AC 2007-1686: INCORPORATING NANOSCALE SCIENCE AND ENGINEERING CONCEPTS INTO MIDDLE AND HIGH SCHOOL CURRICULA

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Incorporating Nanoscale Science and Engineering Concepts into Middle and High School Curricula

Abstract

This study is a first step in the investigation of the issues involved with incorporating nanoscale phenomena concepts in the middle- and high-school curricula. During a two-week summer workshop held by the National Center for Learning and Teaching Nanoscale Science and Engineering (NCLT) at Purdue University, lessons and activities on nanoscale phenomena as well as suggestions for incorporation into curricula and the relationship of these activities to both National and Indiana State Standards were presented and discussed. At the completion of the experience, the twelve participating teachers created lesson plans that they intended to use in their classrooms as a result of their experiences at the workshop. The lesson plans were collected and serve as the qualitative data contributing to this study. They allow for an in-depth exploration of where and how nanoscale phenomena concepts can be incorporated into current middle- and high-school curricula. Analysis of the data reveals difficulties in this incorporation and guides further development of the NCLT professional development experience.

Background

As the impetus for teaching nanoscale phenomena in middle- and high-school classrooms grows,[1,2,3] the question becomes how this integration is to take place. Literature that answers these questions are sparse and unspecific, thus a need exists for investigation. As a means to facilitate the inclusion of nanoscale science and engineering in secondary school classrooms, the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) has formed.[1] This work of this center includes the development of classroom materials, the offering of professional development opportunities, and research on both aforementioned tasks as well as student conceptions and capabilities of understanding nanoscale phenomena. The nanoscale materials and opportunities are designed to impact national Science, Technology, Engineering, and Mathematics (STEM) education, therefore allowing an efficient integration into current science curricula.

Defining Nano

The National Nanotechnology Initiative (NNI) defines nanotechnology as "the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."[2] The National Science Foundation (NSF) emphasizes many of the special properties that occur on the nanoscale and call one nanometer "a magical point on the dimensional scale."[3] This dimension holds its power because it exists as a maximum of one world and a minimum in the other. Nanoscale science and engineering exists in a transitional place where properties move from the dependence on bulk materials to isolated atoms.

Nano in the Middle- and High-School Science Curricula

Various recent literature called for the need of a science curricula revolution and suggested that integrated science courses, which allow students to explore cross-disciplinary concepts, are a better approach to science education.[4,5,6] Integrated science courses can address the needs of the diversity of students and represent a more real-world view of science as opposed to traditional courses that emphasize each area of science standing alone. As integrated science unifies concepts and looks at the reality of the natural world, the science is more relevant and better connected to students' lives, which can increase student interest and motivation to learn.[5] Project 2061 discussed the use of integration in the curriculum, highlighting three key reasons why integration is essential: integrated planning, interconnected knowledge, and coherence.[6] Integrated planning merges teachers of many disciplines including science, mathematics, and technology. This collaborative effort eliminates dividing subjects per person, and may increase the strength of the final product. Interconnected knowledge provides students with the opportunity to understand the complex relationships of subjects in the real world. Coherence in education means a collection of topics that are connected together, as opposed to curricula with stand-alone pieces. Teachers participating in a research survey agreed in the power of integrated science and called it a "valuable and viable alternative" that gave students a more comprehensive picture of the complex relationships that exist in the world.[5] Such a major overhaul to current practice is a long and difficult journey, thus a need exists for smaller transitions that will lead to a more well-rounded presentation of the integrated nature of science. Nanotechnology is an interdisciplinary field that offers great potential for bridging the traditional sciences of chemistry, biology, and physics taught in secondary classrooms with engineering in the educational setting.

Research has suggested that students are more motivated to learn and their achievement levels increase when teachers use practices and topics that stimulate student interest.[7] Student interest is often sparked from topics that are relevant to their lives, such as pharmacology topics.[8,9] The increased relevance and connection found by the students in integrated science classes has been shown to increase their interest and motivation to learn.[5] As nanotechnology is an integrated field of science and engineering, this may be one avenue to increase students' interests, and in turn, increase their achievement levels in science. Nanoscale science and engineering applications demonstrate how traditional topics have a variety of important applications in the modern world. For example, the principles of intermolecular forces are the foundation for how a gecko can walk on walls and ceilings. This type of real-world example has the potential to increase student interest.

Robert Tinker and Qin Xie of the NSF-supported Concord Consortium declared atomic-scale science the missing content in science curricula and claimed that a molecular emphasis is needed to improve introductory curricula.[4] Leon Lederman contends that the science and engineering of atoms and molecules comprise 100% of chemistry, 90% of modern molecular biology, and 85% of physics,[10] thus the science and engineering of atoms and molecules should comprise a much greater percentage of education in these science disciplines. Nanotechnology is built upon the science and engineering of atoms and molecules, thus the incorporation of nanoscale phenomena concepts into curricula answers this call.

