How do you know it's there if you can't even see it?

A lesson on scanning probe microscopy

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Content Area: General/Chemistry/Physics
Grade Level: 7-12

LESSON OVERVIEW

Estimated Time of Lesson: approx. 4 hours

Lesson Description

- Topic: Scanning Probe Microscopy (SPM), specifically atomic force microscopy (AFM) and magnetic force microscopy (MFM)
- How the topic is contextualized: It is initially conceptualized in what tools (types of rulers or instruments) students would use to measure everyday objects. This is to get students thinking of how we can measure things to small to be seen with our eyes.
- Importance of the topic: This topic is important to the realm of nano as SPM is a critical instrument to visualizing objects at the nanoscale, specifically SPM can allow images to be produced at the atomic-scale.
- Connection of the topic to other science concepts: SPM relates to other units of microscopy. SPM is just taking microscopy units a step further in developing students' knowledge of how we can see objects that are even smaller than an optical microscope can see. It also connects to the evolution of science in that we are now better able to visualize objects that we could previously not see.
- Description of what the students will do to investigate the topic: Students begin the lesson by describing what types of tools they would use to measure a variety of everyday objects, and then discuss what they could use to measure nano-objects. Students then progress through a series of four activities: scanning probe microscopy in which students determine a pattern using touch; atomic force microscopy in which students test different probe tips, design their own probe, and create a 3-D scan; hopping magnet in which students model MFM using a refrigerator magnet and map the magnetism of a refrigerator magnet; and magnetic mapping in which students use magnetic probes to map a surface.

Learning Goals

- Students will be able to describe the basic concept of scanning probe microscopy, how it works, why it is important, and why it is useful.
    - Scanning Probe Microscopy (SPM) is a general term encapsulating both atomic force microscopy (AFM) and magnetic force microscopy (MFM) among others. SPM gives images of the surface of the sample by using a physical probe that "feels" the surface, instead of "looking" at the surface.

  - AFM: A type of SPM that maps the topographic surface of the sample by measuring differences in forces as the probe scans.
  - MFM: A type of SPM that maps the magnetism distribution in a sample by measuring the magnetic interaction between sample and tip. The tip is functionalized with magnetic materials.
- Students will be able to conclude why a scanning probe microscope is used to visualize nano-sized materials, as well as atoms, rather than a light (optical) microscope.
  - The wavelength of light is bigger than nano-sized materials and atoms and therefore atoms are molecules cannot be seen using light. We have to use SPM to see nano-sized materials and atoms rather than a light microscope because because nano-sized materials and atoms (0.1-100 nm) are smaller than the wavelength of light (400-700 nm) therefore light waves do not "see" the nano-sized materials and atoms and therefore we cannot see them. We need to use a comparable measuring device of what we want to measure, so using SPM with a tip just a few atoms wide to measure nano-sized materials and atoms is best.
- Students will be able to determine that the size and stiffness of the probe in relation to the sample and the speed of scan affects the end result of the image.
  - For example, a small, stiff tip should be used to scan a "hard" surface, such as metal atoms. The tip should correlate to the size of what you want to "see" so if you want to "see" the resolution of atoms, the tip should be composed of only a few atoms. The faster the scan the lower the resolution.
- Students will be able to determine magnetic surfaces (polarity) and how polarity affects a magnet.
  - Refrigerator magnet surfaces are composed of strips of North and South polarity.
  - Like polarity repel and opposite polarity attracts.

Big Ideas in Nano

- Tools and Instrumentation: Development of new tools and instruments helps drive scientific progress. Recent development of specialized tools has lead to new levels of understanding of matter by helping scientists detect, manipulate, isolate, measure, fabricate, and investigate nanoscale matter with unprecedented precision and accuracy.
  - This lesson relates to tools and instrumentation as SPM is a newly developed tool that has advanced science and technology by allowing the scientific community to visualize objects at the atomic and nano-scales.
- Forces: All interactions can be described by multiple types of forces, but the relative impact of these forces change with scale. On the nanoscale, a range of electrical forces with varying strengths tend to dominate the interactions between objects.

- This lesson relates to the big idea of forces as magnetic and atomic forces are key components of MFM and AFM.

