NanoSense: The Basic Sense behind Nanoscience

Second Year Report
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Contents:

Project Activities and Project Findings attached as separate sections.

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SECTION 1: PARTICIPANTS

Core Participant Individuals

Patricia Schank (PI), Tina Stanford (Co-PI), Anders Rosenquist, Vera Michalchik, Reina Fujii, Nora Sabelli—SRI International
Maureen Scharberg—San Jose State University
Ellen Mandinach—Educational Development Center
Alyssa Wise—Indiana University, Bloomington, IN
Doris Mourad—Teacher, Castilleja School, Palo Alto, CA
Carolina Sylvestri—Teacher, Gunn High School, Palo Alto, CA
Geri Horsma—Teacher, Gunn High School, Palo Alto, CA
Miriam Motoyama—Teacher, Gunn High School, Palo Alto, CA

Partner Organizations

Research and Development Partners

Chemistry Department, San Jose State University, San Jose, CA. We are working closely with Dr. Maureen Scharberg and a student assistant in the Chemistry Department at SJSU to develop standards-based nanotechnology curriculum for high school science classrooms and to host teacher training workshops at SJSU. Dr. Scharberg and her student assistant have developed a database of high school science teachers used for recruiting of teachers for NanoSense workshops.

School of Education, Indiana University. We are working closely with Alyssa Wise, a PhD student in Learning Sciences in the School of Education at Indiana University, to develop, evaluate, and refine our curriculum materials. Ms. Wise holds a Masters in Instructional Systems Technology and has expertise in chemistry, physics, and science instruction. She has led the development and evaluation of the NanoSense Clear Sunscreen unit, contributed sections of the Size Matters unit, and provided verbal and written feedback on other NanoSense units.

Center for Children and Technology, Educational Development Center, New York, NY. Dr. Ellen Mandinach at EDC is leading the evaluation efforts for the project. Dr. Mandinach provides expertise in basic, applied, and formative research to investigate how technology and curriculum can make a difference in the classroom. Acting as a critical partner, EDC helps our team shape our strategies for developing our materials and analyze their usefulness in real classrooms with our teacher partners. EDC uses a multimethod approach to collect and analyze indicators of the usefulness and value of the curriculum units. EDC's efforts are be both formative and summative, providing ongoing and iterative feedback to NanoSense developers in order to appropriately shape the development effort and describe the degree to we meet our goals.

Foothill-DeAnza Community College (FHDA), Los Altos Hills, CA. FHDA is one of the largest community college districts in the United States, providing credit classes for about 44,000 students per quarter. Faculty member Robert Cormia helped the NanoSense team organize the March 2005 Advancing Nanoscience Education workshop. Faculty member Dr. Singh collaborated with the NanoSense team to develop and submit a National Science Foundation Advanced Technological Education (ATE) proposal entitled "Nanotechnology Program Curriculum Articulation (PCA)".

NASA Ames Research Center. NASA Ames has created partnerships with leading universities and high-technology industry leaders, bringing the scientific and corporate communities together in efforts to advance human knowledge and explore the unknown. NASA staff Dr. Meyya Meyyappan and Ms. Valerie Sermon are working with Foothill College to develop a new nanoscience certificate program and offer internships for students to participate in the program and to high school students. NASA also helped the NanoSense team organize the March 2005 Advancing Nanoscience Education workshop, in which Dr. Meyyappan was a featured speaker.

School Partnerships

Several high school teachers are working with the NanoSense team to advise the development of our activities, pilot-test them in their classrooms, and provide feedback on their use.

Antioch High School, Antioch, CA. Antioch's student population is approximately 28% Hispanic, 9% African American, 3% Asian, and 2% Filipino; the highest parent education level is 29% college degree and 7% graduate school; and 31% of the student body qualifies for free or reduced-price lunches. The school's 2001 API score was 589 out of 1000, and its API rank is 2 out of 10. Britt Hammon, a veteran chemistry teacher at Antioch High School, attended our NanoSense teacher meetings in year 1 and pilot-tested activities from the NanoSense Size Matters unit with her chemistry students in June 6, 2005. Ms. Hammon has also served as the school's assessment coordinator, and has developed an integrated science curriculum that combines earth science, physics, and biology. Ms. Hammon was also a partner teacher on the ChemSense project, developing several curriculum activities and testing them in her classroom.

Gunn High School, Palo Alto, CA. Gunn's student population is 26% Asian, 5% Hispanic, and 2% African-American; the highest parent education level is 16% college degree and 75% graduate school; and 4% of the student body qualify for free or reduced-price lunches. The school's 2002 API score was 883 out of 1,000. Carolina Sylvestri, chemistry and physics teacher, Geri Horsma, biology teacher, and Miriam Motoyama, chemistry teacher, attend our NanoSense teacher meetings, provide feedback on our materials, and have pilot tested materials with their students the classroom and at our teacher-student workshops.

Castilleja School, Palo Alto, CA. Castilleja is a nonsectarian, all-female private school; approximately one third of the student population are ethnic minorities, and virtually all graduates go on to four-year colleges. Doris Mourad, chemistry teacher, attends the NanoSense teacher meetings, provides feedback on our materials, and has pilot tested materials with her students and at our teacher-student workshops. Ms. Mourad also attended the March 2005 Advancing Nanoscience Education workshop, and worked closely with the NanoSense team on the development of the Fine Filters unit on nanofiltration.

Menlo-Atherton High School, Menlo Park, CA. Menlo-Atherton's student population is approximately 40% Hispanic, 9% African-American, 4% Asian, and 5% Pacific Islander; the highest parent education parents is 23% college degree and 32% graduate school; and 16% of the student body qualify for free or reduced-price lunches. The school's 2002 API score was 696 out of 1,000. Nancy Day, chemistry teacher at Menlo-Atherton, attended our March 2005 Advancing Nanoscience Education workshop and has indicated interest in pilot-testing our materials with her students.

Miramonte High School, Orinda, CA. Miramonte's student population is 16% Asian, 3% Hispanic, and 1% African-American; the highest parent education level is 35% college degree and 57% graduate school; and fewer than 1% of the student body qualify for free or reduced-price lunches. The school's 2002 API score was 871 out of 1,000. Irene Hahn, chemistry teacher, attended our teacher meetings in year 1 and used the NanoSense Size Matters unit with two classes of chemistry students over the course of two weeks in May 2005. Ms. Hahn was also a partner teacher on the ChemSense project, developing several curriculum activities and testing them in her classroom.

Other Collaborators or Contacts

Advisory Panel

An advisory committee of recognized experts in chemistry, nanoscience, and science education guides and monitors the quality, relevance, and application of our work. Panel members include:

Dr. Larry Dubois—Nanoscientist and vice president of the Physical Sciences Division at SRI International.

Michael Ranney—Professor, Graduate School of Education, University of California, Berkeley. Dr. Ranney's expertise is in science education and scientific reasoning.

Deb Newberry—Former nuclear physicist and current industry consultant and nanoscience technology instructor at Dakota County Technical College Nanoscience Technology Program, and coauthor of the popular nanotechnology book *The Next Big Thing Is Really Small.*

Christine Peterson—Cofounder (with Eric Drexler) and president of Foresight Institute, a nonprofit that educates the public, technical community, and policy-makers on nanotechnology and its long-term effects.

Robert Tinker—Physicist and President of the Concord Consortium. Dr. Tinker directs the Molecular Workbench project, which offers simulations of self-assembly and other nanoscience phenomena.

Other Collaborators

Marcy Berding—A senior research physicist in the Physical Electronics Laboratory at SRI International. Dr. Berding advises on the science content of our units

Brent MacQueen—A senior research chemist in the Chemical Science and Technology Lab at SRI International. Dr. MacQueen advises on the science content of our units.

Grace Chou— A chemical engineer and director of business development at SRI International with expertise in membrane and process science. Dr. Chou advises on the science content of our units.

Ted Mill—A senior research chemist at SRI International with expertise in the oxidation of chemical organic compounds. Dr. Mill advises on the science content of our units.

Robert Cormia—Faculty member at Foothill-De Anza College (FHDA). Mr. Cormia a nanotechnology survey course at Foothill. We have consulted with Mr. Cormia on his “Atlas for Nanoscience” effort to build a topic map for the domain of nanoscience

Dr. Brian Coppola—Professor of chemistry at the University of Michigan and Co-PI of the ChemSense project. Dr. Coppola consults with the NanoSense project to help ensure the accuracy of the content and appropriateness of the curriculum activities.

Joan Carter—Teacher in Residence Science Education Program, San José State University. Ms. Carter collaborated with our SJSU partner, Dr. Scharberg, to develop an Introduction to Nanogeoscience curriculum unit using the Understanding by Design approach. She attended our initial NanoSense teacher workshops and provided feedback on our early materials.

Valerie Sermon, NASA Ames—Director, NASA Ames Research Center & Private Sector Internship Program. Ms. Sermon leads NASA Ames' collaboration with FHDA to support development of a new nanoscience certificate program and offer internships for students to participate in the program. She also helps organize nanoscience internships for high school students at the Ames Research Center. Dr. Sermon collaborated with NanoSense on the organization and structure of the March 2005 Advancing Nanoscience Education workshop.

Adolfo Nemirovsky—Chair of the NanoSIG nanoEducation and Training Forum (nETF). nETF promotes nanotechnology education and workforce development. Mr. Nemirovsky collaborated with the NanoSense team on the organization and structure of the March 2005 Advancing Nanoscience Education workshop.

Sukhjit Singh—Faculty, De Anza College. Dr. Singh collaborated with NanoSense staff and Mr. Cormia to develop and submit an NSF ATE proposal, “Nanotechnology Program Curriculum Articulation,” to create, test, refine and disseminate a nanotechnology curriculum articulation model, a set of modules, and an infrastructure to facilitate a modular set of nanotechnology courses to be offered by community colleges and universities. The proposal was not funded, but we are continuing to refine the idea for future submission.

SECTION 2: ACTIVITIES AND FINDINGS

(See also attached files)

Opportunities for Training and Development

The NanoSense team has a strong commitment to the training of students, researchers and teachers in the area of nanoscience education. This training is accomplished by working closely with researchers at SRI, faculty and students at San Jose State University, and teachers in local high schools. NanoSense staff have also attended professional development seminars and workshops on nanoscale science at Stanford University.

NanoSense funding supports a graduate student from Indiana University at Bloomington and a student assistant at San Jose State University (SJSU). By partnering with Indiana University and SJSU, we are supervising and supporting graduate students who will become the teachers, designers, researchers and educational policy makers of tomorrow.

Additionally, we have worked with at least dozen high school chemistry teachers who have provided useful and frequent feedback on the Nanosense activities and are using some or all activities in their classrooms. In addition to attending our teacher meetings and workshops, two of these teachers have interned with the project during the summer months. By working closely with teachers, we are providing teacher professional development opportunities and creating a teacher-researcher model that scaffolds procedures and activities necessary to co-design research in schools.

Outreach

The NanoSense web site provides public access to NanoSense activities, information about our workshops, presentations and publications, research findings, and project contact information.

NanoSense activities and findings have been presented in numerous forums, including the annual meeting of the American Education Research Association (AERA), the International Conference of the Learning Sciences (ICLS), the Exploratorium, the Boston Museum of Science, the Workshop on K-12 & Informal Nanoscale Science and Engineering Education, the Gordon Research Conference on Visualization in Science and Education, the Advancing Nanoscience Education workshop (Menlo Park, March 2005), and the Nanoscience Learning Goals workshop (Menlo Park, June 2006), and annual NSF IMD meetings.

The ChemSense software—a constructivist representational environment developed by our team and used in some NanoSense activities—is available for free download at http://chemsense.org and was also submitted to the Journal of Chemical Education (JCE) Digital Library in 2005.

SECTION 3: PUBLICATIONS AND PRODUCTS

Publications

Technical Reports

- Hsi, S., & Sabelli, N. (2006). Learning at the nanoscale: Research questions that the rapidly evolving interdisciplinarity of science poses for the learning sciences. Innovative Session, *7th International Conference of the Learning Sciences*, Bloomington, IN. Available online at http://nanosense.org//documents/papers/ICLS2006HsiSabelli.pdf

- Sabelli, N., Schank, P., Rosenquist, A., Stanford, T., Patton, C., Cormia, R., & Hurst, K. (2005). Report of the workshop on science and technology education at the nanoscale (PDF). DRAFT Technical Report, Menlo Park, CA: SRI International. Available online at http://nanosense.org//documents/ reports/NanoWorkshopReportDraft.pdf

Conference Presentations and Workshops

- Schank, P., Wise, A., Stanford, T., & Rosenquist, A. (2006, April). Teaching nanoscience to high school students: A tale of the NanoSense project. Poster presented at the *Annual Meeting of the American Educational Research Association (AERA)*, San Francisco, CA.

- Wise, A., & Schank, P., Stanford, T., & Rosenquist, A. (2006, April). The many challenges of designing and teaching nanoscience. Roundtable discussion at the *Annual Meeting of the American Educational Research Association (AERA)*, San Francisco, CA.

- Stanford, T., Ristevy, J., Schank, P., & Morrow, C. (2006, February). Size and scale: Research and recommendations. Roundtable discussion presented at the Instructional Materials Development Conference, Washington, DC.

- Schank, P., Wise, A., & Stanford, T. (2006, February). NanoSense: *Developing activities to teach high school students about nanoscience principles, applications, and implications*. Presented at the Instructional Materials Development Conference, Washington, DC. Available online at http://nanosense.org/documents/presentations/NanoSensePosterFlyer.pdf

- *Schank, P. (2006, February). Overview of the NanoSense and ChemSense projects. Presented at the* Nanoscale Informal Science Education Network (NISE) Visualization Laboratory Meeting*. February 17-18, San Francisco, CA.*

  - *Schank, P. (2005, October). The NanoSense project: Overview. Presented at the* Workshop on K-12 & Informal Nanoscale Science and Engineering Education *sponsored by the National Science Foundation. October 19-20, Washington, DC. Available online at http://nanosense.org/documents/presentations/NIMDNanoSenseOverview.ppt*

  - Schank, P. (2005, October). The NanoSense project: Design challenges and opportunities. Presented at the *Workshop on K-12 & Informal Nanoscale Science and*

Engineering Education sponsored by the National Science Foundation. October 19-20, Washington, DC. Available online at http://nanosense.org/documents/presentations/NIMDWorkshopOct2005.ppt

- Schank, P. (2005, July). That's what happens: *Students explain chemistry through drawing and animation*. Presented at the Gordon Science Education & Policy Conference on Visualization in Science & Education, Queen's College, Oxford, UK.

- Rosenquist, A. (2005, July). *NanoSense: The basic sense behind nanoscience*. Poster presented at the Gordon Science Education & Policy Conference on Visualization in Science & Education, Queen's College, Oxford, UK.

- Schank, P. (2005, February). NanoSense: *Developing activities to teach high school students about nanoscience principles, applications, and implications*. Presented at the Instructional Materials Development Conference, Washington, DC.

Web Sites

http://nanosense.org

The NanoSense Web site provides access to NanoSense activities, information about our workshops, presentations and publications, research findings, and project contact information.

Other Products

Curriculum Modules

The NanoSense team has developed and pilot-tested two full curriculum units—Size Matters and Clear Sunscreen—and is currently developing two other units—Clean Energy and Fine Filters.

All activities are made available to the public on the NanoSense Web site at http://nanosense.org once they have been pilot-tested, and are distributed at teacher workshops at national conferences and at training facilities at San Jose State University.

1. *Size Matters*. This unit provides an introduction to nanoscience, focusing on concepts related to the size and scale, unusual properties of the nanoscale, and example applications. The unit spans up to ten 50-minute classroom periods if all lessons are used. Available lessons and activities include demonstrations, labs on unique properties at the nanoscale, hands-on activities on size and scale, a black-box activity on probes, PowerPoint slides, readings, worksheets, quizzes, and a poster session performance assessment.

