in the state of Illinois. The results from these tests, in addition to those below, would be discussed in the presentation at the ASEE conference.

A prototype of design project portion of the instructional materials was tested at "Nano-Day," an activity hosted at Northwestern University aimed at introducing high school students to nanoscience and engineering. The activity involved building a LEGO atomic force microscope, and then taking an image with the microscope using Excel, see Figure 4. Students were provided with a variety of "samples" consisting of different wooden shapes representing atoms, nanostructured polymers, or lipid bilayers. Finally, after building and testing a model atomic force microscope, students were taken to see a real atomic force microscope in action. The LEGO atomic force microscope was originally developed at the University of Wisconsin-Madison[2]; the Excel-based mapping activities were developed by Nathan Unterman and Marcel Grdinic of Glenbrook North High School in the state of Illinois.

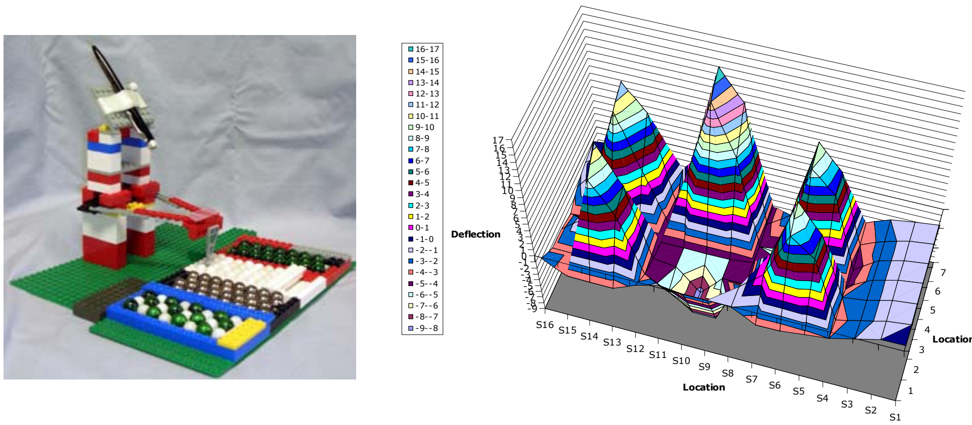

Figure 4: Prototype LEGO atomic force microscope (left) and Excel-based 3D map (right) developed by Nathan Unterman and Marcel Grdinic of Glenbrook North High School

The aim of the Nano-Day, in addition to providing the students with a fun and stimulating science experience, was to try and determine whether or not building a LEGO model atomic force microscope in a classroom setting was feasible, and whether or not it would engage student interest.

The design project appeared to engage students fully for the hour and all had acquired an image of their “sample” by the end of the lab. Students worked through several design challenges successfully, including laser mounting, cantilever length and flexibility, and sample stability. Each group came up with their own unique solutions to the problems. Many students were initially doubtful that what they were “doing it right” and did not believe that the data they collected would result in a final Excel image related to the sample structure.

Students determined their own scanning pattern, and experimented with the impact of the scanning pattern on the images acquired. Students also switched tip geometries to see what effect this had on imaging. At the end of the session, the students walked around and look at the images that the other groups had acquired; they discussed how well the image reflected what the sample actually looked like. In some cases, the images did not have a small enough resolution to resolve certain sample features.

This small test of the design project in a classroom setting suggests that students would find building a macroscopic model of the atomic force microscope engaging. When questioned, all of the students agreed that the model was a helpful and necessary component in understanding how the scanning probe microscope worked. An informal survey of student interest by teachers after completion of the activities was positive. Further work will involve a pre/post test to see what specific knowledge and understanding the students have gained about scanning probe microscopy from the activities, as well as their overall enthusiasm for science and engineering.

Mapping of Nano-Concept Materials to Standards

Since our NCM is designed to cover two weeks in a high school classroom, it is important that it link well with existing concepts as defined by the national science standards. Although teachers are more concerned with state standards than national, we map to national standards here first to provide a universally appropriate mapping. The table below defines the learning goals for each section of the NCM, and illustrates the link to both the National Science Education Standards (NSES) and Project 2061 standards. In addition, new nano-concepts introduced in the instructional materials but not found in the current standards are highlighted in the final column. The NCM align well with multiple standards, and are particularly relevant for high school physics classrooms. In addition, understanding how an atomic force microscope works may help students to better appreciate and understand the atomic nature and structure of matter, relevant for high school chemistry classrooms.

Instructional materials Section	Learning Goal(s)	Standards Link	New Nano-concepts
Activity 1: A Sense of Distance	Many ways to measure distance other than with eyes and ruler; concept of reference	NSES/5-8/B/3,a, c NSES/9-12/B/3, c, d NSES/9-12/B/4, a, b 2061/6-8/12B/5	A nano-nose can be used to detect small amounts of vapors. A nano-ear can be used to listen to small vibrations.
Activity 2: Perceiving with Touch	It is possible to use a touch-based sensing system to measure nanoworld.	NSES/5-8/B/3,f 2061/6-8/9B/3 2061/9-12/9B/4 2061/6-8/9C/6 2061/9-12/9E/4	Need nanoscale tip to measure nanoscale variations with touch; resulting image is combination of tip and sample
Activity 3: Nanoproperties	There are many different properties of interest at the nanoscale. The forces that dominate are different at nanoscale than they are at the macroscale.	NSES/9-12/B/2,c, d, e NSES/5-8/B/2, c 2061/6-8/9B/3 2061/9-12/9B/4 2061/6-8/9C/6 2061/9-12/12B/6 2061/9-12/11D/1	Electromagnetic forces dominate at nanoscale; gravity not important!
Activity 4: Measuring Nanovariations	Measurement and amplification of small signals is possible using cantilevers.	2061/6-8/12B/7, 8 2061/9-12/12B/6 2061/9-12/11D/1 2061/6-8/9D/5 2061/9-12/9E/5	A cantilever can be used to detect small variations in a sample
Design Project: Read an Invisible Message	Combine knowledge from previous sections to create a microscope that can read a message written with magnets	All those listed above as well as: 2061/6-8/11B/1,3 Models 2061/6-8/12D/3 & 2061/9-12/12D/7, Communication Skills	Messages that are "invisible" because they are so small can be read by a scanning probe microscope.

Initial field tests of the NCM will show if the two week format is appropriate for high school classrooms, and what sort of burden introducing this two-week program would place on high school teachers.

Future Directions

Initial results suggest that macroscopic models were successful in facilitating student understanding of how a scanning probe microscope works. Further testing of the entire instructional materials series in a classroom will help to determine the effectiveness of the hands-on activities which have been developed, and will take place in late February and early May. A more extensive assessment will help to determine how well the activities are helping students to learn nanoconcepts. After incorporating changes recommended by initial field tests, a nation-wide test could commence in the early fall of 2006.

Acknowledgments

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