Standards

- Indiana State Standards

  Grade 7: 7.1.2, 7.1.7, 7.1.9, 7.1.10, 7.2.7, 7.3.19, 7.5.3, 7.7.2

  Grade 8: 8.1.6, 8.1.8, 8.2.5, 8.2.6, 8.2.7, 8.2.8, 8.3.8, 8.3.18, 8.5.4, 8.5.5, 8.7.3

  Chemistry: None Stated

  Physics: None Stated

  Integrated Chemistry – Physics: CP.1.22, CP.1.31

- National Science Education Standards

  Content Standards 5-8

  Content Standard A: Science as Inquiry

  Content Standard E: Science and Technology

  Content Standards 9-12

  Content Standard A: Science as Inquiry

  Content Standard B: Physical Science

  Content Standard E: Science and Technology

- Benchmarks for Science Literacy-Project 2061

  Grades 6-8

  1B: The Nature of Science – Scientific Inquiry

  1C: The Nature of Science – The Scientific Enterprise

  3A: The Nature of Technology – Technology and Science

  3B: The Nature of Technology – Design and Systems

  3C: The Nature of Technology – Issues in Technology

  4D: The Physical Setting – Structure of Matter

  4F: The Physical Setting – Motion

  4G: The Physical Setting – Forces of Nature

  9C: The Mathematical World – Shapes

  11B: Common Themes – Models

  12C: Habits of Mind – Manipulation and Observations

  12D: Habits of Mind – Communication Skills

  Grades 9-12

  3A: The Nature of Technology – Technology and Science

  4F: The Physical Setting – Motion

4G: The Physical Setting – Forces of Nature

8B: The Designed World – Materials and Manufacturing

12B: Habits of Mind – Computation and Estimation

12C: Habits of Mind – Manipulation and Observations

12D: Habits of Mind – Communication Skills

LESSON PREPARATION

Teacher Background Content Knowledge

- This is an interesting area because it teaches students about how we can see objects too small to see with an optical microscope.
- Scanning Probe Microscopy (SPM) is a general term encapsulating both atomic force microscopy (AFM) and magnetic force microscopy (MFM) among others. SPM gives images of the surface of the sample by using a physical probe that "feels" the surface, instead of "looking" at the surface.
- AFM: A type of SPM that maps the topographic surface of the sample by measuring differences in forces as the probe scans.
- MFM: A type of SPM that maps the magnetism distribution in a sample by measuring the magnetic interaction between sample and tip. The tip is functionalized with magnetic materials.
- There are various modes of operation for an SPM:

Mode of Operation	Force of Interaction
contact mode	strong (repulsive) - constant force or constant distance
non-contact mode	weak (attractive) - vibrating probe
intermittent contact mode	strong (repulsive) - vibrating probe
lateral force mode	frictional forces exert a torque on the scanning cantilever
magnetic force	the magnetic field of the surface is imaged
thermal scanning	the distribution of thermal conductivity is imaged

Student Prior Knowledge Expectations

- None

Potential Student Alternative Ideas

- You have to be in contact with the surface in order to feel or map it.
    - The simulations should help students to understand that you don't actually have to be in contact with the surface.

Potential Student Difficulties

- Creating the probe measuring device.
    - Students tend to mark the probe with zero even with the box, put then put their next measurements going up on the probe. Students will not be able to measure this way, and need to figure out that their probe will need to have measurements going down.
- Performing the 3-D scan
    - Students tend to have difficulties in determining how to set up their data tables to get the information they need as they will need information in the x, y, and z directions. Showing them a picture of the Lego® board with the 3x3 quadrants may assist in their understanding.
- Graphing the 3-D information
    - If students are familiar with computers and Excel, this is usually not a big difficulty. Students just need to input their information as they have on their data tables. They can then use whatever graph they would like…students will eventually determine which graph they like best (bar or surface).

Materials: *Activity 1-SPM (individual)*

Item	Number/Amount
5" x 5" piece of cardboard (around this)	1/group
Blank paper	1/group
Scotch tape	Several rolls

Materials: *Activity 2-AFM (groups of 2-3)*

Item	Number/Amount
Legos (small and/or medium)	~20 pieces/group (to make sample)
Flat lego board (green one; 10x10)	1/group
4 cm and 1.2 cm cube	1 each/group
4 cm and 1.2 cm ball	1 each/group
2.5 cm pom-pom	1/group
Styrofoam peanut	1/group
Cotton ball	1/group
Probe with attached pen, pencil, or marker	1/group (pre-constructed)
Small magnets***	Enough to attach tips to probe
8 x 8 Cardboard box (only need 4 sides)	1/group
1in x 10in pieces of wood	8 to cover top of box
Velcro	To attach wood to box
Craft materials for kids to make probes	A bunch
Computers with Microsoft Excel	1/group
Graph paper	If computers are not available
Colored pencils/crayons	If computers are not available

***The small magnets should be glued onto the end of the probe and onto each tip sample that students will use. Be sure to glue the magnets so that the tips will magnetically attach to the end of the probe.