2. *Clear Sunscreen.* This unit explores issues related to size and scale, specifically the effect of the size of nanopowders on the interactions of energy and matter (e.g., the absorption of light, addressing the electromagnetic spectrum and associated wavelengths). For example, old sunscreens use "large" zinc oxide particles, which block ultraviolet light but scatter visible light, giving the cream a white color. If

nanopowders of zinc oxide are used instead, the cream is transparent, because the diameter of each nanoparticle is smaller than the wavelength of visible light. The unit spans up to twelve 50-minute classroom periods if all lessons are used. Available lessons and activities include a UV protection lab, ChemSense animation activities, Flash animations, an investigation of sunscreen labels activity, and a consumer information pamphlet project, PowerPoint slides, readings, and worksheets.

3. *Clean Energy* (under development). This unit focuses on how energy production is a pressing global issue and how nanoscience could enable important breakthroughs in energy generation and conversion. The unit will span three to four 50-minute classroom periods if all lessons are used. Available lessons and activities include a solar cell lab, a ChemSense animation activity, PowerPoint slides, quizzes, readings, and worksheets.

4. *Fine Filters* (under development). This unit focuses on the (uneven) scarcity of safe drinking water across the world, how water can be cleaned through a series of filtration steps, and how nanofiltration can be used as a cost-effective way to treat wastewater or as a pre-treatment before desalinization. The unit will span two or three 50-minute classroom periods. Available lessons and activities include a filtration-mechanisms lab, a ChemSense animation activity, a performance assessment, PowerPoint slides, readings, and worksheets.

Software

The ChemSense software supports the sharing, viewing, and editing of a variety of chemistry representations, including text, images, drawings, and animations of nanoscopic processes.

ChemSense is available for free download on the ChemSense web site at http://chemsense.or/download and has been submitted to the Journal of Chemical Education (JCE) Digital Library.

Instruments

The outside evaluator for NanoSense is observing classroom and workshop implementation of the curriculum units, collecting detailed questionnaires regarding students' response to elements of the units, and conducting semi-structured interviews with teachers and students about their understanding and experiences with the activities. Instruments developed include:

- NanoSense Workshop Evaluation for Students
- NanoSense Workshop Evaluation for Teachers
- NanoSense Pilot Testing Observation Protocol

SECTION 4: CONTRIBUTIONS

Nanoscience and Related Disciplines

Our work on NanoSense is generating a number of outcomes of value to nanoscale science learning. These include:

- Tools and curricular activities that help students and teachers understand and build models of nanoscale phenomena.
- A framework for developing nanoscale science curriculum that links to educational standards and introduces nanoscale science at appropriate places in traditional high school curricula.
- Support for science teachers to develop science understandings in unfamiliar science fields through teacher professional development materials.
- New knowledge about the relationships between students' use of representations and their understanding of nanoscale science.
- New knowledge about the forms of teacher practice in relation to student use of nanoscale representations, discussions, and collaborative inquiry.

Contributions to Other Disciplines

- A different lens through which students can revisit core concepts from physics, chemistry, and biology, as well as related areas such as materials science and engineering to support student understanding and (eventually) move these fields forward through interdisciplinary research.
- An improved understanding of the importance that constructivist representational environments can add to science learning—especially for students who have been less well served by traditional approaches to science education.
- An improved understanding of how teachers model and assess representational and collaborative practice to support student representation, discourse, and understanding, and what types of tools and activities support teacher practice.
- A general software environment for representation building and sharing animations that can be used in domains other than chemistry. For example, for nanoscience learning, students could animate concepts such as hydrogen filtration by carbon nanotubes, representing details such as hydrogen and tritium gas, the introduction of nanotubes, and tritium becoming trapped in the nanotubes over time. If adapted for physics learning, students could animate concepts such as Newton's 2nd Law of Motion (F=ma), representing details such as velocity and acceleration at a macroscopic level. If adapted for biology learning, students could animate concepts such as mitotic cell division,

representing details such as chromosome replication and movement to each pole of the cell.

Human Resources

We are developing and disseminating new educational materials that expose teachers and students to the emerging field of nanoscience and provide compelling, real-world examples of science in action that aim to improve student interest (and hopefully retention) in science. We are also contributed to the training of several new researchers—one graduate student and one undergraduate—and are working closely with several high school chemistry teachers. In doing so, we are supervising and supporting graduate students who will become the teachers, designers, researchers and educational policy makers of tomorrow, and are scaffolding procedures and activities that are necessary to co-design research in schools.

Research and Education

Our work on NanoSense is generating a number of outcomes of value to the endeavors of researchers and educators both in and outside of the scientific disciplines. These include:

- The creation of classroom-tested activities to give students direct experience with the methods and processes of science more generally and nanoscale science in particular, in keeping with emerging science standards (National Research Council, 1997; AAAS, 1993).

- Interdisciplinary activities to help tie together the disjoint high school curriculum, support understanding of the interconnections between the traditional scientific domains, and provide compelling, real-world examples of science in action.

- Professional development materials for teachers to increase their understanding of the fundamental scientific disciplines (e.g., chemistry, biology, physics) that contribute to nanoscale science.

- The application of a generalized software framework (ChemSense) that could be used to support collaboration and representation construction in other domains, and to gather student data for research in these domains.

- An improved understanding of the representational environments that can add to science learning

- An improved understanding of how teachers model and assess representational and collaborative practice to support student representation, discourse, and understanding

Public Welfare

We believe that nanoscale science curriculum paired with constructivist representational environments can improve science learning and lead to a populace better educated and able to make informed decisions on issues and technologies that affect many aspects our lives. We also hope that students who are introduced to nanoscience through compelling, real-world examples of science in action will be more motivated to continue studying science than has been the case in the past—and provide the knowledge and skills needed to innovate and solve challenges that we face now and in the future.

NanoSense: The Basic Sense behind Nanoscience

YEAR 2 ACTIVITIES

Activities conducted during second year of the NanoSense project are described below. We categorize the work in terms of 7 activities.

Activity 1: Instructional Materials Development

Overview

In the second year of the grant, we implemented major revisions to our Size Matters unit based on feedback from our teachers, findings from pilot testing, and recommendations from our advisors and site visitor. The Clean Sunscreen unit was also completed, pilot tested, and revised, and we began development on two new units: Fine Filters and Clean Energy. These units are described in more detail below.

Size Matters: An Introduction to Nanoscience

Exhibit 1 shows an outline of the Size Matters unit, which provides an introduction to nanoscience, focusing on concepts related to the size and scale, unusual properties of the nanoscale, and example applications. Upon completing this unit, students will understand:

1. The study of unique phenomena at the nanoscale could vastly change our understanding of matter and lead to new questions and answers in many areas, including health care, the environment, and technology.
2. There are enormous scale differences in our universe, and at different scales, different forces dominate and different models better explain phenomena.
3. Nanosized particles of any given substance exhibit different properties than larger particles of the same substance.
4. New tools for observing and manipulating matter increase our ability to investigate and innovate.

The Size Matters unit spans up to ten 50-minute classroom periods if all lessons are used. Not all lessons are required; the unit overview provides guidance on which lessons to use depending on teacher and student interests. A one-day version is also available. Available lessons and activities include demonstrations, labs on unique properties at the nanoscale, hands-on activities on size and scale, a black-box activity on probes, PowerPoint slides, readings, worksheets, quizzes, and a poster session performance assessment.

This unit was pilot tested in classrooms in 2005, and the results of this testing are described in the Year 1 report. Based on pilot test findings and suggested revisions by our teachers and advisors, the unit was significantly revised in the summer and fall of 2006. Major revisions included the following: revised the enduring understandings to be more specific; added a new lesson on tools of the nanosciences; added more history to the introductory lesson; added alignment charts, a unit overview, and table of contents; supplemented the teacher materials with more background reading and complete keys for all activities; revised the properties lab directions to include more details and safety information; revised the properties slides to map more closely to the student reading; created a 1-day version of the unit; and refined the ordering and reformat the unit with a new look-and-feel designed by a graphic designer. The Size Matters unit is available for download at http://nanosense.org/activities/sizematters/

Clear Sunscreen: How Light Interacts with Matter

Exhibit 2 shows an outline of the Clear Sunscreen unit, which explores issues related to size and scale, specifically the effect of the size of nanopowders on the interactions of energy and matter (e.g., the absorption of light, addressing the electromagnetic spectrum and associated wavelengths). For example, old sunscreens use "large" zinc oxide particles, which block ultraviolet light but scatter visible light, giving the cream a white color. If nanopowders of zinc oxide are used instead, the cream is transparent, because the diameter of each nanoparticle is smaller than the wavelength of visible light. Upon completing this unit, students will understand:

1. How the energies of different wavelengths of light interact differently with our skin and vision.
2. Why particle size can affect the optical properties of a material.
3. That there may be health issues for nanosized particles that are undetermined at this time.
4. That it is possible to engineer useful materials with an incomplete understanding of their properties.
5. There are often multiple valid theoretical explanations for experimental data; to find out which one work best, additional experiments are required.
6. How to apply their scientific knowledge to be an informed consumer of chemical products.

The Clear Sunscreen unit spans up to twelve 50-minute classroom periods if all lessons are used. Not all lessons are required; the unit overview provides guidance on which lessons to use depending on teacher and student interests. Available lessons and activities include a UV protection lab, ChemSense animation activities, Flash animations, an investigation of sunscreen labels activity, and a consumer information pamphlet project, PowerPoint slides, readings, and worksheets.

This unit was pilot-tested in a February 2006 workshop and significantly revised as a result of workshop findings, as described in the Findings section of this report. The unit is available for download on the NanoSense web site at http://nanosense.org/activities/clearsunscreen/

Clean Energy: Nano Solar Cells and Clean Hydrogen Production

Exhibit 3 shows an outline of the Clean Energy unit, currently under development. This unit focuses on how energy production is a pressing global issue and how nanoscience could enable important breakthroughs in energy generation and conversion. This unit will be pilot tested in fall 2006. Tentative enduring understandings for this unit include the following:

1. Energy production is one of the most pressing global issues that humanity must address over the next few decades.
2. Clean alternative energy technologies must be developed to provide sufficient energy to meet growing global demand, and must be sustainable both environmentally and economically.
3. Nanoscience could enable important breakthroughs in solar energy conversion by exposing high surface areas of light-absorbing substances to solar radiation.
4. Nanoscience could enable an important breakthrough in clean energy technology by using nanocatalysts to efficiently produce hydrogen fuel that can be stored and used in fuel cells.

5. Surface are to volume ratio is a function of particle size and shape. Increasing surface area normally increases the rate of reaction because there are more sites available for simultaneous reaction.
6. Energy is neither created nor destroyed—it can only be converted into different forms.

The Clean Energy unit will span three to four 50-minute classroom periods if all lessons are used. Not all lessons will be required; the unit overview will provide guidance on which lessons to use depending on teacher and student interests. Available lessons and activities include a solar cell lab, a ChemSense animation activity, PowerPoint slides, quizzes, readings, and worksheets.

Fine Filters: Nanofiltration

Exhibit 4 shows an outline of the Fine Filters unit, currently under development. This unit focuses on the (uneven) scarcity of safe drinking water across the world, how water can be cleaned through a series of filtration steps, and how nanofiltration can be used as a cost-effective way to treat wastewater or as a pre-treatment before desalinization. This unit will be pilot tested in fall 2006. Tentative enduring understandings for this unit include the following:

1. A shortage of clean drinking water is one of the most pressing global issues.
2. How substances can be separated from heterogeneous and homogeneous solutions.
3. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter. The smaller the pore size of the filter used for separation, the higher the cost of the process.
4. Technology can be used to help improve critical global health problems.

The unit will span two or three 50-minute classroom periods. Available lessons and activities include a filtration-mechanisms lab, a ChemSense animation activity, a performance assessment, PowerPoint slides, readings, and worksheets.

Activity 2: Teacher Meetings and Workshops

In the second year of the NanoSense project, we held 10 meetings with our partner teachers. Primary objectives of the meetings included gathering feedback on activities and planning use of materials in the classroom and in workshops. Meetings lasted from 2 to 4 hours, except for the February 11 workshop, which was a full-day workshop that included both teachers and students.

July 27, 2005: Review Size Matters and Clear Sunscreen units

Teachers provided oral and written feedback on new materials (Tools of the Nanosciences lesson materials, alignment and unit overview charts, nanofiltration reading) that were distributed a week prior to the meeting. Alyssa Wise also solicited feedback on the planned lab activities for the Clear Sunscreen. For each material discussed, we focused on the following questions: What are the core science concepts (and prerequisites) for this lesson? Where would it fit into what you teach? Are there revisions that would make it a better fit for you? What kind of visualizations on this topic would help your students?

September 12, 2005: Review Size Matters and Clear Sunscreen Units, Scheduling

Major updates to the Size Matters (including more teacher materials and keys, and a new layout/look) and updates to the Clear Sunscreen units based on teacher feedback were presented for discussion. Scheduling for pilot testing of activities in teacher classrooms was also discussed, with a goal of identifying a few days or a week in which our evaluator, Ellen Mandinach from EDC, could fly out and observe use of the materials in two or more classrooms. The earliest dates that the teachers could commit to were in late January, early February, or late May.

October 17, 2005: Review Size Matters and Clear Sunscreen Units

We handed out updated Size Matters unit binders and reviewed the One Day lesson plan, mesogold and ferrofluid demonstrations, and slide presentation. The teachers said they really liked the lesson, and two planned to use it in January. Alyssa Wise walked the group through the first draft of the Clear Sunscreen slides and the teachers provided detailed feedback on each slide. The teachers felt that the material was quite sophisticated, but that it worked well for building deeper knowledge. "It's beautiful science," one teacher commented.

December 5, 2005: Review Clear Sunscreen Unit, Visiting Guests, and Scheduling

Doris Mourad described a nanofiltration lab designed and conducted by her students, and we discussed minor updates to the Size Matters and Clear Sunscreen unit. Tina Stanford reported on her experience leading a NanoSense workshop at the Boston Museum of Science in November (see NanoTech 2005 below). Two guests—Miguel Aznar, Director of Education at the Foresight Nanotech Institute, and Celeste Carter, head of the Foothill College Biotechnology program—attended to learn more about the project and describe their work to the teachers. Because we wanted to pilot test the Clear Sunscreen unit with students soon, and our teachers were having difficultly finding time before May to cover the unit, we made a key decision to pilot test the unit with students and teachers in a one-day workshop on a Saturday in February. Our partner teachers both suggested and enthusiastically embraced this workshop alternative, and four of them volunteered to be responsible for teaching one or more of the five Clear Sunscreen lessons.

January 16, 23 and Feb 6, 2006: Student-Teacher Workshop Planning

Our next 3 meetings focused on planning for the February workshop. The teachers choose Clear Sunscreen lessons to lead (see agenda below), practiced with each other, asked questions about the unit, and recruited some of their students to attend the workshop. We coordinated with Maureen Scharberg to hold the workshop at training facilities at San Jose State University, publicized the workshop on our web site, and distributed a flyer about the workshop (see http://nanosense.org/documents/workshops/2006Feb11NanoWorkshopFlyer.pdf), to mailing lists for science teachers in the San Francisco Bay Area.

February 11, 2006: Student-Teacher Workshop

Seven teachers, two student teachers, two visitors, five NanoSense staff members, and 31 high school students attended the all day NanoSense workshop. See Exhibit 5 for the agenda, and the Findings section for a detailed description of student and teacher responses and student understanding based on data (e.g., from evaluation surveys, student work, and interviews) collected at the workshop, and recommended revisions to the Clear Sunscreen unit that were implemented as a result.