While there has been an increase in drive to incorporate nanoscale science and engineering into schools, there has also been an increase in drive to introduce engineering concepts and foster engineering thinking in K-12 schools.[11] The NCLT activities and lessons support the development of engineering thinking and promote awareness of what engineers can do.

Nanotechnology is an ideal vehicle for communicating concepts of engineering as well as highlighting interdisciplinary work between engineers, scientists, and technologists.

Since the inception of the National Nanotechnology Initiative in 2001, federal funding for nanotechnology research and development has increased substantially from $464 million to an estimated $1,081 million in 2005.**Error! Bookmark not defined.** The National Science Foundation has estimated that two million workers will be needed to support nanotechnology industries worldwide within 15 years.[12] Thus, an obvious need exists for prepared engineers, scientists, and technologists. As many students opt out of science-related careers before they enter college,[13] nanotechnology integration into middle- and high-school curricula may spark the interest of students who might otherwise never learn about current and cutting-edge research in nanotechnology. Statistics from the National Science Board in 2006 showed that the number of freshman expressing an interest in majoring in the physical sciences has decreased over the last two decades, although within the past three years, there has been a very slight increase in interest.[12]

The incorporation of nanoscale science and engineering concepts into middle- and high-school curricula may help to serve some of the current needs in science and engineering education. The question that remains is how. Teachers cannot choose to eliminate many of the concepts they are currently teaching, as these concepts are required by state standards. However, there must be a way to connect their current topics with topics in nanoscale science and engineering. While the literature suggests alternative curricula and programs for integrated science approaches,[14] specific details related to nanotechnology integration does not yet exist.

Rationale
During the course of a two-week professional development workshop led by the NCLT, teachers were guided through a series of nanoscale science and engineering activities. The NCLT professional development team created these activities, and content was matched to state and national standards. These activities also served as a potential starting point for teachers as they designed a lesson that included nanoscale phenomena concepts. The lessons designed by the teachers were ones that they intended to use the following school year. These detailed lesson plans guide our understanding of the logistics involved in the incorporation of nanotechnology concepts into middle- and high-school curricula.

This study of how nanoscale science and engineering concepts can be integrated into middle- and high-school curricula was led by the following research questions:

- How do middle- and high-school educators incorporate nanotechnology topics into their pre-existing science curricula?
- How can the NCLT professional development workshops facilitate the integration of nanotechnology?

Research Methods

This study is part of a larger design-based research project conducted by the NCLT professional development team. This qualitative study focused on understanding the specific ways middle- and high-school teachers felt they could incorporate nanoscale science and engineering topics into their curricula. The data used in this introductory study are comprised of the nanoscale phenomena-related lesson plans matched to state standards created by middle- and high-school science teachers participating in a two-week professional development workshop held in the summer of 2006.

Participants

Twelve science teachers participated in the 2006 professional development workshop on nanotechnology held at Purdue University. The creation of a lesson plan constituted a portion of the workshop, thus all twelve completed the activity. One of the twelve teachers opted not to share the lesson plan, thus eleven of the twelve lesson plans created during the workshop comprised the data for this study. The demographic information for the eleven teachers that provided their detailed nano-related lesson plan is shown in Table 1. One of the middle school biology teachers was moving to high school biology for the school year following the workshop, so, although reported as a middle-school teacher, this person chose to create a lesson plan for high-school students.

Table 1. NCLT Professional Development Workshop Participants

	Chemistry	Physics	Chemistry and Physics	Biology	General Science
Middle School	0	0	0	0	2 Male
High School	3 Female, 1 Male	2 Male	1 Female, 1 Male	1Male	0

Methodological Framework

The NCLT aims to understand many of the issues related to the incorporation of nanoscale science and engineering activities into middle- and high-school classrooms, and support teachers in this transition. For at least the next three years, the NCLT professional development team will lead two-week workshops at several universities each summer. Five workshops are expected to be held in the summer of 2007. The series of workshops supports a design-based research framework in our studies.[15,16,17] Designed-based research "simultaneously pursues the goals of developing effective learning environments and using such environments as natural laboratories to study learning and teaching."[17] Bell describes this framework as a strong relationship between design and research that supports an understanding of learning-related educational phenomena.[15]

This particular study focused on gaining a preliminary understanding of how nanoscale science and engineering concepts transition into pre-existing science curricula as well as how the professional development team can facilitate this incorporation by means of workshop instruction, discussion, and activities. Teacher-created lesson plans not only informed research findings for this particular study, but also the iterative cycle of design, implementation, and redesign of the NCLT professional development instruction.