Materials: *Activity 3-The Hopping Magnet (individual)*

Item	Number/Amount
Scissors	1 pair per student
Magnetic business cards (office supply store)	1 per student

Materials: *Activity 4-Magnetic Force Microscopy Simulation (groups of 2-3)*

Item	Number/Amount
Masking tape	Several rolls
Small flat permanent magnets	9-12 per group (differing sizes/forces)
10 x 10 piece of cardboard (or Lego® board)	1 per group
Graph paper	2 sheets per student

Cautions/ Potential Pitfalls

- Students may have difficulties in performing the 3-D scan and graphing their 3-D scan.

Pre-Class Preparation

Getting the Materials Ready

- Have materials set up on tables or lab benches for students to use in groups.

Safety Issues

- None

Doing the Lesson

Opening

- What would you use to measure the following:
  - The length of an ant?
  - The length of a football field?
  - The height of an adult?
  - The distance of the United States from the Pacific to the Atlantic oceans?
  - The diameter of an animal cell?
  - The distance from the Earth to the moon?

NOTE: Have these questions on the board for students to answer in the beginning of class. It will get students thinking of different measurement tools, and what to use to measure various objects.

- After students respond, ask for answers and then ask students why they put that measurement tool instead of something else.

    - For example, student may say they will use a yard stick to measure a football field. Ask why they would not use a 12 inch ruler. Or ask why they would not use a yard stick to measure the length of an ant.
    - You want to get students to understand that they need to use measurement tools that are appropriate for what is being measured.
- After the brief discussion on appropriate measurement tools have students answer the following:
    - We are not able to use a light microscope to see atoms and molecules. Suggest some reasons why this occurs.
    - Also, suggest other ways in which we may be able to "see" these atoms and molecules.

NOTE:

- Students should have an idea from the previous opening, that light may be too large to see the atoms and molecules, however, a pre-lab discussion about why light is not able to be used to see atoms and molecules would be helpful. Students should be able to understand that the atoms and molecules are too small to be seen with a light microscope so we need to use other techniques to "see" them.
    - Light cannot be used to "see" atoms because atoms are too small for visible light waves. Showing the electromagnetic spectrum so students can see the size of the wave and then give them the size of atoms so they will understand.

Body

This lesson consists of a series of four activities to help students learn about scanning probe microscopy in general and more specifically to teach them about atomic force microscopy and magnetic forces microscopy. Activity 1 introduces the idea of seeing by touch rather than by sight and some of the difficulties that can ensue from using touch to see. Activity 2 introduces the concept of atomic force microscopy. It begins by having students test different types of probe tips, followed by students designing their own probe tip, and concluding with students performing a 3-D scan of a surface. Doing all three aspects of this activity helps students to develop a better understanding of what types of probes are good and bad and why as well as developing an understanding of atomic force microscopy. Activities 3 and 4 are both related to magnetic force microscopy. These activities follow activities 1 and 2 as MFM is another type of SPM; however this looks at magnetic forces of the surface rather than the topography of the surface.

Activity 1-Scanning Probe Microscopy (individual)

1. This activity allows students to simulate scanning probes with their finger and punching holes in cardboard. It is much like "reading" a Braille pattern in this activity.
2. See the "Scanning Probe Microscopy" Student Worksheet.

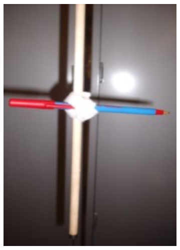
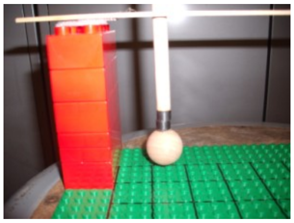
1. You can have the depressions made in the cardboard already instead of having the students make the depressions. This will save time in the classroom.
2. Students will do 4 scans. Two scans will be with tape on both sides of the cardboard and two scans will be without tape on both sides of the cardboard.