April 8, 2006: Workshop Findings and Reflection

Alyssa Wise presented a summary of our workshop findings (see the Findings section of this report) and the teachers reflected on our findings and their experience of the workshop. In particular, the teachers expressed a desire for more structured practice time with the materials before introducing them to their students. Based on our discussions, we decided to focus this summer on polishing the Clean Energy and Nanofiltration units, and hold longer (e.g., 2-day) workshops—one for each of the four existing NanoSense units—at San Jose State University in the fall and spring of 2006/2007. In these workshops, the NanoSense team would (for example) present the materials on the first day, and the teachers would practice with the materials on the second day. We will recruit additional teachers who can commit to try at least one unit in their classroom and report on their experience.

April 24, and May 17, 2006: Review Clean Energy Unit

Prior to the meeting, the first draft of the learning goals for the new Clean Energy unit was distributed to our partner teachers by email. At the meeting, Anders Rosenquist presented the first draft of the PowerPoint slides for the unit, and the teachers provided detailed feedback on the slides and the learning goals.

May 24, 2006: Review Fine Filters Unit

Prior to the meeting, the first draft of the learning goals for the new Fine Filters unit was distributed to our partner teachers by email. At the meeting, Tina Stanford presented the first draft of the PowerPoint slides for the unit, and the teachers provided detailed feedback on the slides and the learning goals.

Meeting Participants

Attendees of the teacher meetings above included the following:

- NanoSense Team:
  - Patricia Schank, SRI International
  - Tina Stanford, SRI International
  - Anders Rosenquist, SRI International
  - Alyssa Wise, SRI International (summer intern) and Indiana University
  - Vera Michalchik, SRI International
  - Maureen Scharberg, San Jose State University

- Core Partner Teachers Attending Most Meetings:
  - Doris Mourad, Castilleja School, Palo Alto, CA
  - Carolina Sylvestri, Gunn High School, Palo Alto, CA
  - Miriam Motoyama, Gunn High School, Palo Alto, CA
  - Geri Horsma, Gunn High School, Palo Alto, CA

- Visiting Teachers Attending One or Two Meetings:
  - Victor Brandalais, San Jose State University (Teacher in Residence)
  - Joan Carter, San Jose State University (Teacher in Residence)
  - Nancy Day, Menlo-Atherton High School, Menlo Park, CA
  - Jeff DeCurtains, Menlo-Atherton High School, Menlo Park, CA
  - Irene Hahn, Miramonte High School, Orinda, CA

- Britt Hammon, Antioch High School, Antioch, CA
- Resa Kelly, San Jose State University
- Claudia Winkler, Gunn High School, Palo Alto, CA

NanoTech 2005 Workshop at Boston Museum of Science

In November 2005, Co-PI Tina Stanford lead a NanoSense workshop at "Nanotech 2005: A Symposium for Educators at the Museum of Science" held at the Boston Museum of Science. NanoSense was invited to lead a workshop by Carol Lynn Alpert, Director of Strategic Projects at the Museum of Science after discussions with Dr. Alpert at the NSF-sponsored Workshop K-12 & Informal Nanoscale Science and Engineering Education on October 19-20, 2005.

The Nanotech 2005 symposium introduced about 75 middle school, high school, and community college science and engineering teachers (mainly from the Boston area) to the basic concepts of nanoscale science and engineering through hands-on classroom workshop sessions and keynotes by Professors Eric Mazur and George Whitesides, both from Harvard University. This symposium was supported by NSF, through partnerships with two Nanoscale Science and Engineering Centers, and by grants from NIH. For more information on the symposium, see http://www.mos.org/doc/1894

Ms. Stanford led two 75-minute sessions on selected lessons from the NanoSense Size Matters unit. A wide range middle and high school, biology, chemistry, and physics teachers participated. Ms. Stanford handed out copies of the unit, walked the teachers through some of the size and scale activities (Cutting it Down and Number Line Card Sort), presented the slides for the One-Day Lesson, and did the Bubble Lab to illustrate self assembly. The teachers reported that the workshop helped them clarify their understanding of nanoscale science and imagine ways that they could fit activities into their existing curriculum. The middle school teachers especially liked the size and scale activities, viewing them as a good way to get their kids to think about "how small is small." After the workshop, several teachers who had not attended the session approached Ms. Stanford to request copies of the curriculum. It was exciting to see our materials met with interest from a wide range of teachers.

Activity 3: Evaluation

The focus of our Year 2 evaluation was on a 1-day NanoSense workshop for high school science teachers and their students, held at training facilities at San Jose State University (hosted by our subcontractor, Maureen Scharberg). The workshop agenda is shown in Exhibit 5. All lessons at the workshop were presented by our partner teachers, except as noted in the agenda (Alyssa Wise, the author of the Clear Sunscreen unit, introduced a couple of lessons). After a general introduction to nanoscience (the One-Day Introduction to Nanoscience lesson from the Size Matters unit), the students and teachers completed the Clear Sunscreen unit. A nanoscientist from SRI International also presented his work over the lunch hour. Participating teachers were given sets of materials to take back to their classroom and were encouraged to give feedback and input on the materials. Student worksheets and project artifacts, an extensive evaluation survey, and written comments and questions were collected from all participants. All participants were given a certificate of completion.

A detailed analysis of the workshop findings, including student and teacher responses and student understanding, is provided in the Findings section of this report.

Activity 4: Use of Materials by Others

University of Wisconsin

In December 2005, Janice Hall, a graduate student at the University of Wisconsin emailed the NanoSense team. She said that the "NanoSense materials have been extremely useful to me (and soon to many others I hope!)". She and her advisor, Dr. John Moore, are working on an online course about Nanoscience for high school teachers. Their goal is to provide teachers with a background on nanoscience and materials they can use in their current curricula. A colleague (Dr. Andrew Greenberg) told them about the NanoSense project and materials, and she has found them to be "so useful we'd love to include them in our course," with a link to the NanoSense website. Dr. Moore plans to offer the course during the summer of 2005, and Ms. Moore said that the NanoSense material "would be a wonderful addition, that clearly shows how teachers can implement this great new subject in their classrooms, and of how it can satisfy current scientific standards."

Christopher Newport University

In spring 2006, Professor S. Raj Chaudhury used the Size Matters unit in his introductory physics course at Christopher Newport University in Newport News, Virginia. The course—PHYS 104, Elementary Physics II—is part of the science breadth requirement for graduation of non-science majors, and emphasizes conceptual understanding and basic problem solving. The PowerPoint slides in the unit were used to introduce students to nanoscience concepts that do not appear in the curriculum or textbooks. Approximately 2-3 weeks were devoted to the topic. Activity sheets were used as homework, and the students were assessed with questions on quizzes and tests. The instructor reported that "the materials fit nicely after an introduction to quantum mechanics, which students had completed," and that "the students appeared to find the materials interesting as they connect to many modern-day applications." A shortened version of the Sunscreen unit, including the UV bead lab, was also used.

NCLT

Molly Yunker and Nikki Guthrie, PhD students working with Joe Krajcik, completed a constructive critique of the NanoSense Clear Sunscreen unit based on the Project 2061 criteria for evaluating curriculum materials. This critique was done as part of a spring 2006 course on designing learning environments. Molly and Nikki identified areas of the unit that they felt could be improved upon and offered their feedback to our Alyssa Wise, the lead developer of this unit, and to the NanoSense research team.

California Community Colleges

In December 2005, Diana Rude from Bina Consulting contacted NanoSense on behalf of California Community Colleges. As a component of their research, they are identifying existing workforce education and training programs/projects in this industry area. They requested use of our materials for their project on workforce training needs in nanotechnology industries. We discussed their need and welcomed them to download the materials on the NanoSense web site.

Feedback on Informal Use by Teachers

In December 2005, biology teacher Geri Horsma used the introductory 1-day overview of the introductory Size Matters unit with her biotech class at Gunn High School in Palo Alto, and reported that it was "a nice experience!" Her student teacher ran the power point presentation, and she did the narration. She said that "Students were very interested, asked questions, and I really appreciated having the "script" to use as a help!" They were also "enthusiastic about seeing red gold" (a demonstration that is part of the 1-day version).

Activity 6: Synergistic Activities

A Workshop to Identify and Clarify Nanoscience Learning Goals

In November 2005, Patricia Schank (NanoSense PI) and Joe Krajcik (NCLT Co-PI) submitted a proposal to NSF to hold a national workshop to bring together leading experts and practitioners in nanoscience, learning science and science education to identify and clarify learning goals for nanoscience. The proposal was funded and is scheduled to be held at SRI International June 14-16, 2006. The major goals of the workshop are to obtain an informed consensus on the major concepts of nanoscience, clarify the meanings of these concepts, turn these concepts into learning goals, link the learning goals to national standards, and point out where links to the standards do not exist. The outcomes of the workshop will be documented in a public report and presented at various national conferences to benefit materials developers and push the research agenda in nanoscience education.

Proposal: Framework for Molecular Modeling Curriculum Project

Leveraging work from the ChemSense project at SRI International and the Modeling Across the Curriculum (MAC) project at the Concord Consortium, the NanoSense team submitted a proposal to produce a robust instructional framework and associated curriculum for grades 6-8 and 9-12 in the areas of modeling and the particulate nature of matter. The framework would detail what content knowledge, process skills, and techniques are developmentally appropriate at each grade level and help students learn how to construct, manipulate, and understand the functionality of models. This proposal was not funded.

Proposal: SCALE: Investigating a Multiscale Modeling Framework to Illustrate Issues of Scale in Introductory Engineering Courses

In August 2005, the NanoSense team submitted a proposal to NSF's Engineering Education Program (EEP) to test the hypothesis that integrated, multiscale, multidisciplinary modeling software can serve as the basis for student "cognitive apprenticeship" and "cognitive flexibility" in lower-division engineering courses. We proposed to develop a prototype, "proof-of-concept" application to be tested and refined with engineering students and instrumented with assessment tools geared to core concepts—focusing on how specific properties change as the size scale changes, since this relationship provides an easy access point for students to understand how different theoretical models represent different parts of the scale. This proposal was not funded.

Activity 6: Advisory Activities

On July 26, 2006, Dr. Lawrence Woolf from General Dynamics visited SRI to conduct a site visit of the NanoSense project, addressing several "big questions" including: What did you say you would do? What are you actually doing? How do you know you are doing it well? How can nanoscience help students obtain a coherent and comprehensive view of important science concepts? Before the meeting, Dr. Woolf reviewed our annual report, Size Matters unit, and early drafts of parts of our Clear Sunscreen unit. We also sent Dr. Woolf a document with our responses to the big questions and to other questions (e.g., about visualization, enduring understandings, topics covered in our materials, and the science behind clear sunscreen) that he and our program officer submitted. During the meeting, we discussed these questions in depth, and with helpful suggestions from Dr. Woolf, refined our materials and processes. For example, we refined our enduring understandings to be more specific, added more organizing structure to our units (e.g., table of contents, unit overviews), included more history in the introductory unit, and refined our process for choosing topics to focus on those at the intersection of available expertise, common curricular gaps, engaging topics, and opportunities for innovative approaches. After the meeting, we sent Dr. Woolf a copy of the Clear Sunscreen materials (in development at the time) to which he provided extensive feedback via email. Dr. Woolf also sent us some final questions and submitted his site visit report, which we responded to in a separate document submitted to him and to our program officer.

In line with our refined plan for choosing topics for our upcoming units, we identified potential topics and then held meetings with SRI nanoscientists Grace Chou, Ted Mill, Brent MacQueen, and Marcy Berding to better understand engaging aspects of these topics, the science behind the topics, and the availability of expertise at SRI in the identified areas. These discussions (and follow-on question-answer sessions with the scientists) were very helpful in guiding the choice, focus, and development of two new units on nanofiltration and clean energy.

Grace Chou, a chemical engineer with expertise in membrane and process science, discussed with us a variety of filtration processes and applications of nanofiltration in food processing and water treatment. She explained how nanofiltration does not work for desalination (reverse osmosis is required), but it can be used to purify wastewater and as a pre-treatment before desalination. Grace emailed several references to the team after our meeting and offered to serve as an expert consultant on our proposed nanofiltration unit. We are currently developing a unit on water treatment (nanofiltration) that will fit into chemistry curriculum under the topic of separating mixtures.

Ted Mill described his research on oxidation of chemical organic compounds and how it can be applied to remove organics from water. He is currently looking at ways of treating water with sunlight or artificial light through photosemiconductors (using nanoparticles of TiO2 as a catalyst) to oxidize organic compounds. He noted that oxidation may work better than filtration in some instances, since odor-causing compounds are often organic. Ted and Grace agreed that catalysis and optical phenomena are promising areas of nanoscience, since chemical and optical properties fundamentally change in the nanoscale size range. Ted recommended that we consider a unit on mechanical properties, for example, of carbon nanotubes. Finally, they described ways that nanoscience could impact research in clean energy (energy produced without pollutants) and renewable energy (such as solar energy), noting that this is a very promising field of research and that SRI has expertise in this area.

Brent MacQueen described in depth the science and technology behind clean and renewable energy. Brent explained how nanoscience could enable important breakthroughs in (renewable) solar energy conversion by exposing high surface areas of light-absorbing substances to solar radiation. Nanoparticulate titanium Graetzel cells are an example of such a technology. He explained how conventional solar cells work, how Graetzel-cell-based solar cells work, and the advantages and disadvantages of each. He also described how nanocatalysts could be used to efficiently produce hydrogen fuel that could be stored and used in fuel cells. After the meeting, Brent sent us additional references, we asked clarifying questions via email, and he reviewed the learning goals that we developed for the Clean Energy unit for scientific accuracy.

Activity 7: Dissemination and Outreach Activities

Papers and presentations

NanoSense activity development progress and current findings were presented at AERA, ICLS, the Exploratorium, the Workshop on K-12 & Informal Nanoscale Science and Engineering Education, and at the annual IMD meeting. At the IMD conference, Tina Stanford highlighted year 2 activities of the NanoSense project, materials that were developed, challenges and opportunities, and our implementation approach.

Publication citations

- Hsi, S., & Sabelli, N. (2006). Learning at the nanoscale: Research questions that the rapidly evolving interdisciplinarity of science poses for the learning sciences. Innovative Session, *7th International Conference of the Learning Sciences*, Bloomington, IN. Available online at http://nanosense.org//documents/papers/ICLS2006HsiSabelli.pdf

- Sabelli, N., Schank, P., Rosenquist, A., Stanford, T., Patton, C., Cormia, R., & Hurst, K. (2005). Report of the workshop on science and technology education at the nanoscale (PDF). DRAFT Technical Report, Menlo Park, CA: SRI International. Available online at http://nanosense.org//documents/ reports/NanoWorkshopReportDraft.pdf

Presentation citations

- Schank, P., Wise, A., Stanford, T., & Rosenquist, A. (2006, April). Teaching nanoscience to high school students: A tale of the NanoSense project. Poster presented at the *Annual Meeting of the American Educational Research Association (AERA)*, San Francisco, CA.

- Wise, A., & Schank, P., Stanford, T., & Rosenquist, A. (2006, April). The many challenges of designing and teaching nanoscience. Roundtable discussion at the *Annual Meeting of the American Educational Research Association (AERA)*, San Francisco, CA.

- Stanford, T., Ristevy, J., Schank, P., & Morrow, C. (2006, February). Size and scale: Research and recommendations. Roundtable discussion presented at the Instructional Materials Development Conference, Washington, DC.
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- Schank, P., Wise, A., & Stanford, T. (2006, February). NanoSense: *Developing activities to teach high school students about nanoscience principles, applications, and implications*. Presented at the Instructional Materials Development Conference, Washington, DC. Available online at http://nanosense.org/documents/presentations/NanoSensePosterFlyer.pdf

- Schank, P. (2006, February). Overview of the NanoSense and ChemSense projects. Presented at the *Nanoscale Informal Science Education Network (NISE) Visualization Laboratory Meeting*. February 17-18, San Francisco, CA.