Workshop Design

The workshop addressed a variety of topics in nanoscale science and engineering beginning with more traditional topics such as size and scale, the structure of matter, and forces. In the middle of the first week, the topics transitioned to less-traditionally taught topics in middle and high school. These topics included the allotropes of carbon, self-assembly, scanning probe microscopy, and nano-based products currently on the market. Each topic included a series of hands-on activities, discussions on the concepts and pedagogy involved, and research seminars given by scientists and engineers. A general description of the activities which focused on modern nanotechnology topics follows:

- Allotropes of carbon: This topic included modeling the idea of a space elevator with composite materials, creating models of nanotubes and buckyballs, and presentations and discussions on the discovery of the allotropes of carbon, their properties, and their applications.
- Self-assembly: These activities were guided by the inquiry questions: "What is self-assembly?", "What causes components to self-assemble?", and "What are examples of self-assembling systems?" To answer these questions, teachers read a series of news articles on products made with self-assembly processes, manipulated a computer simulation of self-assembling molecules, and designed a self-assembling system using magnets, Velcro, and Legos®. Research seminars and large group discussions supplemented their knowledge on the principles of self-assembly.
- Scanning probe microscopy: To understand the principles of the atomic force microscope, teachers designed their own probe to map a Lego® surface. For the magnetic force microscope lesson, teachers mapped a magnetic surface using a functionalized magnetic probe. Discussions on concepts and pedagogy were included following each activity and research presentations and a demonstration of a real AFM used in research provided teachers with a better understanding of scanning probe microscopy.
- Nano-based products: The lesson began with teachers investigating the claim of Nanotex® pants to repel stains and resist spills. Teachers were also given a list of products claiming to be nano-based. They researched the products to determine what was "nano" about the product and how the product worked. This provided teachers with the opportunity to connect their nanoscale science and engineering knowledge to real-world products utilizing these properties.

Also included in the workshop were discussions surrounding pedagogy. Topics included eliciting students' conceptions, models and modeling, scientific inquiry in the classroom, and lesson planning.

For the lesson planning component, teachers were given a lesson plan template. This template is shown in Appendix A. They chose their own topic, and were given approximately 8 hours of the workshop time in addition to the time they had in the evenings. During the workshop time, the NCLT professional development team assisted the teachers if they had any questions. The teachers were also provided with the Indiana State Standards.[18] Additionally, the lesson plans created by the professional development team were given to the teachers to serve as examples.

Data Sources

The data used for this study were the lesson plans created by the teachers, including the matching of their lesson plans to their state standards. The nature of this data allowed us to use a qualitative approach for analysis. "Qualitative methods facilitate study of issues in depth and detail,"[19] and this depth and detail is exactly what we needed to begin to understand the issues involved with the incorporation of nanoscale concepts into current curricula.

Data Analysis

The research questions and sources of data required the analysis to take a qualitative approach. While a qualitative approach does not seek to generalize findings, it allowed for an in-depth look at specific details related to nanoscale concept integration into middle- and high-school curricula.

The first round of data analysis was conducted independently by the first two authors. Each conducted multiple iterations of reading and reviewing the data to determine tentative patterns and themes with the lesson plans, after which they collaborated with the professional development team to confirm the themes discovered. The emergent themes are discussed following a summary of the nano-based lesson plans created by teachers for use in their classrooms.

Findings

Teacher-created Nanoscale Phenomena Lesson Plans
The following section includes a summary of eleven lesson plans created by teachers as a means to incorporate topics on nanoscale phenomena. A fuller description is included in Appendix B. Each lesson begins with a number and a title. In the tables following the lesson plan summaries, the lessons are referred to by their numbers.

Table 2. Descriptions of Teacher-Created Nanoscale Phenomena Lesson Plans

	Title of Lesson	Grade/ Subject	Topic	Description
1	Do You Size Up As A Perfect 10?	7-12/ General Science	Size & Scale	To understand size and scale, the metric system, and powers of ten, students order a set of ten cards with varying objects from largest to smallest. The power of ten, metric prefix, and metric symbol are determined.
2	Does Size Really Matter?	9-12/ Chemistry and Physics	Size & Scale and Scanning Probe Microscopes	This lesson was part of a forensic unit where students identify a criminal based on hair. Students investigate powers of ten, size dependent properties, and various microscopes used in science.
3	Surface Area and Volume	11/ Biology and Nanoscale Science and Engineering	Surface Area, Volume, Scientific Notation	Students determine the surface area and volume of a cube and continually cut the cube in half, determining the new surface area and volume. This lesson follows with extensions on surface and volume of nanoparticles.

4	Hula Hoop Physics: Overcoming Gravity's Pull	10-12/ Physics	Dominance of Forces	An investigation occurs as to how a group of students can lower a hula hoop without allowing their finger to leave the hoop. A discussion of the ease of overcoming gravitational forces versus electric forces takes place.
5	Molecular Attractions: Why do Chemicals Behave the Way They Do?	10-12/ Chemistry	Intermolecular Forces	Students investigate the various types of intermolecular forces and the importance of these forces at the nanoscale while participating in "discovery" activities, group discussions, laboratory, and an application follow-up relating to nanoscience.
6	Intermolecular Forces	10-12/ Chemistry	Intermolecular Forces	The lesson allows students to investigate the relationship between physical properties of liquids and intermolecular forces. The Internet and textbooks are used as an introduction for students to intermolecular forces followed by a laboratory activity.
7	Why Water?	9-12/ Biology and Chemistry	Properties of Water	Students investigate evaporation, capillary action, and specific heat of water and how these properties differ from other liquids. They determine which liquid is best suited for life and make a commercial to sell their liquid based upon their data and results.
8	Mapping a Surface	9-12/ Physics	Scanning Probe Microscopes	Students design and test a method to map the surface of the classroom using a motion detector. An article describing scanning probe microscopy is read followed by a discussion of similarities to and differences from a motion detector.
9	If They Could See Me Now – How Do We See Atoms?	10-12/ Chemistry	Scanning Probe Microscopes	This lesson focused on students creating ways they can "see" without using their eyes. They perform both hands-on and Internet activities on scanning probe and magnetic force microscopy. Students also read an article on DNA origami followed by a group discussion.