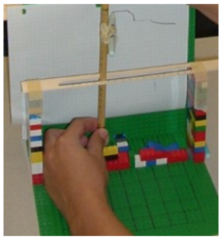
3. Allow students work on the activity with little outside influence, however, teachers should still have discussions with students throughout the lesson about what their findings are.
4. Have a discussion about the conclusion questions, especially the final question about how this model relates to scanning probe microscopy.
    1. Most students will find that when their finger is taped they are not as able to feel the bumps and depressions in the cardboard. This is due to a lack of elasticity when tape is added to the finger. Students will not be able to get all of the bumps/ depressions represented in most cases, especially if the bumps/ depressions were small or not punched all the way through the cardboard.
        i. Note: some students may do better with the tape, but they usually do not have the tape completely over their finger and rather have a little bit that can make a "sharp" point therefore allowing them to feel more of the bumps/ depressions.
    2. The scan with the bare finger is usually close to the actual bump pattern, although students will probably still be missing several depressions, especially depending upon which side of the cardboard was used. There is most often more detail and more bumps seen with the bare finger as opposed to the tape finger. Students should discuss the differences between their images here to back up their statements.
    3. When you cover your finger you are losing your ability to feel as some of the nerves are being covered up. Also, your finger no longer as the elasticity to go into small holes as the tape is holding it tight.
    4. The slight depressions are harder to sense than the larger depressions.
    5. The side of the cardboard affects the scan. The side in which the depressions were made usually has more depressions on it than the other side as some of the holes are not punched all the way through. However, the side in which the holes are raised up is easier to feel.
        i. Students also comment that the side in which the bumps are raised is more like atoms than the other side because the atoms would be raised up on the surface.
        ii. This is also a point where you can show that there may be stuff below the surface that we are still unable to see. That by scanning with an SPM, we are still only able to visualize the surface of the material.

6. This model of SPM relates to SPM in that both are touch-based. In this model, students scanned the surface of the sample (most likely in an orderly fashion (line-by-line)) by touch in order to determine what the surface image was. In SPM, a tip is scanned back and forth across the surface to determine what the surface looks like. Therefore, the tip for SPM is the same as the finger in this model.

Activity 2-Atomic Force Microscopy (groups of 2-3)

1. This activity will allow students to simulate an AFM using contact techniques. They will have to determine the best probe tip to be used and then design their own probe, scan the surface, and then plot the surface of their sample using Excel.
    a. If Microsoft Excel is not available, it can be plotted using graph paper and colored pencils.
2. See “Atomic Force Microscopy” Student Worksheet.
    a. Students will need to set up the AFM apparatus. This includes getting a probe, probe stand, Lego® board, probe tips, and several small Legos®. The apparatus can be set-up as shown in the pictures below. Students should set-up the probe stand near the edge of the Lego® board and near a wall so they can tape a piece of paper to the wall and do their scans to test the various tips.



    b. After the apparatus is set-up. Students should test various tips to determine the best probe tip. They will find that the large ones do not allow for very much detail; the hard ones are sometimes difficult to move and may break their sample; the soft ones may not give very good detail because it may change depending upon the pressure put on the probe. Students should find that the smaller tips are better and that the type of tip should depend upon the sample.
        i. The probe should have a magnet on the end of it that will attach to different probe tips that also have magnets on them. Having magnets on both the probe and tips allows for quick changes of the tips saving time.

c. Based upon their results, students will design and create their own probe tip.

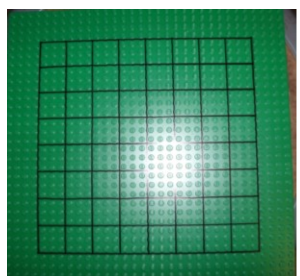
    i. Many students choose to use something small and hard, such as a pen, pencil, or paperclip. Other students choose to use something of similar size to what they are measuring, such as a 1x1 Lego®. Still others have decided that they want their tip to have a little bit of give, but still be slightly hard and they want it to be small, so they have used the eraser from the pencil.

    ii. The point here is to let students design their own using evidence that they gathered earlier as to what the best tip was for them. They should also test this tip and compare it to the tips they tested earlier.

d. Students will then take their newly created probe and scan a 3-D sample.

e. To create a 3-D sample, follow the directions below. It is recommended that the samples be pre-made for the students to save on time.

    i. Create 3x3 quadrants on the Lego® board.



    ii. Build your sample.

        1. Inside each 3x3 quadrant, the height needs to be the same. Be sure that each 3x3 square contains the same height throughout.

        2. Not all quadrants need to be filled.

        3. Quadrants next to each other can be the same height.

    iii. Cover the sample with the cardboard box and 1x10 balsa wood pieces.

f. To do a 3-D scan, follow the advice below:

    i. Create a data table.

        1. The data table needs to have room for each measurement that you will make. You will make 8 measurements during each pass and you will make 8 passes.

ii. Remove the first wood strip.

iii. Insert your probe.

1. The probe will need to have ruler markings on it in order to record the height of the sample.

iv. Make your first pass and measurements.

1. In each quadrant as shown on the top of the box, you will need to make a height measurement of your probe and record it in your data table.

v. Replace the wood strip and remove the second strip.

vi. Repeat steps 3-5 until all passes have been made.

vii. Create a 3-D Excel graph.