- Schank, P. (2005, October). The NanoSense project: Overview. Presented at the *Workshop on K-12 & Informal Nanoscale Science and Engineering Education* sponsored by the National Science Foundation. October 19-20, Washington, DC. Available online at http://nanosense.org/documents/presentations/NIMDNanoSenseOverview.ppt

- Schank, P. (2005, October). The NanoSense project: Design challenges and

opportunities. Presented at the *Workshop on K-12 & Informal Nanoscale Science and Engineering Education* sponsored by the National Science Foundation. October 19-20, Washington, DC. Available online at http://nanosense.org/documents/presentations/NIMDWorkshopOct2005.ppt

NanoSense Web site

Activities developed by the NanoSense team are made available to the public on the NanoSense Web site (http://nanosense.org) as they are pilot-tested and vetted by our partner teachers. The introductory Size Matters unit and the Clear Sunscreen unit are currently available on the Web site, and 2 more units (Clean Energy and Fine Filters) will be posted in 2006. The units are also distributed at conferences and teacher workshops.

Exhibit 1. Size Matters unit materials.

Overview of Unit
Teacher Materials
- For Anyone Planning to Teach Nanoscience…Read This First!
- Size Matters Overview and Learning Goals
- Unit at a Glance: Suggested Sequencing of Activities
- Alignment Chart: Enduring Understandings
- Alignment Chart: Key Knowledge and Skills

Lesson 1: Introduction to Nanoscience
Teacher Materials
- Introduction to Nanoscience: Teacher Lesson Plan
- Introduction to Nanoscience: PowerPoint with Teacher Notes
- Introduction to Nanoscience Worksheet: Teacher Key

Student Materials
- Introduction to Nanoscience: Student Reading
- Introduction to Nanoscience: Student Worksheet
- Scale Diagram: Dominant Objects, Tools, Models, and Forces at Different Scales
- The Personal Touch: Student Reading
- The Personal Touch: Student Worksheet

Lesson 2: Scale of Objects
Teacher Materials
- Scale of Objects: Teacher Lesson Plan
- Number Line Activity: Teacher Key
- Scale of Objects Activity: Teacher Key
- Cutting it Down Activity: Teacher Key
- Scale of Small Objects Quiz: Teacher Key

Student Materials
- Visualizing the Nanoscale: Student Reading
- Scale Diagram: Dominant Objects, Tools, Models, and Forces at Different Scales
- Number Line Activity: Student Instructions
- Scale of Objects Activity: Student Instructions
- Cards and Line Markers for Number Line and Scale of Objects Activities
- Cutting it Down Activity: Student Instructions
- Scale of Small Objects: Student Quiz

Lesson 3: Unique Properties at the Nanoscale
Teacher Materials
- Unique Properties at the Nanoscale: Teacher Lesson Plan
- Unique Properties at the Nanoscale: PowerPoint with Teacher Notes
- Unique Properties Lab Activities: Teacher Instructions
- Unique Properties at the Nanoscale: Teacher Reading
- Unique Properties at the Nanoscale Quiz: Teacher Key

Student Materials

- Size-Dependent Properties: Student Reading
- Unique Properties Lab Activities: Student Instructions
- Unique Properties Lab Activities: Student Worksheet
- Unique Properties at the Nanoscale: Student Quiz

Lesson 4: Tools of the Nanosciences
Teacher Materials
- Tools of the Nanosciences: Teacher Lesson Plan
- Scanning Probe Microscopy: Teacher Reading
- Scanning Probe Microscopy: PowerPoint with Teacher Notes
- Black Box Activity: Teacher Instructions
- Seeing and Building Small Things Quiz: Teacher Key
- Optional Extensions for Exploring Nanoscale Modeling Tools: Teacher Notes

Student Materials
- Black Box Lab Activity: Student Instructions and Worksheet
- Seeing and Building Small Things: Student Reading
- Seeing and Building Small Things: Student Quiz

Lesson 5: Applications of Nanoscience
Teacher Materials
- Applications of Nanoscience: Teacher Lesson Plan
- Applications of Nanoscience: PowerPoint with Teacher Notes
- What's New Nanocat? Poster Session: Teacher Instructions and Rubric

Student Materials
- What's New Nanocat? Poster Session: Student Instructions
- What's New Nanocat? Poster Session: Student Topic List
- What's New Nanocat? Poster Session: Peer Feedback Form

One Day Introduction to Nanoscience
Teacher Materials
- One Day Introduction to Nanoscience: Teacher Lesson Plan
- One Day Introduction to Nanoscience: Teacher Demonstration Instructions
- One Day Introduction to Nanoscience: PowerPoint with Teacher Notes

Exhibit 2. Clear Sunscreen unit materials.

Overview of Unit
Teacher Materials
- For Anyone Planning to Teach Nanoscience…Read This First!
- Clear Sunscreen Overview, Learning Goals & Standards
- Unit at a Glance: Suggested Sequencing of Activities
- Alignment of Unit Activities with Learning Goals
- List of Sunscreen Products that use Nanoparticle Ingredients

Lesson 1: Introduction to Sun Protection & Initial Ideas
Teacher Materials
- Clear Sunscreen Introduction to Sun Protection & Initial Ideas: Teacher Lesson Plan
- Nano Sunscreen – The Wave of the Future?: PowerPoint with Teacher Notes
- Clear Sunscreen Initial Ideas: Teacher Instructions
- Ultra-Violet (UV) Protection Lab Activity: Teacher Instructions & Answer Key

Student Materials
- Kinds of Sun Radiation: Student Handout
- Clear Sunscreen Initial Ideas: Student Worksheet
- Ultra-Violet (UV) Protection Lab Activity: Student Instructions & Worksheet

Lesson 2: All About Sunscreens
Teacher Materials
- All About Sunscreens: Teacher Lesson Plan
- All About Sunscreens: PowerPoint with Teacher Notes
- Sunscreen Ingredients Lab Activity: Teacher Instructions & Answer Key
- Reflecting on the Guiding Questions: Teacher Instructions

Student Materials
- Sunscreen Ingredients Lab Activity: Student Instructions & Worksheet
- Summary of FDA Approved Sunscreen Ingredients
- Reflecting on the Guiding Questions: Student Worksheet

Lesson 3: The Science Behind Sunscreen Protection: Absorption
Teacher Materials
- The Science Behind Sunscreen Protection: Absorption: Teacher Lesson Plan
- The Science Behind Sunscreen Protection: Absorption: PowerPoint with Teacher Notes
- Reflecting on the Guiding Questions: Teacher Instructions

Student Materials
- Absorption of Light by Matter: Student Reading
- Reflecting on the Guiding Questions: Student Worksheet

Lesson 4: The Science Behind Sunscreen Protection: Scattering
Teacher Materials
- The Science Behind Sunscreen Protection: Scattering: Teacher Lesson Plan
- The Science Behind Sunscreen Protection: Scattering: PowerPoint with Teacher Notes
- Scattering of UV Light Animations: Teacher Instructions & Answer Key

- Ad Campaign Project I (ChemSense Activity): Teacher Instructions & Rubric
- Reflecting on the Guiding Questions: Teacher Instructions

Student Materials

- Scattering of Light by Particles: Student Reading
- Scattering of UV Light Animations: Student Instructions & Worksheet
- Ad Campaign Project I (ChemSense Activity): Student Instructions
- Reflecting on the Guiding Questions: Student Worksheet

Lesson 5: Stylish Sunscreens: What Determines Sunscreens' Appearance

Teacher Materials

- Stylish Sunscreens: What Determines Sunscreens' Appearance: Teacher Lesson Plan
- Stylish Sunscreens: What Determines Sunscreens' Appearance: PowerPoint with Teacher Notes
- Scattering of Visible Light Animations: Teacher Instructions & Answer Key
- Ad Campaign Project II (ChemSense Activity): Teacher Instructions & Rubric
- Reflecting on the Guiding Questions: Teacher Instructions

Student Materials

- Scattering of Visible Light Animations: Student Instructions & Worksheet
- Ad Campaign Project II (ChemSense Activity): Student Instructions
- Reflecting on the Guiding Questions: Student Worksheet

Lesson 6: Summary & Culminating Activities

Teacher Materials

- Culminating Activities: Teacher Lesson Plan
- Consumer Choice Project: Teacher Instructions & Rubric
- The Science Behind the Sunscreen: Teacher Answer Key to Quiz
- Final Reflections: Teacher Instructions

Student Materials

- Consumer Choice Project: Student Instructions
- Consumer Choice Project: Peer Feedback Form
- The Science Behind the Sunscreen: Student Quiz
- Final Reflections: Student Worksheet

Exhibit 3. Proposed Clean Energy unit materials.

Overview of Unit
Teacher Materials
- For Anyone Planning to Teach Nanoscience…Read This First!
- Clean Energy Overview, Learning Goals & Standards
- Unit at a Glance: Suggested Sequencing of Activities
- Alignment of Unit Activities with Learning Goals

Lesson 1: Introduction & Initial Ideas
Teacher Materials
- Clean Energy Introduction & Initial Ideas: Teacher Lesson Plan
- Clean Energy – The Potential of Nanoscience for Energy Production and Use: PowerPoint with Teacher Notes
- Clean Energy Initial Ideas: Teacher Instructions

Student Materials
- Clean Energy Initial Ideas: Student Worksheet

Lesson 2: Solar Energy and Nanoscience
Teacher Materials
- Solar Energy: Teacher Lesson Plan
- Solar Energy – The impact of nanoscale science on solar energy production: PowerPoint with Teacher Notes
- Graetzel Solar Cell Lab Activity: Teacher Instructions & Answer Key
- Reflecting on the Guiding Questions: Teacher Instructions

Student Materials
- Graetzel Solar Cell Lab Activity: Student Instructions & Worksheet
- Reflecting on the Guiding Questions: Student Worksheet

Lesson 3: Hydrogen Fuel Cells and Nanoscience
Teacher Materials
- Hydrogen Fuel Cells: Teacher Lesson Plan
- Hydrogen Fuel Cells – The impact of nanoscale science in hydrogen fuel cell technology: Teacher Instructions & Answer Key
- ChemSense Lab Activity: Teacher Instructions
- Hydrogen Fuel Cells: Teacher Answer Key to Quiz
- Reflecting on the Guiding Questions: Teacher Instructions

Student Materials
- ChemSense Lab Activity: Student Instructions
- Hydrogen Fuel Cells: Student Quiz
- Reflecting on the Guiding Questions: Student Worksheet

Exhibit 4. Proposed Fine Filters unit materials.

Overview of Unit
Teacher Materials
- For Anyone Planning to Teach Nanoscience…Read This First!
- Fine Filters Overview, Learning Goals & Standards
- Unit at a Glance: Suggested Sequencing of Activities
- Alignment of Unit Activities with Learning Goals

Lesson 1: Introduction & Initial Ideas
Teacher Materials
- Fine Filters Introduction & Initial Ideas: Teacher Lesson Plan
- Fine Filters – A Nanotechnology Application used to Prepare Clean Drinking Water: PowerPoint with Teacher Notes
- Cleaning Jarny's Water: Teacher Instructions & Rubric
- Fine Filters Initial Ideas: Teacher Instructions

Student Materials
- Fine Filters Initial Ideas: Student Worksheet
- Cleaning Jarny's Water: Student Instructions & Worksheet
- Introduction to Filtration: Student Reading

Lesson 2: Filtration Mechanisms
Teacher Materials
- Filtration Mechanisms: Teacher Lesson Plan
- Animating Filtration Methods (ChemSense Activity): Teacher Instructions & Rubric
- Comparing Nanofilters to Conventional Filters Lab Activity: Teacher Instructions and Rubric
- Reflecting on the Guiding Questions: Teacher Instructions

Student Materials
- Animating Filtration Methods (ChemSense Activity): Student Instructions
- Comparing Nanofilters to Conventional Filters Lab Activity: Student Instructions and Worksheet
- Reflecting on the Guiding Questions: Student Worksheet

Exhibit 5. Agenda for nanoscience workshop for high school teachers and students.

Saturday, February 11, 2006

8:45 am	**ARRIVAL AND CONTINENTAL BREAKFAST** *Duncan Hall 505* Arrive, pick up materials and make a name badge. Muffins and juice will be available.
9:00 am	**INTRODUCTION TO NANOSCIENCE** *Geri Horsma and Carolina Sylvestri* *Duncan Hall 505* How small is a nanometer? What are some unusual properties of the nanoscale? How might nanotechnology impact our lives? These and other questions will be addressed through presentation and hands-on activities.
10:00 am	**INTRODUCTION TO CLEAR SUNSCREEN** *Alyssa Wise* *Duncan Hall 505* How do "nano-sunscreens" differ from traditional sunscreens? What is the best kind of sunscreen to use and why? Alyssa will give introduce the clear sunscreen unit and issues related to such questions.
10:30 am	**BREAK** Divide into two groups and make your way to the lab rooms.
10:45 am	**HANDS-ON ACTIVITY: SUNSCREEN LABELS** *Carolina Sylvestri* *Duncan Hall 507* **HANDS-ON ACTIVITY: ULTRA-VIOLET BEADS** *Miriam Motoyama* *Duncan Hall 506*
11:30 pm	**LUNCH AND GUEST SPEAKER** *Brent MacQueen, Nanoscientist from SRI International* *Duncan Hall 505* We'll have sandwiches, chips and drinks. From 12-12:30, Brent will present and answer questions on the topic of "Nanotechnology: What it is, is not, and where it's going to have an impact."
12:30 pm	**THE SCIENCE BEHIND THE SUNSCREEN** *Doris Mourad and Carolina Sylvestri* *Duncan Hall 505* A presentation and discussion of the core ideas behind how sunscreens block UV light and why they appear the way that they do.
1:30 pm	**SCATTERING OF LIGHT BY** **SCATTERING OF LIGHT BY PARTICLES: SUNSCREEN**

	PARTICLES: CHEMSENSE ACTIVITY *Tina Stanford and Patti Schank* *Duncan Hall 246* Students use the ChemSense Animator to create an animation for an advertisement that shows consumers how nano sunscreen particles don't scatter visible light and thus are transparent.	**ANIMATIONS** *Alyssa Wise* *Duncan Hall 246* Students view and discuss animated models of how visible light interacts with "large" and nano-sized zinc oxide particles.
2:00 pm	***(CHEMSENSE ACTIVITY, CONTINUED)***	**CONSUMER CHOICE PAMPHLET** *Geri Horsma, Tina Stanford, and Alyssa Wise* *Duncan Hall 246* Students create a pamphlet to inform consumers about nanoparticulate sunscreens, how they work, and their benefits and drawbacks.
3:00 pm	**COOKIES AND WORKSHOP SURVEY** *Duncan Hall 505* Enjoy cookies and drinks while completing a short survey about the workshop.	
3:15 pm	**SMALL GROUP REFLECTIONS** *Duncan Hall 505* In small groups, reflect on the day and discuss ideas that were particularly interesting or perhaps unclear.	
3:45 pm	**GET CERTIFICATES AND ADJOURN** Teachers and students pick up their certificates of participation. Teachers remember to pick up your classroom kits!	

NanoSense: The Basic Sense behind Nanoscience

YEAR 2 FINDINGS

We categorize our observations, conclusions, and recommendations from the second year of the NanoSense grant in terms of three main findings: A report by our external evaluator of teacher and student reactions to the February 11 NanoSense workshop, our own analysis of student reactions to the workshop, and an in-depth analysis of student misconceptions and understandings of clear sunscreen concepts.

Finding 1: External Evaluation of Workshop for High School Teachers and Students

The report written by our evaluator, Ellen Mandinach, is reproduced in its entirety below. In this report, Dr. Mandinach outlines the categories she used to approach the formative work, describes her observations, and makes recommendations based on these observations.

Report on the NanoSense Workshop for High School Teachers and their Students held at San Jose State University by External Evaluator, Ellen Mandinach, Center for Children and Technology – February, 2005

Evaluation of the NanoSense workshop was conducted by developing and administering survey instruments to participating students and teachers [see Exhibits 6 and 7] through observations of workshop activities, and by conducting a debriefing session with students at the conclusion of the day. It is important to keep in mind that the purpose of this workshop was for teachers to try out teaching materials and to obtain formative information from them, as well as their students, on the effectiveness of the NanoSense unit. This formative information is being fed back to the NanoSense team to help them to determine "what worked", what did not work so well, what engaged the students, and what was confusing.