10	The Size of Matter Matters! Making Nanosize Clusters of Magnetite in a Ferrofluid	8-12/ Any Science Class	Ferrofluids	The lesson begins with a series of questions for students surrounding magnetism and chemical reactions. Students then synthesize ferrofluids and engage in a group discussion to make sense of the activity including rate and effects of grain size on magnetism.
11	How do You Make Your Favorite Color?	11/ Integrated Chemistry & Physics	Waves (Light and Sound)	The lesson was designed for students to understand that light is both a wave and particle and how LEDs work. Students first explore sound waves and then investigate LEDs compared to a small light bulb.

Matching Nanoscience Content to the Indiana State Standards

In most cases, teachers correlated their lesson plans to state standards. Some teachers found many standards they felt were addressed by their lessons, while others only found one or two. The teachers had access to the standards for all subject areas, and the number of standards matched for each subject is shown in Table 3.

Table 3. Standards addressed by each lesson

Lesson	Designed Grade	Designed Content Area	7	8	Chem	Physics	ICP	Unclear	Total
(1)	7-12	General Science	1	2	0	1	0	0	4
(2)	9-12	Chemistry/Physics	2	4	0	0	0	0	6
(3)	11	Biology/nano	0	0	0	0	0	1	1
(4)	10-12	Physics	0	0	0	3	0	0	3
(5)	10-12	Chemistry	0	0	2	0	0	0	2
(6)	10-12	Chemistry	0	0	3	0	0	0	3
(7)	9-12	Biology/Chemistry	0	0	2	0	0	0	2
(8)	9-12	Physics	0	0	0	Unspec.	0	0	Unspec.
(9)	10-12	Chemistry	0	0	3	0	0	0	3
(10)	8-12	Nano/magnetism/ chemical processes	0	3	6	0	0	0	9
(11)	11	ICP	0	0	0	0	10	0	10
Total	---	---	3	9	16	4	10	1	44

From the table, it is evident that teachers looked at specific content standards for the content related to the subject they taught rather than looking across disciplines for other standards. For example, the teacher that designed a lesson for Integrated Chemistry/Physics looked at the ICP standards, finding ten, but did not include standards for 7th and 8th grade science, biology, chemistry, or physics. We did not ask teachers to consider different grades or subject areas when writing their lesson plans, thus we did not expect that they would. However, in retrospect, we realize that requesting that they look outside of their own content areas would provide an opportunity for them to engage in the discussion on interdisciplinary science education. By highlighting our effort to demonstrate the interdisciplinary nature of nanotechnology within our lesson plans, we can promote a discussion of interdisciplinary educational opportunities.

One teacher matched his lesson plan to a standard from a document of nanotechnology education standards that he wrote. He felt the current standards did not incorporate nanoscale concepts and felt that a need existed for specific nanotechnology standards. As one of the goals of the professional development staff is to highlight how nanoscale science and engineering concepts meets current standards, this teacher's inability to see these connections called for better communication from the NCLT professional development staff.

Lesson Plan Content

One means for identifying themes within lesson plans was to characterize the content included in the lessons. Table 4 summarizes the lesson plan number and the content included within the lesson.

Table 4. Content Incorporated in Teacher-Created Lessons

Lesson	Size and Scale	Surface Area to Volume	Dominance of Forces	Intermolecular Forces	Microscopes	Ferrofluids	Waves (Light/Sound)
(1)	X						
(2)	X				X		
(3)		X					
(4)			X				
(5)				X			
(6)				X			
(7)				X			
(8)					X		
(9)					X		
(10)						X	
(11)							X
Total	2	1	1	3	3	1	1

Lessons on forces and microscopy comprised the largest percentage of topics chosen by teachers. One trend is not evident from this table alone. Teachers chose not to focus or incorporate activities on the allotropes of carbon, self-assembly, or nanotechnology products in their lesson plans. These topics were the focus of three and a half days of the two-week workshop, and the teacher evaluations of these activities showed they enjoyed them just as much, and in some cases more than the other activities.

Three of the teachers incorporated nanoscale science and engineering concepts into their lesson plans by including discussions and activities on atomic force microscopes. Two of the three teachers related atomic force microscopy to size and scale and how to "see" material smaller than the limits of an optical microscope. Of the nanoscale science and engineering topics presented in the workshop, teachers seemed most able to connect microscopy with their current classroom content. The NCLT will investigate ways we can convey the connections traditional concepts have to the other nanoscale phenomena we discuss in our workshop.