3. During the time that the students are testing, designing, and creating their probe tips, small group discussions should be going on that are facilitated by the teacher. Questions that could be asked towards students are:

   a. What tips are better than others? Why?

      i. Smaller and harder tips tend to be better for the Lego® sample has Legos® are small and hard as well.

   b. Is there any reason to pick a certain tip over another one?

      i. You would pick a certain tip depending upon the resolution that you need for the project. If you have to have a really high resolution, then you should have a very small tip. If resolution is not super important, then a bigger tip can be used. Also, it will depend upon the sample.

   c. How does the hardness of the tip affect the sample?

      i. The hardness can affect the sample. For example, in biological systems, a hard tip can ruin the sample because it is much harder than the sample. Depending upon the research this is OK, but other times it is not and the researchers need to use softer tips.

   d. Does the speed in which you scan affect your results? May it affect results in an actual AFM?

      i. The slower you scan, the more accurate your results will be. In the AFM, the slower the scan, the more data points that are being collected giving you more information and a better idea of what the surface of the sample looks like.

Follow-up

1. Simulations of Scanning Probe Microscopy

   a. The websites in the table below provide information and simulations about various types of SPM for more advanced learning. The Wisconsin MRSEC site also has good information about SPM which students can include in their posters.

Simulation Name	Website
Contact mode	http://www.ntmdt.ru/SPM-Techniques/Principles/AFM/dc_Contact_techniques/Constant_Force_mode_mode9.html
Intermittent contact mode	http://www.ntmdt.ru/SPM-Techniques/Principles/AFM/Semicontact_techniques/Semicontact_mode_mode28.html
Non-contact mode	http://www.ntmdt.ru/SPM-Techniques/Principles/AFM/Non-Contact_techniques/Non-Contact_mode_mode57.html

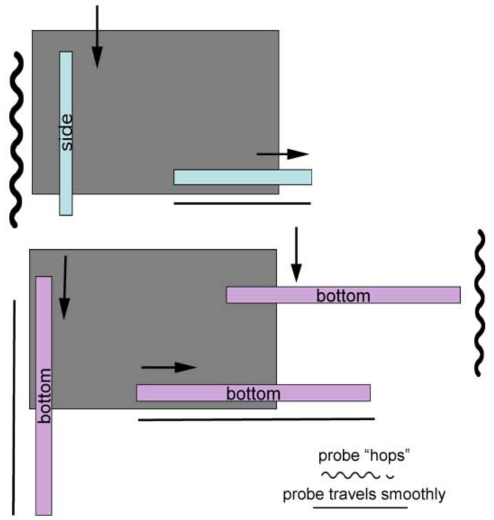
2. Go back to opening question about light microscopes compared to scanning probe microscopes and have students re-evaluate their original responses. They should now be able to make a more scientific response.
3. Ask students to describe in a discussion what SPM is, how it works, and why it is useful, specifically in regards to AFM.

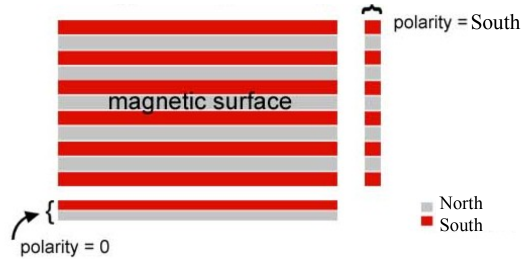
Introduction to activities 3 and 4

- Have students answer the following questions before doing the activities:
    - Consider how magnets may be produced.
    - What causes some materials to be magnetic?
    - You are told that you should not put magnets near computer hard drives since it will erase your data.
        - Why would this happen?
        - How can you measure the magnetic surface of a computer hard drive?

Activity 3 – The Hopping Magnet (Individual)

1. See "The Hopping Magnet" Student Worksheet
    a. This activity allows students to investigate the magnetic surface of a single magnet and how cutting in different directions affects hopping.
    b. This is a lead-in activity to magnetic force microscopy.
2. Students should be able to make the observation as seen in the sketches below and should conclude that the magnet is made up of positive and negative polarity strips which cause the magnet to hop in certain directions and slide in others.





3. During the activity, teachers should be walking around talking to the students and asking them questions about what they think the magnetic properties of the magnet are.
4. You should also have a discussion about the conclusion questions.
    a. The magnet hops due to repulsion and attraction between the poles.
    b. The magnet hops in some directions because it is actually changing between north and south poles. It does not hop at times because the poles can cancel each other out.
    c. The diagram above is a representation of what the back of a refrigerator magnet may look like. The poles may also be changed to vertical instead of horizontal depending upon the magnet.