SRI solicited by invitation and announcement the workshop to Bay Area teachers. Seven teachers, two student teachers, and one Stanford-affiliated person attended, along with 31 high school students. The students represented three high schools in Palo Alto: Palo Alto High School, Gunn High School, and The Castilleja School (an all-girls private school). Because Castilleja is all-girls, the gender distribution was heavily skewed toward females – 26 girls to 5 boys. There were 5 freshmen, 18 sophomores, 7 juniors, and 1 senior. Other than the two student teachers who were moving from industry into education, all of the other teachers were seasoned veterans.

It is important to keep in mind that the students and teachers who attended the workshop are not representative of the general population of high school students and teachers. The teachers, particularly those who did the presentations at the workshop, are quite gifted and experienced. Three of the teachers have had training and experience with nanoscience. They teach a range of science courses across middle and high school. The students, other than with the exception of perhaps the freshmen, have had extensive exposure to advanced science and mathematics courses and are among the elite of students in elite schools. When asked about future plans, all of the students reported that they planned to pursue careers in the math and science fields. Interestingly, no one reported that they wanted to go into the computer sciences. Also of note was the lack of diversity among the students. There were 12 Asians but not one African American or Hispanic student. Clearly, this was a select group of young people.

Categories for Data Collection

When the classroom observations were conducted in May, 2005 and reported in a prior document, the following categories were used to collect formative data:

Student Understanding
Student Interest and Level of Engagement
Student Reactions
Student Individual Differences
Teacher Knowledge and Needed Level of Knowledge
Teacher Response
- Ease of Use and Confusions
- Misconceptions

Materials
- Accuracy
- Slides
- Activities
- Ease of Implementation

Other Issues
- Fit in Curriculum and Integration
- AP versus Traditional Chemistry
- Other Possibilities

As mentioned above, the purpose of the workshop was to elicit information from teachers and students about the materials in terms of potential for learning, points, of confusion, and level of engagement. Thus, most of the previously used categories can also be applied to the workshop.

Student Understanding

A number of students expressed a concern that some of the materials were beyond their level of understanding. In particular, the guest speaker's lecture was geared to a knowledge level well beyond high school. It was a highly technical and professional-level presentation. Some of the activities and lectures also were beyond a stretch for many students, particularly the freshmen. One student commented that s/he did not learn much from the workshop while another reported that s/he received a good introduction to nanoscience. Students disagreed about the difficulty of creating the animation with one student stating that it was too difficult largely because the computers were slow, and another reporting that it was fun and educational. One student mentioned that it was unclear what were the effects and the purpose. It would have aided understanding if these concepts could have been made more explicitly.

When asked if there were parts of the workshop that were confusing, 17 students said yes, 11 said sort of, and 3 said no. Most students reported that the guest speaker's presentation was too complex for them to understand. He was far too technical. This was further evidenced by the lack of questions by the students. Only the teachers asked him questions. Several students commented about a lack of prior knowledge or not having the right science background or courses to understand the materials. They were confused by certain terms and some of the slides. In particular, some students mentioned the inorganic/organic distinction and the quantum mechanics versus the classical mechanics in the introduction. Different students mentioned various specific topics that were confusing: scattering of light by particles, light waves, absorption, and sunscreen.

Student Interest and Level of Engagement

It was clear from observations and the debriefing session that the students much preferred the hands-on and interactive activities in which they could be active, rather than passive learners. The students showed interest during the demonstration activity and the labs. They also seemed to be engaged by having an opportunity to ask the guest speaker questions. They also became much more animated once the teachers or presenters opened the floor for questions. There was a marked difference in level of engagement between when students were being lectured at versus when someone like Alyssa Wise espoused a more interactive mode of presentation. The presentation was short, focused, and engaging and the students seemed to respond by getting into the content. Despite the passivity of the lectures, most students seemed to be tracking the content, as evidenced by their level of responsiveness to questions and the questions they asked of the teachers. Similarly, among the labs, the more didactic the activity, the more passive the students appeared.

Students were asked on the survey and in their introductions why they attended the workshop. They gave three reasons. Most students wanted to learn about science, nanoscience, or nanotechnology. Many expressed an interest in the topic as it relates to the future. Many students also reported that their teacher recommended them for the workshop or suggested that it would be of relevance or interest to them.

Most students thought the materials were interesting, despite being difficult. One student commented that s/he was so tired that that it was difficult to maintain a level of attention. Despite this fact, the student also commented that s/he liked the workshop. Another student commented that s/he thought the afternoon lectures were boring, and much preferred the hands-on activities. Also students also echoed the sentiment that hands-on activities were more engaging. The lectures were perceived as too boring, too difficult, too long, confusing, or irrelevant by some. One student commented on the amount of repeated material that diminished the degree to which the workshop was interesting.

Another factor that seemingly affected level of engagement was time of day and the flow of activities. Several students noted in the debriefing that the workshop started too early! It took a bit of time for the students generally to get into the flow of the workshop, despite their obvious engagement with the demonstration materials. There was a discernable low point during the lunch speaker and the after lunch lecture. This seemed to be a deadly combination. The students were already lost from the guest speaker and then were confronted with another hour of didactic presentation. They were in cognitive overload. It was far too much passivity over the course of two hours, in combination with post-lunch. The students did, however, seem to perk up once the activities returned to the hands-on labs.

Another indication of student engagement was when workshop organizers asked students to write down questions on file cards and submit them. Students used two kinds of cards. Yellow cards indicated “aha’s” or ideas. White cards indicated questions and confusions. Students were engaged in the task. They readily submitted idea and confusion cards, indicating that they were tracking the content and willing to extend themselves beyond the formal workshop activities.

Student Reactions

Students seemingly liked the workshop. They expressed their approval on the evaluation forms and in the debriefing. When asked did they like the workshop, 17 of 31 said yes, 12 said sort of, and 2 responded somewhere between yes and sort of. As noted above, students were more positive about the hands-on activities than about the lectures. When asked was the workshop interesting, 24 students said yes, 5 said sort of, and 2 said yes to sort of. Twenty-two students said that the material made them want to learn more about nanoscience, while 6 said maybe, 1 said no, and 2 said yes or maybe.

Most students thought the workshop was a good use of their time: 24 said yes, 6 said sort of, and 1 said yes or sort of. About half (17) reported that they would like to take another workshop like this, whereas 11 said maybe, 1 said yes or maybe, and 2 did not respond. Fewer reported that they thought the content was relevant to their school work: 13 said it was relevant, 2 said yes to maybe, 10 said maybe, 1 said maybe to no, 3 said no, and 2 did not respond.

Student Individual Differences

The one issue that was most clearly articulated was that the freshmen struggled with the material. Of the 5 freshmen, 1 young man was quite explicit about how he was completely lost throughout the workshop. He articulated that he sort of understood the discussion about gold, but all the other topics were beyond his level of comprehension. Although the other freshmen did not articulate this problem as vocally, it is clear that students this young do not have sufficient preparation to benefit from the NanoSense materials. It is probably safe to say that in order for students to understand the materials, they need more than a middle school science background.

We collected background information on students' academic preparation. Twenty-one students are currently taking chemistry or honors chemistry; 5 are taking biology; 5 are taking physics; and 4 are taking biotechnology in addition to their other science course. Eleven students are currently taking a math course that combines algebra 2, trigonometry, and statistics; 6 are taking calculus; 1 is enrolled in precalculus; 4 are taking algebra 2; 4 are taking algebra 1; 1 is taking geometry and another geometry while also enrolled in algebra 1; 1 is in trigonometry; 2 are in a course called analysis; and 1 student is taking precalculus while also taking algebra 2. When asked about prior course taking, 17 students had already taken physics; 8 had taken biology 1; 5 had taken chemistry; 1 had general science; and 3 had taken eighth grade science (although 2 others should have reported the course but did not). Seven students had taken coordinate geometry and matrices; 6 had taken algebra 2, trigonometry, and statistics; 7 had taken algebra 1; 10 had taken geometry; 2 had taken algebra 2; 1 precalculus; 1 general math; 1 middle school math; and 3 students failed to report any prior math courses. Students had fairly limited exposure to formal technology courses. Two had taken biotechnology; 1 had taken design and technology; 1 had taken Java and C++; 1 had taken drafting; 1 web design; and 1 had taken an array of classes that included Flash Photo Animation, web design, and automotive technology.

Teacher Knowledge and Needed Level of Knowledge

The teachers did a reasonably good job with the presentations. Some content errors were noted, however. It is clear that teachers need to be more familiar with the content and have a stronger background in order to be able to function effectively in the classroom.

Teacher Response

All of the teachers reported that they liked the workshop and all found it interesting. Seven of the 10 thought it was well organized and the other 3 thought it was somewhat well organized. Nine teachers reported that the content was valuable. When asked about confusions, 3 teachers said that there were parts that were confusing, 4 said somewhat, and 3 said no. The confusions were about absorption, property change, light refraction, the sequencing of the science, and the need for proper introductions to the labs. Nine teachers thought the workshop was a good use of their time, but one commented that it was too long and the material would benefit from chunking, while another commented that all students should do all activities. Seven teachers plan to use the materials; 2 said maybe; and 1 said yes or maybe. The concern was curricular fit.

When asked about the best part of the workshop and what they would change, a number of teachers reported that they really liked the guest speaker, but acknowledged that the presentation was way beyond the level of the students and that something more age appropriate would be better. They also liked the collegial interactions and the various activities and labs. The teachers also indicated that they thought that all students should do all the activities and that the activities needed to be broken up into smaller segments. They thought that the students would benefit from working in smaller groups. They liked the hands-on activities and reported that less lecturing would be better. One teacher mentioned that it would be helpful to have a big question and open the discussion with the potential of nanoscience. The teachers gave a range of responses to what ideas and topics they would most likely apply. Many thought that the introductory lesson would have potential in their classes to provide appropriate background for nanoscience. Others thought that the sunscreen, beads, chemistry animation, and light units could be applied.

Teachers were asked about student understanding and engagement. They thought the students were engaged, particularly by the hands-on activities, the labs, and the introduction. They perceived that the students were not engaged by the speaker and some of the PowerPoint presentations, particularly the science behind sunscreen. Only 5 of the 10 teachers responded to the question about sufficiency of student background. Two reported that their students had an appropriate background, 2 said somewhat , and 1 said no. Having physics and chemistry would be helpful to the students. The teachers also thought that having background materials for teachers and students would be helpful. Six of the 7 teachers who responded reported that they thought that the students generally understood the materials. However, they also reported that the younger students and those without physics or chemistry would have a more difficult time.

In terms of planning for future workshops, the teachers reported that the big ideas they gained from the session included an understanding of the modern applications of nanotechnology, particle size, and light scattering. They recommended that the teachers be trained before a workshop and know how to run any demonstrations. They also thought that the workshop should include more fundamental science, and make the PowerPoint slides less wordy and simpler.

Materials

What students liked best. Students were given the option of identifying various components of the workshop – the introductory lesson, the lab activities, the guest speaker, the afternoon lesson, the animation activities, or other topics (we won't discuss the free food here) – and providing explanations. Students reported that they liked the animation activities (21) and the lab activities (20) the best. Fifteen students liked the introductory lesson and 9 the afternoon lesson. Only 8 students mentioned that the speaker was the best part of the day. It was clear from their comments that the students preferred active and hands-on activities, rather than passively sitting and listening to lectures. One student commented that the Question and Answer session was the best part of the workshop. Many students thought the materials in general were fun, engaging, and interesting.

What students liked least. The students like the guest speak least, with 15 students identifying this activity. They thought he was confusing, boring, too technical, and could not understand the material he covered. Six students liked the afternoon lesson the least. They reported that it was too hard, too boring, and too hard to focus after lunch. Four students each identified the introductory lesson or the animation activities what they least liked. For two students, the introduction was too early for them to focus and contained too much information. The students who did not like the animation activities complained that they were too difficult, not useful, a repeat of content, that the computers and program were slow/awkward.

What students thought was the most important thing they learned. Student responses generally fell into two categories – specific topical content and general comments. Sixteen students reported that they learned about sunscreens, the difference between organic and inorganic sunscreens, and SPF. One student mentioned UV light and another mentioned that gold changes color. Fifteen students commented that they learned about the importance of nanoscience for the future, its potential benefits, its importance in medicine, and its applications.

Suggestions for future workshops. Corresponding to the above comments, most students recommended that there be more hands-on and interactive activities. Students articulated that there simply was too much material in a short period of time and asked about the feasibility of breaking things up – shorter days, more breaks, and the like. Some wanted more pictures, better computers, and more animation activities. One student wanted to do all the activities rather than having to choose among options. Several students commented that there needs to be more and better explanations to accompany slides and activities. If there is to be another guest speaker, the individual must be more understandable, less technical, and more relevant.

Accuracy. Some questions arose about the accuracy of some of the comments made by the teachers in their presentations of the materials. As the teachers embellished and explained the prepared slides and materials, it was obvious in some places that the teachers were treading on limited experience and materials. The accuracy issue has more to do with teacher knowledge and preparation than about the accuracy of the materials.

Slides and lab materials. Student responses varied about the slides. Many reported that they thought the slides were generally boring while others reported that the material was interesting. Almost universally, students preferred the lab materials over the lecture slides.

Activities. Student responses to the activities were generally positive. They much preferred the activities because they provided the opportunity for hands-on and active participation, rather than passive learning. One student reported that s/he did not like being forced into making a pamphlet while others really enjoyed the activity. The students seemed quite motivated by and interested in the hands-on items that were available to handle before the workshop began. Most students congregated around the table and examined the items. They also seemed to like having the opportunity to ask the guest speaker and nanoscience expert questions. This was in sharp contrast to their expressed feeling of being lost by the speaker's formal presentation.

Ease of implementation. Teachers had little difficult implementing the lectures, labs, and activities. There was some set up time required for the labs. The computers were fairly slow and therefore the animation construction activity did not work as smoothly as it might have had faster computers been available.

Other Issues

Fit in curriculum and integration. Some students reported seeing little relevance between the nanoscience content and what is being taught in their classes. Other students saw nanoscience as a topic for the future, an emerging discipline.

A concern worth mentioning, as in the prior report, is the appropriate place for nanoscience in the curriculum. Because it is cross-disciplinary, the fit is not easy. There remains a question of prerequisite knowledge. Many of the students in the workshop, with the exception of the freshmen, have taken a myriad of science and math courses, yet different students reported holes in their knowledge that prevented them from fully understanding the material. Some said they needed more biology, other more chemistry or physics. Thus, there is a need to consider how nanoscience fits into the curriculum course wise, as well as the needed prior knowledge, and developmental status of the students. It is important to keep in mind that the students who attended the workshop are not a representative sample of the typical high school science student. These students are more advanced, more academically prepared, and probably much higher in achievement and intelligence level than the majority of high school students.

Finding 2: Our Analysis of the Workshop for High School Teachers and Students

Student Demographics and Science Background

31 students from 3 high schools attended the NanoSense Clear Sunscreen workshop on February 11, 2006. 16 were from the all-girls Castilleja private school and 15 were from the two public high schools in the Palo Alto Unified School District (11 from Palo Alto High School and 4 from Gunn High school). All 16 of the students from Castelleja were 10th grade girls which skewed the student distribution somewhat; there were 18 sophomores compared with 5 freshman, 7 junior and 1 senior and 26 girls compared with 5 boys as shown in Chart 1.