While the NCLT professional development team provided a variety of activities on modern topics in nanoscale science and engineering, the team also emphasized that nanoscale science and engineering incorporates many of the concepts that are already a part of the science standards, such as size and scale and forces. As a result, many of the teacher-made lesson plans focused on these more traditional topics currently included in their individual school curricula.

Microscopy and intermolecular forces may have appeared in more of the lesson plans because their connection to currently-taught topics and standards seems more natural to teachers. The NCLT professional development team intends to investigate this idea further with teachers from the previous workshop and in our future professional development experiences.

The lessons created by the teachers used and adapted lessons created by the professional development staff in developing their lessons. Many of the lessons focused on infusing nanoscale concepts as asides or extensions of the lesson, while a few of the teachers found ways to make the nanoscale science and engineering content integral to the lesson.

Nano Phenomena Lessons in Middle- and High-school Curricula

The lack of lessons that incorporated more modern ideas of nanoscale science and engineering suggest that middle- and high-school educators are not clear on where and how to integrate these new topics into their curriculum. They are not the only ones struggling with this problem. The literature is extremely sparse in this area, and even programs like our own that are creating and researching the implementation of nanoscale science and engineering activities do not provide specific information of where nanoscale science and engineering belongs in the current curricula or how to incorporate the nanoscale science and engineering topics. The bottom line is that it is not an easy transition.

A few of the lesson plans centered around traditionally-taught concepts had extensions that tied in more modern advances in nanoscale science and engineering, such as the atomic force microscope serving as an extension to a size and scale lesson to teach forensic science. The lesson plans created by the teachers suggest that they are much more able to envision improved lesson plans on already-taught topics such as size as scale or intermolecular forces rather than adding in a new lesson on a more modern nanoscale science and engineering topic such as self-assembly. The key to incorporating nanoscale phenomena concepts into middle- and high-school classrooms may be in the form of extensions. A lesson on intermolecular forces could be extended with a discussion of the role intermolecular forces play in self-assembling processes, and how self-assembling processes provide opportunities for building better and specific materials that can be used in biological and computer applications. This type of lesson would incorporate current applications of a traditional topic and allow for discussions on the integrated nature of science.

Changes to the Professional Development Program

The professional development team plans to implement changes to the next round of workshops based on this research and other research projects related to our program. These changes include more specific examples and discussions on how modern nanoscale science and engineering applications can be tied with things that are already being taught. Additionally, we will spend more time as a group with the standards, and discuss as a group the number and variety of standards the lessons incorporate. We also plan to have more specific discussions with the teacher on the concerns and issues they see with the incorporation of nanoscale science and engineering concepts into the curricula. The professional development teams plans to emphasize the integrated nature of nanotechnology. The lessons we have created are not just lessons of biology, chemistry, or physics, but a tie among the sciences and engineering. We intend to promote discussions on how each lesson can be used in a variety of science courses.

Conclusions

Nanoscale science and engineering concepts are related to traditionally taught areas of science. The technology produced from these concepts provides real-world applications and present-day cutting edge research that can enhance middle- and high-school curricula. The data collected in this qualitative research project allows us to begin to understand the avenues to incorporate nanoscale phenomena concepts. It should not be as a solitary unit by itself because of space constraints in curricula. Incorporation may occur more smoothly by integrating nanoscale science and engineering concepts into current lesson plans on the traditional science in which nanotechnology is built. Nanotechnology products can provide applications and examples that help students tie science and engineering to the real-world, which may positively influence student interest and motivation in the STEM fields. The NCLT professional development program will continue to investigate means of nanoscale science and engineering integration into middle- and high-school education, and provide support and specific examples of how this integration can take place and satisfy the standards in hopes of creating a more integrated science and engineering curricula.

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Appendix A: Lesson Plan Template

[Title of Lesson]

Author: [Author Name]
Draft Date:[Draft Date]

Content Area: [Content Area]
Grade Level: [Grade Level]

LESSON RATIONALE

Instructional Objectives

- [Instructional Objectives]

Standards

- [State Standards]

  Grade Level

    Standard Name and Number

- [National Standards]
- [Subject Standards]

LESSON PREPARATION

Materials

Item	Number/Amount

Pre-Class Preparation

Getting the Materials Ready

-

Adaptation/Cautions

- Example:

Doing the Lesson

Opening

- [Opening Question/Remarks]

NOTE:

  - [Special Instructions]

Body

Activity 1 – Name

1. Step 1

Appendix B: Detailed descriptions of teacher lesson plans

(1) Do You Size Up As A Perfect 10?

Lesson 1 was adapted from a card sort activity created by the professional development staff. The lesson was created for 7-12 grade general science students to develop an understanding of size and scale, specifically using the metric scale and powers of ten. The teacher that created this lesson matched it to one 7^{th} grade, two 8^{th} grade, and one high-school physics state standards.