Activity 4 – Magnetic Force Microscopy Simulation (Groups of 2-3)

1. See "Magnetic Mapping" Student Worksheet
    a. To shorten the activity, you can have pre-made magnetic samples.
2. During the activity, teachers should ask students what is happening as they are going through the mapping of the sample.
3. A discussion should follow the students answering the conclusion questions.
    a. The magnetic probe becomes attracted to and repelled by the sample depending upon the magnetic surface. Some parts are very strong and others are not. Also, you can feel the magnetism around the edge of the large magnets in addition to the center of the magnet.
    b. The magnetic probe works well as a magnetic force sensor. The probe moves pretty much on its own depending upon the strength of the magnets.
    c. The probe was either very attracted to or repelled by the magnets.
    d. This will depend on whether or not a pattern was made.

e. This will vary as well.
f. This will vary. Students just need to be able to explain and justify their answers.
g. Another way to functionalize the probe tip could be with a heat sensor. This would get at the thermal conductivity.
h. MFM works by measuring the magnetic properties of the surface. The tip is functionalized with a magnet and the tip is dragged over the surface to determine the magnetic properties.

Follow-up

1. Hold a class discussion. What did they find difficult in performing MFM? How could they tell differences in magnets? How can this relate to the touch based microscopes studied earlier?
2. Give each student group a board with a pattern. The pattern should be something common that all the students will recognize, but with a magnet or two out of place. This will allow the teacher to easily see if the students are scanning the entire board thoroughly of if they are just looking for a pattern and when they think they have it, they just draw what they believe the rest to be.

Wrap-Up/ Assessments

1. Why do you have to use a scanning probe microscope instead of a light microscope to visualize atoms and molecules?
2. What are some properties that scanning probe microscopes measure?
3. *Poster Assignment:* Have students (individually or in a group) create a poster about SPM. This poster should explain what SPM is, how it works, why it is helpful, and the various types of SPM and how various information can be gathered dependent upon the microscope. Students should include why scientists use a SPM to visualize atoms and molecules rather than a light microscope. The students will need to be able to communicate this information to a large population range including younger students, peers, and parents. Tables, figures, and diagrams should be included to explain the science and make it more aesthetically pleasing. It would be nice to have a poster night where the parents come to school and are able to learn about SPM from students.

   OR

   Writing Assignment: Using what you have learned in this activity, as well as any other resources (Internet, books), write a one page article describing SPM, what it is used for, why it is useful, and the various types of SPM. They should discuss how the various types of SPM give different information about the sample. This article should be written as if it will be included in the local newspaper. They will need to be careful of using too many technical terms in their writing, and when they do use a technical term, they should be sure to explain what it means. They many also want to include a brief paragraph of what nanotechnology is and its uses.

RESOURCES

- Exploring the Nanoworld with LEGO® Bricks: Chapter 2 – Probing the Structure of Materials at the Nanoscale. MRSEC, University of Wisconsin – Madison http://mrsec.wisc.edu/Edetc/LEGO/PDFfiles/bookchap2.PDF
- Exploring the Nanoworld: Materials Science and Nanotechnology Modules for K-12 Science. MRSEC, University of Wisconsin – Madison. (2002). Mapping the Unknown: Atomic Force Microscopy and other Scanning Probe Microscopy Techniques. http://mrsec.wisc.edu/Edetc/modules/MiddleSchool/SPM/MappingtheUnknown.pdf
- Exploring the Nanoworld: Materials Science and Nanotechnology Modules for K-12 Science. MRSEC, University of Wisconsin – Madison. (2002). Mapping an Unknown Surface. http://mrsec.wisc.edu/Edetc/modules/MiddleSchool/SPM/Mapping.xls
- MRSEC, University of Wisconsin – Madison Homepage. **http://mrsec.wisc.edu/Edetc/**
- Refrigerator Magnet Activity Guide by MRSEC Education and Outreach, University of Wisconsin – Madison http://mrsec.wisc.edu/Edetc/ActivityGuides/Refrig_Magnet_Guide_2005.pdf

SUPPLEMENTAL MATERIALS

Summary of lesson:

This lesson is designed for 7-12 grade students to gain an understanding of what scanning probe microscopes (SPM) are, what they do, and how they work. Students should also learn why scanning probe microscopes need to be used instead of the optical microscopes they use in their classrooms. Students will investigate two specific kinds of SPM: atomic force microscopy (AFM) and magnetic force microscopy (MFM). There is a design aspect in this lesson as students will investigate various probe tips and will have to determine what the best probe tip is (small and stiff) for their Lego® "sample." Students will then design their own probe to create a 3-D scan of their "sample." During the lesson, students should also learn that the probe tip depends on the sample being tested and that if they were using a different sample, they would need a different tip.