Chart 1: Student Demographics

Grade Level		School		Gender	
9th	5	**Gunn**	4	**Female**	**26**
10th	**18**	**Castilleja**	**16**	**Male**	5
11th	7	**Palo Alto**	11		
12th	1				

The science background of the students was similarly slanted as shown in Chart 2. All 16 of the Castilleja students were are currently in Chemistry class, having completed Physics in 9th grade. The only other students who had a Physics background were the 4 juniors from Palo Alto HS and the one senior from Gunn HS, leaving 10 students without any Physics background at all. All students except for the 5 freshmen from Palo Alto had taken or were currently taking Chemistry and all 15 students from Palo Alto and Gunn HS had taken or were currently Biology. None of the Castilleja students had taken Biology. Though biology does play a role in the sunscreen unit, chemistry and physics were the core disciplines drawn upon, and thus with the exclusion of the 5 freshman, most students had the background in coursework that we were designing for. It should be noted however that these were a group of high achieving students in high achieving schools and thus the average student with a similar coursework background might not be as well prepared.

Chart 2: Science Class Progression and Number of Students in Each Class

	9th	10th	11th	12th
Castilleja	**Physics**	**Chem**		
		16		
Gunn	**Gen Sci**	**Bio**	**Chem**	**Physics**
			3	1
Palo Alto	**Bio**	**Chem**	**Physics**	
	5	2	4	

Motivation for Attending the Workshop

When asked why they came to the workshop, 29 out of 31 students gave an answer related to being interested in the topic and wanting to learn. Of these 29, 17 mentioned being specifically interested in learning about nanoscience or nanotechnology, with answers being split almost equally between the two terms. This motivation seemed to stem from two sources: one a love of science (mentioned by 2 of these 17 students as well as by 2 other students) and two, an interest in new things (mentioned by 1 of the 17 students plus 2 others). Finally the remaining 8 of these 17 students said that the workshop sounded interesting or cool and something they wanted to learn about, but were not specific as to what about the workshop attracted them. There seems to be an overwhelming feeling that nanoscience is a field primarily concerned with applications as opposed to creating a greater fundamental understanding of matter. A greater emphasis on the fact that many of these applications are only possible because of a greater understanding (though we can still manipulate matter with an incomplete understanding) would be valuable.

10 students mentioned their science teacher among their reasons for coming, which was not surprising given that these science teachers were our primary mechanism for recruiting students. It is difficult to distinguish between these science teachers being *how* students learned about the workshop as opposed to their motivation *for* coming (we heard afterwards that one teacher offered her students extra credit for attending), but given that all but 2 students mentioned some interest or desire to learn in addition to their teacher as their reason for coming, we feel confident that most students attended because they wanted to do so. This is noteworthy since this may not be the case when the materials are used in traditional classroom situations.

Overall Student Reactions

Overall, students liked the workshop, found it interesting and a good use of their time and said that it made them want to learn more about the topics studied. A breakdown of student responses to these questions is shown in Chart 3. While many students had comments on how to improve the workshop, which will be discussed shortly, it is noteworthy that no students replied in the negative to any of these questions. It is also noteworthy that despite the high science content of the workshop, less than half of the students saw the workshop as relevant to what they are learning in school. It was unclear whether students felt that this topic was unconnected to what they are *currently* working on in science class or to science class in *general*, however regardless it would be valuable to tap into more topics that are currently covered in the curriculum to highlight this connection for students. After the workshop, one teacher noted that this result was not surprising since nanoscience topics are notably absent in most high school science curricula. She felt that a more important question would be whether students see nanoscience as relevant to their lives (current and future).

Chart 3: Summary of Student Reactions						
	Yes	**Yes / Sort of**	**Sort of**	**Sort of / No**	**No**	**No Response**
Did you like workshop?	**17**	2	12	0	0	0
Was it interesting?	**23**	2	5	0	0	1
Good use of time?	**24**	1	6	0	0	0
	Yes	**Yes / Maybe**	**Maybe**	**Maybe / No**	**No**	**No Response**
Want to learn more?	**22**	2	6	0	0	1
Take another?	**17**	1	11	0	0	2
Relevant to school?	**13**	2	10	1	3	2

In discussing what parts they liked best and least about the workshop, students clearly favored the hands-on lab and animation activities as shown in Chart 4. The primary reason given for this choice was the chance "to get to do something" (9 students) with additional reasons citing "more engaging" (3 students) and "gave me a chance to solidify my knowledge" (3 students) as secondary reasons. While several students commented that the lectures were boring or confusing, as Chart 4 shows, a significant portion of the students enjoyed them saying that they helped them understand topic. Part (but certainly not all) of the problem for the afternoon lecture (the primary sunscreen lecture) was its position directly following another lecture—the guest lecture that most students had difficulty understanding. When the sunscreen lecture began, many students were still confused and tired from having sat through the guest lecture. This suggests that students would enjoy the lectures more if they were made to be shorter and more interspersed with activities. As one student put it "[The lab and animation activities] were the most interactive and interesting, but they wouldn't have been if I hadn't had the lectures." Related to this, several students mentioned not understanding the connection between the activities and lectures. Better integrating these elements may also help student response to the lectures.

Chart 4: Most and Least Favorite Parts of the Workshop		
	Like Most?	**Like Least?**
Introductory Lesson	**15**	4
Lab Activities	**20**	1
Guest Speaker	8	**15**
Afternoon Lesson	**10**	6
Animation Activities	**22**	4
Note: Students could select multiple items for each category, thus totals will exceed 31.		

Other general comments from students suggested that the workshop was too long and had too much content to learn all at once. A workshop format that breaks up the content into several days, giving students time to "digest" the material would facilitate this, as would the standard format for an in-class or after-school implementation. Based on this and the previous comments about activities we are revising the unit into period long chunks that each contains a connected lecture and activity portion.

Student Reaction to Specific Workshop Sections

UV Bead Lab. Two main issues arose with the UV Bead Lab. First, the introduction was drawn out and too didactic. This happened because the lab was positioned early in the unit before students had the lecture about different wavelengths of UV light. As part of the planned reorganization of the unit, we will be moving these sections from the main lecture to be a shorter lecture that introduces the lab, hopefully reducing the lag time in starting the lab. The second issue was that students did not understand the results of the lab and found them inconclusive. As one student put it, they needed the teacher to "explain what it means to not get a pattern". This indicates a need to provide a greater teacher explanation about why a pattern should or should not appear and whether a non-pattern indicates a lack of relationship between variables or a need for more data. These issues are currently included in the teacher's guide, but clearly need to be emphasized more. One reason the lack of pattern was such a problem was due to a lack of variety in the opacity of substances (most substances tested were opaque, white sunscreens). The few non-opaque substances available for the lab were not used by students, indicating a lack of understanding of what kinds of things they would need to test to answer the research question. This relates to the lack of explanation of what a non-pattern would mean discussed above. We are revising this lab in two ways to address these issues: one, the group of substances to test will be varied to include many more non-sunscreen products (this will involve shifting the focus of the lab some) and two, the meaning of non-patterns will be emphasized to both teachers and students.

Sunscreen Label Activity. For the sunscreen label activity, several students felt that it was not "hands on" enough and that they were not sure what they learned by looking at sunscreen labels besides the long names of the ingredients. We are planning to shorten and reconceptualize this activity in the context of exploring the differences between organic and inorganic chemicals (as discussed in the "confusions" section below).

Science Behind the Sunscreen Lecture. The primary complaints about the sunscreen lecture were that it was confusing or boring. Students indicated that more visuals, clearer explanations and more interaction in the lecture itself would have been valuable. As one student put it "make it more of a classroom environment so people can as questions during the lectures so it's more like class." This raises an important issue about the workshop: because of the unanticipated large number of participants and because many students and teacher did not know each other beforehand, there was a general lack of "community" feeling to the workshop. By "community" we refer to sense of cohesion and give-and-take that is normally present in a classroom. We suspect that this was a strong contributing factor to the teachers' very didactic lecturing in conjunction with the novelty and difficulty of the material being presented. In the one case when a lecturer did try to engage the students in a dialogue, it was very successful and several teachers at the workshop had the experience of being asked questions about the material "on the side". This indicates that a great deal of student confusion (and possibly) boredom could be alleviated simply by conducting the "lectures" in a more participatory mode. However, this is easier said than done and the PowerPoint slides were in fact prepared to guide a class discussion, not to be presented as a lecture. The slide notes already contain a great number of "student discussion questions", none of which were used by the teachers and an explanation in the lesson plan to use them in this way. While we do plan to restructure the slides somewhat, dedicating whole slides to the discussion questions throughout the presentation, we do not feel that materials revision alone can address the issue of teacher pedagogy. Increasing teachers' comfort level with the material and encouraging an interactive lecturing mode is something we plan to address in our future teacher workshops. The issue of the balance between text and visuals in the slides is a related issue we have struggled with. As with the student discussion questions, we have found that the explanations in the teacher's notes often are not used in the moment leading teachers to "improve" based on the slide itself. Having witnessed teachers improve incorrect explanations on multiple occasions, we a reluctant to remove too much text from the slides, leading to further misinformation, however we acknowledge that for students, more visuals would be helpful. This is a tension we continue to struggle with.

Animation Activities. Most students reported enjoying the animation activities however several students reported difficulties with the animation program or that they needed more time to complete their animations. This strict time limit on the animations was an artificial constraint of the workshop format that we were aware of ahead of time. Given that only 2 students reported problems with the program itself, and that the program has been used successfully in multiple other implementations, we do not see a need to make revisions to it. One other comment that several students made was that they did not see the relevance of the animation project to the principles behind clear sunscreen. One reason for this is that the animation project currently centers only on visible light (why nanosunscreen is clear). This caused a lot of confusion for students who were expecting to deal with the blocking of UV rays (this was not originally done because of the multiple factors that influence whether an absorption or scattering mechanism is responsible for the blocking in a specific application). We plan to address this issue in two ways: one, we will expand the explanatory section in the PowerPoint about how and why objects appear different colors to our eyes (this will actually be broken off as a separate presentation); two, we plan to add UV rays to the animation project as a mix of absorption and scattering.

Student Confusions

Most students indicated that at least some parts of the workshop were confusing for them as shown in Chart 5. A common comment was that the presentation needed to be clearer and simpler in order for students to follow.

Chart 5: Summary of Student Reactions Re Confusions

	Yes	Yes / Sort of	Sort of	Sort of / No	No	No Response
Were parts of the workshop confusing?	**17**	0	11	0	3	0

Apart from the guest speaker, who talked above the students heads in many ways, student comments about confusions fell into three categories: confusions about the different kinds of sunscreen ingredients, confusions about the nature of light and how it interacts with matter (general principles), and confusions about how the sunscreens specifically interacted with light. The specific issues that students had trouble with in each category are shown in Chart 6. In addition, it was mentioned that there was terminology used that the students were not familiar with, indicating a need to include a glossary or explanations of terms as they are introduced.

Chart 6: Summary of Student Confusions
Sunscreen Ingredients & the differences between them
Sunscreens & the differences between them
Differences between organic and inorganic ingredients and which are which
Light Basics and Interaction w/ Matter
Light waves

Band gap absorption
Scattering of light by particles
How sunscreens interact with light
Whether organic/inorganic absorb or scatter or both
Why Visible & UV interact differently w/ clear sunscreen (why does one but not the other get through)

Conclusions

This workshop piloted the NanoSense Clear Sunscreen unit using a group of high achieving students with a strong interest in science. Overall students liked the workshop, found it interesting and a good use of their time and said it made them want to learn more about the topics studied. Students favored the more "hands-on" and interactive activities and wanted the lectures to be more interactive and connected to the activities. In addition, students felt that there was a very large amount of new content to learn in such a short time and that it would be better to break the content up more. These general takeaways, in addition to students' responses about specific activities, are being used to revise the unit (see Exhibit 8).

Finding 3: Student Misconceptions and Understandings of Clear Sunscreen Concepts

Guiding Questions for Analysis

This analysis of student work from the workshop attempts to answer the following two questions:

1. What kinds of understandings of clear sunscreen concepts did students develop as a result of participating in the workshop?
2. What are prominent student misconceptions / areas of difficulty related to clear sunscreen concepts?

Data sources to answer these questions came from 4 main sources, discussed below:

1. *Initial Ideas.* This worksheet asked students to write down their ideas about nanosunscreens before the unit began and to rate their certainty in these ideas.
2. *Student Notecards.* Students were given blank index cards to write down their questions and "aha" moments during the course of the workshop.
3. *Student Artifacts.* During the course of the workshop students filled out a lab worksheet, a reflection worksheet for the lecture and created either a scattering animation or a pamphlet informing consumers about nanosunscreens.
4. *Final Explanation.* After the workshop was over, students were asked to respond to two new questions about how nanosunscreens work.

Initial Ideas

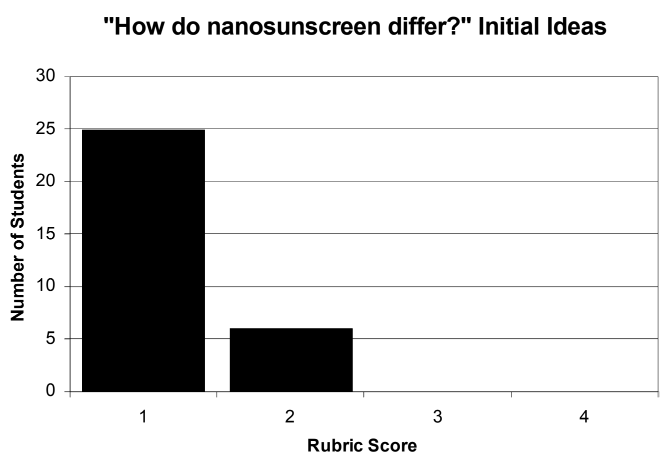
For the initial ideas section, students were asked three questions; one about nano-sunscreen differ from traditional sunscreens, one about what is the best kind of sunscreen to use and why and one about whether nanoproducts should have special regulations associated with them. Students' answers to the first two questions were rated on a four-point scale as shown below (the third question was primarily a value/opinion question and thus was not rated for scientific understanding.)

Chart 7: Rubric for Scoring Student Responses			
1 **No Understanding**	**2** **Limited Understanding**	**3** **Basic Understanding**	**4** **Solid Understanding**
Comments are absent or irrelevant.	Comments use some relevant terminology but many assertions are inaccurate or incomplete.	Comments use relevant terminology and are mostly accurate, but the overall explanation is incomplete or contains some inaccurate statements.	Comments use relevant terminology to provide an accurate and thorough explanation of the scientific concepts.

For questions one and two, the depth of understanding of the pertinent science concepts (bold headings) is inferred based on the observable descriptors described below each heading.

Question 1: How "nano-sunscreens" differ from traditional sunscreens?

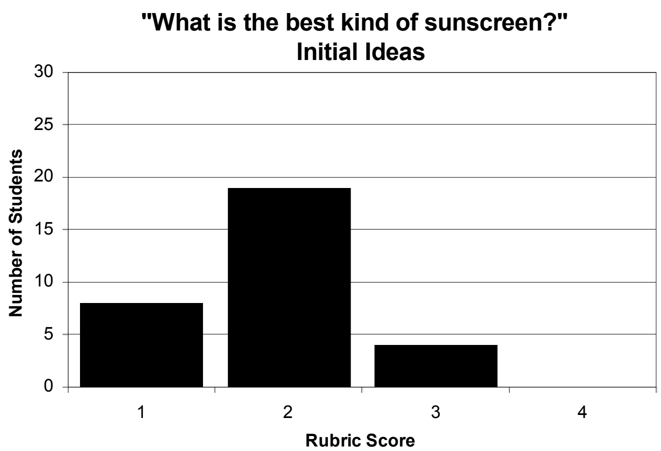
For this question, 25 students gave answers that were scored as a "1". Among these, the most common answers were that "nanosunscreens have smaller particles" mentioned by 17 students and that nanosunscreens are "better", mentioned by 13 students. Such answers were marked as "1" because they referenced the general claim that nano indicates small and good and not any specific understanding of the science of the sunscreens per se. The six answers scored as a "2" discussed some element of how nanosunscreens "interacted differently with light"; in addition, one student mentioned that they have a different chemical structure – this is true when compared with organic sunscreens, but not when compared with traditional inorganic sunscreens. One misconception mentioned by several students was that the small size of the nanosunscreens allowed them to cover more skin surface or "get into smaller places" where traditional sunscreens couldn't go. It is also noteworthy that only one student mentioned the smallness of the sunscreen particles in the context of the delivery vehicle.