The lesson is designed to begin by eliciting students' ideas about the smallest thing of which they can think, see with their eyes, and see with technology. Students record their answers on paper and then a discussion of the questions follows with the whole class. Following the discussion, students are asked to take a set of ten cards containing objects of varying sizes and order the objects on the cards from largest to smallest. They determine to what power of ten the object belongs, what the metric prefix is, and the metric symbol of the prefix. Students then have to compare five cards on the basis of scale and determine how many times bigger or smaller an object is based on a central card object. After completing the activity, students return for a whole class discussion. Assessment of this activity involves inserting five new cards with different objects into the original set of ten cards and determining the power of ten, prefix, and symbol.

(2) Does Size Really Matter

This lesson was designed for high school 9-12 grade Chemistry and Physics students to learn about size and scale. The lesson is one part of a forensic science unit in which the students attempt to identify the criminal through hair morphology. The students should learn that as the scale gets smaller, they are able to develop more insight into the properties of the object, in this particular case, hair. The teacher that created this lesson wanted students to understand powers of ten, macro-, micro-, and nanoscopic properties, and the types of equipment and microscopes used in science. Although the lesson was designed for high school, it was matched by the teacher to two 7^{th} grade standards and four 8^{th} grade state standards.

The lesson would begin by eliciting students' ideas where students create answers to posed questions, such as "what are properties, what are properties of hair, and which two hairs came from the same source" in their classroom journals and then come back together as a whole class to answer. These are general questions created to encourage thinking and conversation before beginning the three activities, including an Internet exploration, brainstorming, and laboratory experience. Students begin to learn about size and scale through an Internet site in which they are able to zoom in and out of an object to discover how the picture of the object changes at different levels as well as listen to scientists. This site also offers students the opportunity to see ferrofluids and how to bake ice cream without melting the ice cream. A discussion then follows the Internet site exploration. The second activity begins with a brainstorming activity for the students to determine if objects can be observed at the nanoscale with a person's eyes, and if not, to brainstorm how they can be "seen". Students then return to the Internet site to research different microscopes and how they work. Students perform an atomic force microscope (AFM) scan using a model of Legos® and a dowel rod as a probe. This model scan was adapted from one of the activities designed by the professional development team. The third activity within the lesson requires students to observe hair samples at the macro-

, micro-, and nanoscales with access to a light microscale and simulated AFM. Students develop their methods, collect data, determine the results, and make conclusions. Following the activity, students return to the initial questions asked at the beginning of the lesson and revise their answers. As assessment, students present their findings of the hair samples to the class.

(3) Surface Area and Volume

This lesson was written as a biology and nanoscale science and engineering lesson for grade 11, which focused on the concepts of surface area, volume, and scientific notation. It included extensions to nanoscale concepts such as the relationship between surface area and reaction speed, how exponential change limits cell size, atomic and intra-atomic distances, and growing carbon nanotubes (CNT). This teacher wanted students to be able to understand that the ratio of total surface area to total volume of a given substance increases as it is broken down. One standard was identified by the author to fit this lesson: "Students will understand the concept of scale, and be able to convert simple spatial relationships from abstractly large orders of magnitude to abstractly small orders of magnitude." This standard is from a set of nanoscience learning standards created by the author of the lesson, rather than using national or state standards that already exist.

This lesson plan consisted of a series of activities to lead students to the desired outcome of an understanding of surface and volume. Eliciting students' ideas began the lesson. Students would create a cube and then determine the shortest path along the surface and then the shortest path possible in any dimension between a set of given corners. A discussion of volume versus surface area follows. Students partake in an investigation in which they are given a cube and are to determine the volume and surface area of the object; they then predict what will happen to the volume and surface area if the object is cut in half. The students test their predictions by cutting the object, and the investigation ends with the determination of the volume and surface area of a spread of butter, both when it is hard and soft. After the class comes back together for a discussion, the activity can be extended by having students test how many times they can cut the object in half and discuss the limitations of their tool. The students complete a worksheet in which they are to make calculations of volume and surface area each time a cube is cut into smaller pieces. The lesson plan included some potential extensions that incorporate a discussion of nanoparticles. The discussions on nanoscience concepts appeared only in the follow-up section. These extensions seemed intended as asides, not the focus of the lesson.

(4) Hula Hoop Physics: Overcoming Gravity's Pull

This lesson was developed for Physics students in grades 10-12, and focused on the concept of gravitational force. The message of this lesson is that this force is easy to overcome if the mass of an object is small or insignificant compared to other forces, as is the case on the nanoscale. This lesson was matched three physics state standards by the teacher who designed it.

The lesson begins with the students receiving a worksheet to read on how to perform the activity. The teacher discusses the task the students will perform and then the students create predictions. The task is performed in groups of eight students who see if they can lower a hula hoop to the ground without allowing their finger to leave it. After completing the task, students are split into smaller groups to discuss their findings. Students are challenged to develop a protocol in which they will be able to actually lower the hula hoop to the ground, discuss the protocol with the teacher, and perform the investigation reuniting with their original group members. After completing the activity, a class discussion takes place. Students complete another investigation in which they are given a stack of paper with the same mass as the hula hoop and continually split the paper in half, keeping track of the number of times the can split the sample. They are to then answer questions and make predictions relating to the ease in overcoming the gravitational force for a proton or electron. Students complete a third worksheet to fill out individually in which they compare gravitational forces to electric forces. A classroom discussion then takes place.