In the beginning of the lesson, students are given a series of objects and are asked what they would use to measure each object. This is to get students thinking that they need to use appropriate measurement tools to measure various objects. Students are then told that "we are not able to use a light microscope to see atoms and molecules. Suggest some reasons why this occurs. Also, suggest other ways in which we may be able to "see" these atoms and molecules." Students should record their answers in their notebooks. As students may not have an understanding of why we cannot use light to visualize atoms and molecules, a brief lecture/ discussion would be helpful to explain that light waves are bigger than atoms and molecules.

The activities begin with students using their finger as a probe to "see" the surface of a piece of cardboard. This is a simulation of how a scanning probe works. As another

SPM model, specifically AFM, students use a wooden dowel with different tips attached to investigate which probe tip is the best to scan a Lego® surface. After this investigation, students design their own probe using tips investigated or a tip they believe will be better. The design project ends with students testing their probe through a 3D scan of a Lego® surface they cannot see with their eyes (the sample is covered with a box). Students will plot their scan using the computer (Microsoft Excel). Following the design project, students investigate various scanning probe simulations on the Internet.

Students then continue with SPM with learning about MFM. Students perform an investigation using a magnetic business card. They are to determine how the magnetic business card is designed by cutting off a side and bottom piece of the magnet. Students will learn that depending on the piece cut off and the direction in which they drag the sliver, they can make the sliver hop. The activity continues with a magnetic force microscopy simulation in which students functionalize a probe with a magnet and scan a pre-designed magnetic surface to determine the magnetic layout. A large group discussion occurs to discuss their knowledge of magnets and magnetic force microscopy.

As an assessment activity, students are to research SPM and create a poster or newspaper article describing SPM, what it is used for and why it is useful. Students should also give a brief description of nanotechnology in the article.

Standards:

- Indiana State Standards

  Grade 7

  7.1.2 – Explain that what people expect to observe often affects what they actually do observe and provide an example of a solution to this problem.

  7.1.7 – Explain how engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems.

  7.1.9 – Explain how societies influence what types of technology are developed and used in fields such as agriculture, manufacturing, sanitation, medicine, warfare, transformation, information processing, and communication.

  7.1.10 – Identify ways that technology has strongly influenced the course of history and continues to do so.

  7.2.7 – Incorporate circle charts, bar and line graphs, diagrams, scatterplots, and symbols into writing, such as lab or research reports, to serve as evidence for claims and/or conclusions.

  7.3.19 – Explain that human eyes respond to a narrow range of wavelengths of the electromagnetic spectrum.

  7.5.3 – Demonstrate how the scale chosen for a graph or drawing determines its interpretation.

  7.7.2 – Use different models to represent the same thing, noting that the kind of model and its complexity should depend on its purpose.

  Grade 8

  8.1.6 – Identify the constraints that must be taken into account as a new design is developed, such as gravity and the properties of the materials to be used.

8.1.8 – Explain that humans help shape the future by generating knowledge, developing new technologies, and communicating ideas to others.

8.2.5 – Use computers to store and retrieve information in topical, alphabetical, numerical, and keyword files and create simple files of students' own devising.

8.2.6 – Write clear, step-by-step instructions (procedural summaries) for conducting investigations, operating something, or following a procedure.

8.2.7 – Participate in group discussions on scientific topics by restating or summarizing accurately what others have said, asking for clarification or elaboration, and expressing alternative positions.

8.2.8 – Use tables, charts, and graphs in making arguments and claims in, for example, oral and written presentations about lab or fieldwork.

8.3.8 – Explain that all matter is made up of atoms which are far too small to see directly through an optical microscope. Understand that the atoms of any element are similar but are different from atoms of other elements. Further understand that atoms may stick together in well-defined molecules or may be packed together in large arrays. Also understand that different arrangements of atoms into groups comprise all substances.

8.3.18 – Investigate and explain that electric currents and magnets can exert force on each other.

8.5.4 – Illustrate how graphs can show a variety of possible relationships between two variables.

8.5.5 – Illustrate that it takes two numbers to locate a point on a map or any other two-dimensional surface.

8.7.3 – Use technology to assist in graphing and with simulations that compute and display results of changing factors in models.