Overall students came to the unit with few well-formed ideas about nanosunscreens. They also seemed to have few well-formed ideas about the nature and function of sunscreens in general. A greater introduction to the basics of sunscreens (suspended particles that "block" (absorb or scatter) different types of sun rays) would be a valuable addition to the unit. In reference to the notion that nanosunscreens worked better by "getting into smaller places", it is interesting that students reverted to this "small stuff behaves the same as large stuff but is smaller" view after just completing a introductory unit on how things often "behave differently" at the nanoscale. Clearly this is a concept that students may accept easily, but takes longer to be internalized.

Question 2: What is the best kind of sunscreen to use and why?

Students seemed to have more familiarity with the qualities to look for in a sunscreen. Only eight students gave answers scored as "1" indicating no understanding of the factors involved. Of the 19 students whose answers were scored as a "2", all made mention of the importance of SPF and many added other concerns such as being waterproof and non-allergenic. In addition, four of these students mentioned that it was important to have "broadband" protection, but did not clarify what this meant. The four students whose answers were marked as a "3" brought in mention of the different kinds of light involved, either referring to the need to block both UVA and UVB or a "broad range of wavelengths."



It was interesting to see the extent to which students focused on "practical" qualities of sunscreens. For most students, the only factor mentioned which directly relates to blocking ability is the SPF and in class discussion and observations revealed that even though most students knew that SPF was important, few knew what it actually meant and referred to (number of times longer you can stay in the sun without burning, only refers to UVB, not UVA protection.)

The greatest misconception seen in the initial ideas was the notion that nanosunscreens worked better by providing better coverage. This fits with the overall idea of sunscreen as a single "thing" whose protection ability depends on its "strength" (represented by the SPF rating) and "coverage".

Student Notecards

As part of our data gathering strategy during the workshop we handed out two kinds of index cards to students. White cards were for them to write down things they found confusing or had questions about during the workshop and yellow cards were for sharing "light bulb" or "aha" moments. Students were asked to fill out the cards at any point during the workshop and cards were collected at the end of each activity.

We received a total of 32 question cards and 11 idea cards over the course of the workshop and cards often had more than one idea or question on them. The questions and ideas were compiled and broken into categories with redundant ideas condensed. Most questions and comments were mentioned by only one or two students, but several questions were asked repeatedly; these questions are denoted by an * in the lists below. Some student comments indicated a misunderstanding; these are denoted by a † in the lists below.

Question cards. The majority of questions asked had to do with the first lesson, the introduction to nanoscience. It is tempting to think that this occurred because this was the first lesson of the day and occurred right after students were given the note cards and explanation of them, however since only four of the eleven "idea" cards (discussed in the next section) related to the this lesson, this is unlikely. Instead, we suggest that since the first lesson had short descriptions of many nanoscience applications (as opposed to the in-depth treatment of a single topic for sunscreen) students were left with many unanswered questions. This makes sense given that most questions for this lesson were not "I didn't understand X" kinds of questions, but asking about things not covered in the presentation. This gives us some good ideas about where to expand and elaborate in the presentation. Students seemed most interested in learning about the biomedical application of nanogold and nanorobots; these might be topics for further development in the future.

For the sunscreen lesson, there were fewer student questions. These questions were not asked as questions per se, but listed as topic areas that students did not understand. Unfortunately, these comments were relatively broad and thus only give a general idea about what changes to the unit need to be made. The general lack of questions about the guest speaker's presentation is presumed to be due to the fact that the talk was far enough above the students' heads that they could not (and potentially did not want to) formulate meaningful questions.

Question Card Topic: Introduction to Nanoscience

General

- Does matter naturally aggregate into bulk substances?
- How do we separate matter into nanosized particles and prevent them from coming together?*
- How do you make nano-sized things if you can't see them?*

Nanotechnology in Society

- Where does most nanoscience research take place?
- What are current uses of nanoscience being actually used today?*
- How can nanotechnology be used in science advancements?
- What are some complications / disadvantages of nanotechnology?*

Gold

- Why is <u>gold</u> used (in the body, in general)? *
- Does it have specific properties that make it particularly useful in nanoscience?
- How do you target and coat a virus in someone's body?*
- How would putting gold around cells stop AIDS and why?
- Why does the gold change color / react to light differently according to its size?

Robots

- How do you make nano-robots?
- How would you control the behavior of nano-robots?*
- Would you feel the nanorobots inside of you? What are the side effects?
- Do nano-robots live inside the body or do they dissolve into our systems? How would you get them out?

Other Applications

- How does the high-powered microscope really work?
- How did they change metals to liquids (ferrofluid)?

- How come on the nanoscale there is no longer a boiling point?
- How do they make the (microscope) probes?
- Quantum Dots
- Neuron growing on a silicon chip
- Quantum mechanics versus classical mechanics

Question Card Topic: Clear Sunscreen

- Wave activity
- Absorption spectrum
- Inorganic versus organic compounds*
- In the sunscreen lab, was there supposed to be a specific pattern in the data?
- Band gap absorption

Question Card Topic: Guest Speaker

- Multiplexing

Understandings & Interesting Things Cards

Students had two main types of comments they put on the "light bulb" cards. They either listed the things they found interesting, or listed the principles they felt they understood. Which of these two categories they were referring to was generally indicated on the cards themselves.

For the Introduction to Nanoscience lesson, students felt that many of the applications were interesting, but listed few understandings. For the Clear Sunscreen lessons, the situation was reversed; students listed a great deal of things they understood, but only three comments referred to things being "interesting" per se. It is not surprising that there were fewer "interesting" comments given that the sunscreen lessons dealt with one topic in depth; however it does indicate that it might be helpful to "jazz up" the sunscreen unit a bit. In terms of understandings, all but four comments were consistent with an accurate view of the topic. The greatest confusions were seen in the scattering and absorption blocking mechanisms and the distinction between organic and inorganic ingredients. This reinforces data from workshop observations and student surveys. In addition, one student seemed thoroughly confused about the process of molecular absorption indicating a need for more clarity in this explanation.

Understandings: Introduction to Nanoscience

- Nano changes properties
- No boiling point in nano b/c no pressure
- Less gravitational force, electromagnetic force dominates
- Gold fixes everything (†not exactly, if taken literally)

Interesting Things: Introduction to Nanoscience

- Nanorobots – break up kidney stones, clear plaque from blood vessels, ferry drugs to tumor cells
- Careers / current projects with nanotechnology (the whole intro was interesting)
- Hybrid Neuroelectronics
- Quantum dots glow in UV light – can detect tumors
- Growing cardiac muscle tissue

- Nanocoating – cover virus protein with gold for instance
- It is very cool that when gold is broken into tiny parts that the color is different
- You cannot "boil" a small number of atoms!
- Electromagnetic forces are more dominant than gravitational forces at the nanoscale
- Stain resistant cloth
- Paint on solar cells - sounds good but would it path enough energy?*
- Wow! A DVD with 1 million movies* and early cancer detection
- Impeding infections, self-cleaning windows

Understandings: Clear Sunscreen

General Light-Matter Interactions

- Small particles absorb light, but scatter light differently
- Light refraction
- Light scattering is multiple refraction; light hits the molecules and gets refracted twice
- Light is a form of electromagnetic energy
- Energy = Planck's constant frequency
- Absorption spectrum is the opposite of emission spectrum
- Molecule's atoms individually do their jumps…photons with a range of atoms are absorbed (†confusion of concepts)
- Energy "bands"
- Maximum scattering occurs when the size of the particle is about half the wavelength of light

General Sun and Sunscreen

- SPF only refers to UVB*
- If you have an SPF 10 and can normally stay in the sun for 10 minutes before burning, you can now sty in the sun for 100 min
- Of the total radiant energy emitted by the sun, 43% is visible, 49% is IR, 7% is UV and <1% x-rays, gamma and radio waves
- UV spectrum has 3 parts: UVB = sunburn causing rays, UVC = rays with higher frequencies and UVA
- UVA penetrates skin the most, UVC penetrates the least

UV Blocking

- Most organic sunscreens are strong UVB absorbers but weak UVA absorbers ZnO and Ti02 absorb UV lights and scatter it too
- Absorption of ZnO is effective until a certain point
- Smaller ZnO particles scatter UV better (†misconception)
- Inorganic block UV light by scattering it (†only partially true)
- ZnO and TiO2 absorb UV light (†only partially true)
- Sunscreen blocks UV light by absorbing it (†only partially true)

Appearance of Sunscreen

- Scattering occurs when particle size is 200-350 nm; if you make the particles smaller, then they look clear because less visible light is scattered
- Traditional inorganic compounds look white
- When sunscreen looks white, all visible light bounces back
- If sunscreen particles are <250-300 nm, you can make clear sunscreen b/c it won't scatter light in the visible range (sunscreen appears white b/c the particles scatter the light)

Interesting Things: Clear Sunscreen

- UVA rays penetrate the skin more than UVB even though they are lower energy
- Absorption spectrum versus emission spectrum
- Sunscreen scatters (bends) UV light

Student Artifacts

The first three student artifacts discussed are worksheets. For these artifacts, student work was reviewed as a whole and the most salient questions (those that asked core conceptual questions as opposed to descriptive questions and had a high response rate) were chosen for analysis. The final two student artifacts were the products of student projects and for these artifacts each student product is described and then group is analyzed collectively highlight common student understandings and misconceptions.

Sunscreen Ingredient Lab Worksheets

Sixteen students participated in this lab in which students were asked to examine the ingredients list for several different sunscreens. For this lab two questions were analyzed in depth: one asking students to think about why sunscreens might have more than one active ingredient and one asking students for their prior knowledge about UVA and UVB light and the meaning of the SPF number. In addition, students were asked to reflect on the two essential questions that were raised in the initial ideas activity.

Question 1: Why do you think that sunscreens have more than one active ingredient? Why can't they just put in more of the "best" one?

For this question, most of the students (14 out of 16) correctly hypothesized that sunscreens had more than one active ingredient because the different ingredients "did different things" or were useful "in different conditions" however only two students mentioned that the "different thing" was related to blocking different wavelengths of light. Several students mentioned "waterproofing" as a function that one of the ingredients might serve (this is incorrect since this would be a function of an inactive ingredient) and one student mentioned that different ingredients could block against "UVA, UVB and SPF." Four students alluded to the idea that there might be some sort of an interaction between the ingredients that would lead to enhanced protection, with one of these students specifically mentioning reactions between ingredients as being important. Two other students mentioned vaguely that the ingredients "worked together" but it was unclear if they were referring to an addition effective or reactions between ingredients.

Overall, students produced reasonable and expected hypothesis about why sunscreens have more than one ingredient. Student responses indicated a lower familiarity with the idea of active versus inactive ingredients and the meaning of "SPF" – a brief discussion of these at the beginning of the lab could improve student comprehension. In addition the question of if the different sunscreen ingredients produce a greater than additive effect could be brought up later in the unit as a check to see if students understand the underlying scattering and absorption mechanisms.

Question 2: based on your prior knowledge, what is the different between UVA and UVB protection? Is one more important than the other? Which one does the SPF measure?

This question had a very strange set of answers; 6 of the 16 students referred to the difference between UVA and UVB as the difference between alpha and beta particles (one student also mentioned gamma rays) and went on to talk about properties related to these particles. It is unclear where this idea came from, since there is no mention of this (incorrect) idea in any of the unit materials. It is presumed that one of the students had the idea that these concepts were connected and was very vocal about sharing and convincing their classmates that they were correct, however it is disturbing that given the high teacher presence during the workshop and the subsequent discussion of the worksheet that this misconception was not addressed. While puzzling, the happenstance nature of this occurrence does not seem to require changes to the materials.

Of the remaining 10 students in the group, 5 identified UVA and UVB as different wavelengths of UV light and two identified UVA and UVB as two different kinds of blocking that protect against different types of UV light. It is possible that this misconception came from the wording of the question, which will be revised – but this is also something to watch out for. In answering the part of the question related to the relative importance of blocking UVA and UVB light, students unequivocally chose one or the other. While in many cases students did acknowledge the different effects and time frame of effects for the different types of UV light, it is important to emphasize the need and ability to protect against both kinds of UV light. Of the students who mentioned SPF, seven correctly stated that is measured UVB blocking and one student said "SPF measures UVA?".

Reflection Question 1: What did you learn in this activity to help you answer the question "How do 'nano-sunscreens' differ from traditional sunscreens? How are they the same?"

The most interesting thing about student answers to this question was that many students focused on how they knew if a sunscreen was a nanosunscreen, generally indicating that the presence of ZnO or TiO_2 and a clear appearance were the key factors. One student also mentioned the importance of the particles in the sunscreens and another pointed out that nanosunscreens use the same substances, just in smaller particles; two students noted that sunscreens were "more complicated" than they had thought. Taken together, these comments indicate the need for a more basic line of questioning about what sunscreens are (a colloidal suspension of active ingredient particles) and more precision about the components to which the "nano" language is applied (the size of certain active ingredient particles).

Reflection Question 2: What did you learn in this activity to help you answer the question "What is the best kind of sunscreen to use and why?"

Eight of the 14 students who answered this question mentioned high SPF as an important quality of a sunscreen, seven pointed to dual UVA/UVB protections and four mentioned "broadband protection." Two of the students who mentioned broadband protection had also mentioned UVA/UVB protection, indicating a lack of deep understanding as to what these terms mean. This would be an important question to ask towards the end of the unit to check student understanding.

UV Bead Lab Worksheets

Fifteen students participated in this lab in which they were asked to test a variety of substances for opacity and UV blocking ability to determine if there is a relationship between the two properties. Unfortunately, most students only filled out the hypothesis, data, and analysis sections of the worksheet, leaving most to all of the concluding thought questions blank. Thus analysis of student artifacts from this activity is limited.

The hypothesis given were mixed with seven students predicting that more opaque substances would be better UV blockers, six student expecting UV blocking ability not to be strongly related to opacity, and two students predicted that the transparent substances would be better blockers (the reasonable rationale given was that if the particles are very small, the sunscreen would appear relatively transparent and the more small particles that can be jammed in, the more light will be blocked). This suggests a reasonable experimental question without an obvious answer.

Despite some problems of restrictions of range, most students arrived at an answer close to the actual relationship between opacity and UV blocking, (no relationship) but few were satisfied with this answer. Students seemed to be frustrated that there was no clear "pattern" in the data. This raises the issue of how to make this result more "exciting" for students. One possibility might be to couch the problem in a scenario that assumes the opposite – for example how well does a new white t-shirt block UV rays? Do we need to wear sunscreen under our shirts?

Several groups of students in the lab had their one data point for the transparent substance happen to fall at a lower blocking score than all of their opaque substances and unproblematically drew the conclusion that this indicated a pattern, despite the fact that there was only one point away from a large clump of points (i.e. no real pattern). The importance of having multiple points to create a pattern needs to be further emphasized either through the lab questions or instructions.

Reflections on the Science behind the Sunscreen Lecture and Discussion

All 31 students participated in the Science behind the Sunscreen Lecture and Discussion. For this activity, two teachers presented a set of prepared PowerPoint slides detailing the scientific concepts behind the blocking and appearance of nanoparticle sunscreen ingredients. Though the activity was designed to be an interactive discussion, what occurred during the workshop was very teacher driven. At the end of the lecture, students were asked to reflect on the two essential questions that were raised in the initial ideas activity.