(5) Molecular Attractions: Why do Chemicals Behave the Way They Do?

The high school chemistry teacher who wrote this lesson for 10-12 grade chemistry students focused on the various types of intermolecular forces and their relationship to physical properties of substances. The goals of the lesson included students understanding how intermolecular forces are involved in phase changes and their importance at the nanoscale level. Two nanoscale examples were provided: zinc oxide sunscreen and gecko tape. Two high school chemistry state standards were believed to be addressed by this lesson.

This teacher created a lesson in the format currently used by her high school, in which students participate in a "discovery" to begin to understand the phenomena on their own, a large group discussion, a laboratory experiment, and an application assignment. The lesson begins with the discovery where students use their textbooks and the Internet to investigate the four types of intermolecular forces. Students make observations, collect data, and propose explanations about intermolecular forces of liquids by examining solubility, surface tension, capillary action, and volatility of a sample. The last part of the discovery requires students to determine what happens to intermolecular forces during a phase change by using both pre-constructed data on a computer and an Internet site. Following the discovery, a large group discussion occurs in which the class discusses their ideas of the concepts addressed in the discovery. Students complete a laboratory experiment adapted from the intermolecular forces lesson created by the NCLT professional development team. This experiment challenges students to identify five unknown liquids using what they have learned in both the discovery and discussion. The final portion of this lesson is an application assignment adapted from another NCLT lesson where students choose from one of two tasks: learning how geckos can walk upside-down on a ceiling or how solid zinc oxide can turn into a solution usable as sunscreen. This assignment asks students "How are intermolecular forces used by the macroworld in a nanosense?" Students are to perform the tasks to determine why the material needs to be "nanosized". The incorporation of nanotechnology into the lesson is incorporated as an application of the concepts learned about through the discovery and laboratory experiment.

(6) Intermolecular Forces

This high school chemistry teacher chose to create a lesson for 10-12 grade chemistry students focusing on three types of intermolecular forces (dispersion, dipole-dipole, and hydrogen). The goals of the lesson also included students understanding of vapor pressure exerted by a liquid and the relationship between physical properties and intermolecular forces. This lesson addressed three state chemistry standards.

This lesson was developed to span two days. Day one begins by eliciting students' ideas with a demonstration of four manometers, each containing a different liquid. The use of a manometer to investigate intermolecular forces was adapted from an activity from the NCLT professional development program. The lesson continues with a discussion in which the teacher describes the manometer and the function of the manometer. Any questions asked by the students will then be placed on the board, but not answered until the following day. Students then fill out a worksheet on intermolecular forces using the Internet and textbooks. After completing the worksheet, students are to complete two Internet tutorials on intermolecular forces. During the course of the class, the teacher is to circulate and ask students questions about intermolecular forces. For homework, students are to determine several physical and chemical properties of five defined liquids (hexane, acetone, butanol, water, and glycerol). Day two begins with students getting into groups and discussing their worksheets. Students then perform a laboratory experiment on intermolecular forces, provided by the NCLT professional development program, in which students are to identify five unknown liquids using the physical and chemical properties of the liquids they investigated for homework. As a follow-up, students are given the formulas of five chemical compounds and asked to determine the types of intermolecular forces and rank the compounds depending upon the strength of the forces. There is a class discussion leading into a return to the manometers and student predictions of the identity of the liquid in each manometer. As a final aside on this lesson, a nanotechnology connection is given in which an MP3 player is to be dismantled and a discussion of how is operates is to take place.

(7) Why Water?

This high school biology teacher created a lesson for 9-12 grade biology and chemistry students focused on water, the physical and chemical properties of water, the importance of water to life, and a comparison of water with other liquids to determine if another liquid could be substituted for water in certain situations. Two state chemistry standards were listed to be addressed by this lesson.

The lesson begins by eliciting students' ideas about water, why it is so important, and the potential for a water substitute. Students record their answers to the questions in their notebooks and share their answers with the class. In groups, students determine how to compare the properties of several different liquids. Students speculate which liquid (water, acetone, or ethyl alcohol) is best suited for life, and create a commercial to sell this liquid. The investigation begins, and students make qualitative observations of the three liquids by placing them on a glass slide. Students continue the investigation by observing evaporation, capillary action, and specific heat. The class comes back together to discuss what they have discovered. Students perform a follow-up activity developed by the NCLT professional development team to demonstrate their knowledge of water and hydrogen bonding. The assessment in this activity is the commercial that students are to develop to sell their preferred liquid.

(8) Mapping a Surface

This lesson, developed by a high school Physics teacher for 9-12 grade physics students, is centered on student design of an experiment to model sonar and/or atomic (magnetic) force microscopes. The lesson asks students to use a motion detector to map a surface and to then correlate that to a scanning probe microscope. This teacher did not indicate which standards this lesson addressed, rather, just gave the overview for the state physics standards, and implied the lesson related to this overview.