Chemistry

None Stated

Physics

None Stated

Integrated Chemistry – Physics

CP.1.22 – Recognize and explain that whenever one object exerts a force on another, an equal and opposite force exerted back on it by the other object.

CP.1.31 – Realize and explain that moving electric charges produce magnetic forces, and moving magnets produce electric forces.

- National Science Education Standards

Content Standards 5-8

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E: Science and Technology

- Abilities of technological design.

- Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

Content Standards 9-12

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. These effects help students to understand electric motors and generators.

Content Standard E: Science and Technology

- Abilities of technological design (all)
- Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.

- Benchmarks for Science Literacy-Project 2061

Grades 6-8

1B: The Nature of Science – Scientific Inquiry

- What people expect to observe often affects what they actually do observe. Strong beliefs about what should happen in particular circumstances can prevent them from detecting other results. Scientists know about this danger to objectivity and take steps to try and avoid it when designing investigations and examining data. One safeguard is to have different investigators conduct independent studies of the same questions.

1C: The Nature of Science – The Scientific Enterprise

- Computers have become invaluable in science because they speed up and extend people's ability to collect, store, compile, and analyze data, prepare research reports, and share data and ideas with investigators all over the world.

3A: The Nature of Technology – Technology and Science

- Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

3B: The Nature of Technology – Design and Systems

- Design usually requires taking constraints into account. Some constraints, such as gravity or the properties of the materials to be used, are unavoidable. Other constraints, including economic, political, social, ethical, and aesthetic ones, limit choices.

3C: The Nature of Technology – Issues in Technology

- Societies influence what aspects of technology are developed and how these are used. People control technology (as well as science) and are responsible for its effects.

4D: The Physical Setting – Structure of Matter

- All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.

4F: The Physical Setting – Motion

- Something can be "seen" when light waves emitted or reflected by it enter the eye—just as something can be "heard" when sound waves from it enter the ear.
- Human eyes respond to only a narrow range of wavelengths of electromagnetic radiation—visible light. Differences of wavelength within that range are perceived as differences in color.

4G: The Physical Setting – Forces of Nature

- Every object exerts gravitational force on every other object. The force depends on how much mass the objects have an on how far apart they are. The force is hard to detect unless at least one of the objects has a lot of mass.
- Electric currents and magnets can exert a force on each other.

9C: The Mathematical World – Shapes

- The graphic display of numbers may help to show patterns such as trends, varying rates of change, gaps, or clusters. Such patterns sometimes can be used to make predictions about the phenomena being graphed.
- The scale chosen for a graph or drawing makes a big difference in how useful it is.

11B: Common Themes – Models

- Different models can be used to represent the same thing. What kind of a model to use and how complex it should be depends on its purpose. The usefulness of a model may be limited if it is too simple or if it is needlessly complicated. Choosing a useful model is one of the instances in which intuition and creativity come into play in science, mathematics, and technology.

12C: Habits of Mind – Manipulation and Observations

- Use computers to store and retrieve information in topical, alphabetical, numerical, and key-word files, and create simple files of their own devising.

12D: Habits of Mind – Communication Skills

- Organize information in simple tables and graphs and identify relationships they reveal.
- Read simple tables and graphs produced by others and describe in words what they show.
- Locate information in reference books, back issues of newspapers and magazines, compact discs, and computer databases.

Grades 9-12

3A: The Nature of Technology – Technology and Science

- Technological problems often create a demand for new scientific knowledge, and new technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research. The very availability of new technology itself often sparks scientific advances.

4F: The Physical Setting – Motion

- Whenever one thing exerts a force on another, an equal amount of force is exerted back on it.

4G: The Physical Setting – Forces of Nature

- Magnetic forces are very closely related to electric forces and can be thought of as different aspects of a single electromagnetic force. Moving electro charges produce magnetic forces and moving magnets produce electric forces. The interplay of electric and magnetic forces is the basis for electric motors, generators, and many other modern technologies, including the production of electromagnetic waves.

8B: The Designed World – Materials and Manufacturing

- Increased knowledge of the molecular structure of materials helps in the design and synthesis of new materials for special purposes.

12B: Habits of Mind – Computation and Estimation

- Use computer spreadsheet, graphing, and database programs to assist in quantitative analysis.

12C: Habits of Mind – Manipulation and Observations

- Use computers for producing tables and graphs and for making spreadsheet calculations.

12D: Habits of Mind – Communication Skills

- Make and interpret scale drawings.
- Participate in group discussions on scientific topics by restating or summarizing accurately what other have said, asking for clarification or elaboration, and expressing alternative positions.
- Use tables, charts, and graphs in making arguments and claims in oral and written presentations.