At the start of this lesson, the teacher explains and demonstrates how a motion detector is used to measure distance using ultrasonic sound waves. Students in small groups are challenged to develop a method using a motion detector to map a portion of the classroom surface including the floor, desks, chairs, and books. The groups present their ideas to the class for critique. Next, they perform the actual classroom mapping sampling distances with the motion detector at regular intervals to cover a two-dimensional grid. Students use a graphing program to represent the surface in three dimensions. Follow-up to this activity is a reading describing how scanning probe microscopes work. The students consider the similarities and differences of the motion detector and the scanning probe microscopes with worksheet questions. The assessment of this lesson is the follow-up worksheet.

(9) If They Could See Me Now -- How Do We See Atoms?

This lesson, created by a high school chemistry teacher for 10-12 grade chemistry students, focused on the relationship between the size of an object and its physical properties as well as technology used to measure the size of atoms. This lesson included an emphasis on the social and technological implications of nanotechnology in the future. The teacher who created this lesson matched it to three chemistry state standards.

Students individually consider their answers to questions on the board about atoms, how scientists can see atoms or things smaller than atoms, and the ability of a light microscope to see atoms. A presentation from the Internet on the powers of ten is shown to the class. Students share their answers to the previously-asked questions with the class in a student-led discussion, in which the teacher does not provide any answers. Students are placed into groups and brainstorm ways in which you can "see" without using your eyes. They engage in a scanning probe microscopy lesson created by the NCLT professional development staff followed by a whole class discussion. The teacher shows an animated probe simulation in which students are to decide which probes will work best depending upon the surface. Students will return to their journals and revise their answers to the opening questions. Students see pictorial results form an atomic force microscope (AFM) and comment on what the color in the picture means. The lesson continues the next class period with a discussion on the advantages and disadvantages of the AFM and a reading on an article about DNA origami. Students are encouraged to think of other ways to see atoms, such as sonar. More animations of microscopes are then shown and discussed. Students engage in two more activities looking at magnetic force microscopy (MFM) developed by the NCLT professional development staff, with each activity concluding with a group discussion. PowerPoint slides of each type of microscope discussed are then shown. Students complete a follow-up activity which is to write a newspaper article describing one the microscopes investigated and how this microscope assists in "seeing" atoms.

(10) The Size of Matter Matters! Making Nanosize Clusters of Magnetite in a Ferrofluid

This lesson was developed by middle school science teacher. The lesson was developed to span across several grade levels (8-12) in any science class, as the depth of instruction can change dependent upon the background knowledge of the students. Students will learn the following concepts: "The behavior of magnetite grains in a fluid medium as a ferrofluid will depend on the size of the grains formed in the chemical reaction and the presence of a surfactant surrounding the grains. The size of the magnetite grains formed will depend on the rate at which the reactants are introduced in the reaction. Ionic forces attach the surfactant to the magnetite grains. Like a bumper around bumper cars, the surfactant minimizes weaker molecular forces (such as van der Waal forces) and magnetic forces that can attract magnetite grains to each other to form larger clusters, thereby preventing the ferrofluid behavior." This lesson was believed to address three 8th grade and six chemistry state standards.

The lesson begins by eliciting students' ideas about what they know about magnetism, including metals that are magnetic and fluids being magnetic, magnetic forces around a magnet, and how small a magnet can become and still have poles. Other questions in this discussion include those on how soap works, chemical reactions, and oxidation numbers to elicit students' ideas for this activity. The students create ferrofluids on their own using a procedure found on the Internet. A modification of the procedure is provided if the teacher prefers to discuss reaction rates with their students. After completing the activity, a large group discussion ensues to allow students to make sense of the activity. This includes a discussion about the rate in which the chemicals were added and the effects of the grain size on magnetism. The follow-up of this activity is a list of questions for the students to answer.

(11) How do You Make Your Favorite Color?

This lesson was created by a teacher of Integrated Chemistry and Physics (ICP) for 11th grade ICP students. This lesson addressed the concepts of light as being both a wave and a stream of particles, semiconductors including light-emitting diodes (LED), and how the color of light produced by the LED can be controlled. One method discussed of controlling the color is controlling the size of the quantum dots in the LED. This lesson indicated it addressed ten ICP state standards.

The lesson begins by eliciting students' ideas about waves, how they behave, and their relationship to energy. A discussion follows in which students generate answers about how sound is generated and how musical instruments work. The first activity requires students to explore tones produced by test tubes filled with different levels of water, including the difference between tapping the test tubes and blowing across the top of the tubes. After completing the activity, a whole-class discussion takes place. In the second activity, students investigate the similarities and differences in LEDs compared to a small light bulb. Students should compare both the different types of light sources and the difference colors of LEDs. Students are challenged to determine how an LED works and how an LED is made to produce different colors. This lesson did not contain a follow-up or assessment.