> *Reflection Question: What did you learn in this activity to help you answer the question "How do 'nano-sunscreens' differ from traditional sunscreens? How are they the same?"*

In comparison to their relatively sparse initial ideas about this question, after the science lecture, students had much more to say. Fourteen students mentioned that nanosunscreens were inorganic as compared to many of the organic sunscreens currently on the market and eleven students described how nanosunscreens were better than traditional sunscreens because they were able to block a greater range of the UV spectrum (both UVB and UVA wavelengths); an additional six students commented that nanosunscreens were "better blockers" but did not elaborate as to why this was the case. Surprisingly, only five students mentioned that nanosunscreens were clear, but since the majority of the organic sunscreens the students are accustomed to rub in clear, perhaps this was not as salient a difference to them.

While on the whole students did well describing the improved blocking of the nanosunscreens, they displayed a great deal of difficulty and confusion about the underlying blocking mechanisms. Fourteen students mentioned scattering and / or absorption in their answer, but only eight of these referred to these mechanisms accurately; six used the concepts incorrectly, for example relating more scattering to transparency or stating that nanoparticles only scattered or only absorbed. Of the eight answers that used the concepts correctly, only one mentioned the downshift in maximum scattering wavelength when the particle size was reduced; no students specifically mentioned band gap absorption.

Reflection Question: What did you learn in this activity to help you answer the question "What is the best kind of sunscreen to use and why?"

Interestingly students answered this question on two different levels. Many students gave a "macro" answer indicating that the best sunscreens are "nanosunscreens" (15 students), sunscreens with "small particles" (3 students) or "inorganics" (11 students). At the same time some student gave a "micro" answer choosing to list the series of features that the "best" sunscreen would have (6 students) and several students supported their "macro" answer with "micro" reasons (18 students). Interestingly, only two students mentioned the SPF of a sunscreen (compared with 19 who gave this answer as their initial idea in an earlier activity).

Of the "micro" answers or reasons given, most students cited protection from a larger portion of the UV spectrum (19 students) and a clear appearance (11 students) while fewer students mentioned "good UV scattering" (5 students) and "no allergic reactions (3 students). These answers seem to indicate that students assimilated the idea that it was important to block many different wavelengths of UV light, but did not integrate this idea with their previous ideas about the importance of SPF. Future revisions to the unit will explicitly try to help students make this connection. In addition, the lack of answers refereeing to blocking mechanisms in general (and band gap absorption specifically) reinforces the idea that this was an area of difficulty for students.

Scattering Animations Created in ChemSense

Sixteen students divided themselves into seven groups to make animations of how visible light interacts with ZnO sunscreen (large or nano sized) and how the sunscreen thus appears to observers. The purpose of this exercise in large part is for students to make their thinking visible and considered explicitly many of the ideas they were holding implicitly as part of the process of making animation design decisions. At the end of the animation creation process, animations were shared and discussed and inconsistencies and misconceptions were identified. Thus, this post hoc analysis of the animations is not directed towards the degree of correctness, but at the misconceptions that the animations reveal. Each of the seven animations is briefly described and inferences about misconceptions are drawn.

- *Animation 1.* This "animation" actual is a single frame showing a sun, black waves going in to peach-colored skin where sunscreen particles are embedded and peach-colored waves coming out of the skin. The accompanying text reads "The photons interact with the ZnO particles and most goes through, while the harmful UV light is scattered and absorbed. Your skin color is seen by a viewer, and not the sunscreen."
- *Animation 2.* In this animation, a black and white line drawing shows several light rays approach the "ZnO2" layer, which is very thin (very thin) and all of these rays are shown to reflect back away from the skin. The accompany text reads "All the effectiveness of old fashioned sunscreen and not even visible."
- *Animation 3.* In this full color animation, ZnO "molecules" are shown embedded in the sunscreen layer (the O atoms are shown as larger than the Zn atoms) and all of the light (shown as white waves) goes through this layer to the skin and never comes back out. The accompanying text reads "I can't see any scattered visible light coming from the ZnO because it is all passing right through to my skin! However, because visible light does not cause sunburn or skin damage, I'm good to go!"
- *Animation 4.* This animation shows two ZnO "crystals" (one for 300 nm ZnO and one for 50 nm ZnO) but even though the atom spacing is appropriate for a crystal, bonds are only shown between single Zn and O atoms, making the structure more like "molecules". In addition, the "particle" size for both pictures is the same, but the individual Zn and O atoms are drawn larger and smaller. In the action of the animation, UVA and UVB light comes in and UVA, UVB and an unidentified third kind of ray are "reflected" out (even though some of the light enters into the "crystal", all deflection occurs in one shot, more akin to reflection than scattering). It appears that some of the UVB light gets through the sunscreen - leaving a "shadow" on the skin below it.
- *Animation 5.* This animation shows light waves with white circles on them (presumably to label the rays as "white") coming in and going through the sunscreen to the pink skin and "pink" rays (labeled in a similar fashion) being reflected from skin surface to the eye.
- *Animation 6.* In this animation, sun rays come in towards sunscreen with embedded large ZnO particles. The large ZnO particles scatter visible light towards the viewer (in one frame the light appears to actually scatter in all directions, however in the following one a set of parallel waves move towards the viewer's eye) and the viewer exclaims, "This sunscreen looks white". Some of the visible light also seems to go through the sunscreen to the skin but does not come back out.
- *Animation 7.* This animation shows photons as yellow balls moving towards a set of ZnO "molecules" which scatter the photons. In this animation actual scattering between ZnO particles is shown.

A core confusion shown in the animations is a lack of distinction between the concept of scattering and that of reflection. Four of the animations showed light being deflected in a "reflection" type fashion (all light is deflected away from the sunscreen in a single frame) and only one animation showed true scattering behavior where the photons were bounced around between particles. Another animation showed a hybrid of scattering and reflection models and the final animation has all light passing through to the skin and thus no deflection behavior was shown. These animation are useful in fleshing the understanding behind students' interchange of the words "reflection" and "scattering" and suggest that current explanation of scattering (based on the principles of refraction) is not working for students. Revisions to the unit plan to eliminate the discussion of refraction and present scattering as a property of small particles (as opposed to bulk substances), focusing on the similarities and differences between reflection and scattering.

A second core confusion that is important—not only for this unit but for nanoscience instruction in general—is how students represented the nanoparticles at the molecular level. In Animation 4, the two supposedly different sized particles appeared the same size – but one had fewer larger Zn and O atoms in at and one had more smaller Zn and O atoms. This shows a clear disconnect between the particle level (at which students can correct assert that nanoparticles are smaller) and the molecular level (at which the smaller particles should show fewer of the same sized atoms to make up the smaller particle). This is an important connection that may be assumed by researchers and teachers, yet not intuitive to students. Related to this, all three animations that showed the actual Zn and O atoms, showed them connected as molecules (bonds only between single Zn and O atoms) and not in a crystalline structure and two of these animations showed the individual ZnO molecules embedded directly in the sunscreen. This further emphasizes the need to makes connections between the particular and molecular level and the bond structure in inorganic substances.

In addition to these core confusions, several smaller issues emerged in the animation. Students seem to confuse visible and UV light in some places and that each kind of light could interact differently with the sunscreen particles. Students also seem to "forget" about the light waves once they had passed through the sunscreen layer, often leaving them in the skin layer without being absorbed or reflected. Finally, two animations showed light waves changing from white or black to the color of the skin and it is unclear if students thought that the actual light wave was changing color. These observations suggest that a greater focus is needed on how light waves combine to produce color and why objects appear certain colors to us. It also suggests that while separating out the treatment of UV and visible light may be necessary for instruction, students needs support in tying these ideas back together.

Finally, it is worth noting that there was a large disconnect between the student experiences creating animations, discussed here, and the student experiences viewing the pre-made animations (not analyzed in this document). In contrast to the many difficulties and misconceptions seen by the animation-creating group, the viewing group appeared nonplussed by the pre-made animations, stating that it was obvious and intuitive what would occur. Perhaps adding some sort of a prediction activity prior to viewing the pre-made animations would help alert students to the non-obvious features of the animations.

Consumer Choice Pamphlets

The 15 students who participated in this activity were given the option to create a "Smart Shopper" consumer guide either on their own or with a partner. Students were engaged in the activity, but since it was the last activity of a very long day, many students focused more on the "fun" aspects of their pamphlet than the concept. A brief description and the text from each pamphlet are given below and student understandings and misconceptions are then discussed.

- *Pamphlet 1 "NanoSunscreen".* This traditional 3-panel pamphlet provided the following text: "Clear, but still provide UV protection; particles are smaller, but still refract and absorb harmful UV light. While UV is absorbed and scattered, visible light goes through to the skin; then the skin absorbs the normal visible rays and reflect others through the sunscreen to the eye which interprets the skin color as normal and not pasty white. UV rays are refracted by the particles and thus don't reach the skin to cause damage."

- *Pamphlet 2 "Nanoparticulate Sunscreen".* This horizontal 3-panel pamphlet provided the following text: "Regular sunscreens refract the light several times so that *none* of the visible light is absorbed by the skin and this makes the sunscreen and your skin appear white as a ghost; clear nanoparticle sunscreen reflects all the UV light but keeps your skin looking beautifully skin-colored." An image of the sunrays hitting the skin for large and small particles was shown, but the illustrations didn't show a difference between the two cases.
- *Pamphlet 3 "Your Guide to Protection".* This colorful 3-panel pamphlet provided the following text: "The light goes into the sunscreen and the ZnO and TiO2 absorb and scatter the UV light but the visible light will not be absorbed so the sunscreen will not make your skin look white." There was also an illustrations of the "peaks" of absorption shown by organic sunscreens, but the graph but says it refers to nanosunscreen.
- *Pamphlet 4 "Self Defense Against the Sun".* This colorful 3-panel pamphlet provided the following text: "Old sunscreen has larger particles. This means that it will be able to refract the harmful UV rays, but at the same time it will refract all the visible rays of light. This will make your skin look white; the new inorganic nanoparticle sunscreens allow you to apply a lot of sunscreen w/o looking unattractively white -> more protection."
- *Pamphlet 5 "Sunscreen and Nanoparticulate Sunscreen Ingredients".* This colorful 3-panel pamphlet provided the following text: "Nanoparticle inorganic ingredients are smaller than those organic sunscreens which are often opaque and white. By having smaller particles the sunscreen scatters UV rays (which are not visible) thus skin remains skin colored b/c the sunscreen appears to be clear and not opaque"
- *Pamphlet 6 "Buy Inorganic Nanosunscreen!".* This brief pamphlet had an illustration of a nanosunscreen bottle with inorganic ingredients and provided the following text as a continuation from the title: "…because it is better and protects you!!!!"
- *Pamphlet 7 "Nanosunscreens: Are they for you?".* This traditional 3-panel pamphlet provided the following text: "Nano sunscreens absorb and scatter harmful UV light to protect you from sunburn and skin cancer. Why are they so different from other sun lotion? Other traditional sunscreens absorb UVB rays, but nano sunscreens use many tiny particles to absorb and reflect, or scatter, UVB rays as well as UVA rays. Traditional sunscreens go on white, an ugly color to go into the sun with. Nano sunscreens go on clear because of the many particles that let visible light through, but not UV light."
- *Pamphlet 8 "Clear Sunscreen: The benefits of nanoscience".* This colorful 3-panel pamphlet provided the following text: "Nanoparticles of inorganic ingredients are useful because while providing the strong protection of traditional ZnO and TiO2, the visible light is not scattered by the particles. This characteristic makes the sunscreen "clear" so that there is no white color to the skin after application. Many sunscreens contain other organic and inorganic ingredients (ZnO and TiO2) check the label." The pamphlet also correctly showed a graph comparing the absorption and scattering blocking for nano ZnO but it was given somewhat out of context.
- *Pamphlet 9 "Nanosunscreen: Yay".* This colorful 3-panel pamphlet provided the following text: "Nanoparticle sunscreens are made of teeny particles that scatter UV light but not visible light, thus looking clear. They are made up of one of two inorganic compounds, which function the same (relatively) as the organic sunscreen particles. Instead of protecting in peaks, the inorganic sunscreen protects against a larger area of UV light w/ needing a large amount of ingredients. The inorganic particles must be small enough to block the UV range and to let the visible light go past to the skin: reflects visible light. Why clear? Because the

particle are so small, the substance will look clearer b/c it is nearly impossible to see particles on that scale - also, they do not bend the visible light which would result in very white sunscreen. (White light = summation of all wavelengths in the visible spectrum).” The pamphlet also correctly showed a graph comparing the absorption and scattering blocking for nano ZnO but it was given somewhat out of context. There was also an illustration of different colored wavelengths of light approaching sunscreen-covered skin.

- *Pamphlet 10 “Buried Treasure aka Ingredients”*. This pirate themed pamphlet focused on the ingredients in the different kinds of sunscreen stating that “Inorganic ingredients only consist of oxygen and another element (ZnO, TiO2). Organic compounds are individual molecules (PABA, oxybenzone and other stuff).”
- *Pamphlet 11 “Fortune Teller”*. The “pamphlet” was created like a finger-fold fortuneteller where you have to pick which part to open. Four possible fortunes are available. In the first no sunscreen is used and you burn; in the second you stay inside and are safe but bored, in the third you use nanosunscreen and are happy without skin cancer and in the fourth you use large particle sunscreen and look pasty white.

The majority of pamphlets (8 out of 11) reported that nanosunscreens use small inorganic particles of ZnO or TiO_2, which block UV rays. The blocking mechanism was described as scattering (3 pamphlets), absorption and scattering (3 pamphlets), and refraction (2 pamphlets). It is interesting that no pamphlets mentioned reflection as the blocking mechanism since this was a common answer in other activities. It is hypothesized that this may be due to the fact that the students who made the pamphlets has previously viewed the pre-made scattering animations that clearly showed scattering as a different process than reflection. This gives some support to the effectiveness of the animation. In terms of appearance, four of the pamphlets referred to the nanoparticles letting the visible rays “pass through” and two pamphlets discussed only the converse (large particle not letting visible light through). The other pamphlets promoted the “clear” appearance of the nanosunscreens but did not explain the mechanism behind this clearness.

There were two areas of confusion that arose in the pamphlets. The first relates to how the light interacts with the skin once it has “passed through” the nanoparticulate sunscreen. Pamphlets glossed over this part or made strange claims such as “the skin absorbs the ‘normal’ rays and reflects others” or “the visible light is not absorbed by the sunscreen to make your skin look white.” This is somewhat surprising since this group of students had viewed the pre-made animations that clearly show the skin absorbing green and blue rays while reflection red, yellow and orange ones. Perhaps questioning in the worksheet can be added to direct student’s attention to this feature of the animation. The other confusion came from a pamphlet that described how the small nanoparticles let the light “pass through” and the separately said that it is also “nearly impossible to see particles on that scale” without realizing that the first is the reason for the second.

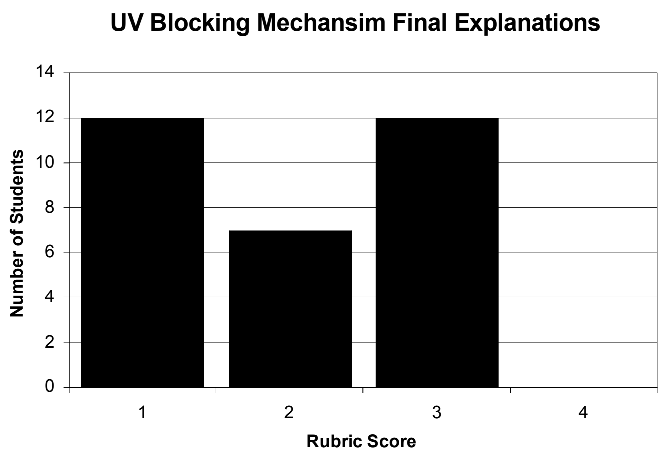
Final Explanations

For the final explanations, students were asked two questions; one about UV blocking and one about sunscreen appearance. Students’ answers were rated on a four-point scale as shown in Chart 7 earlier in this report. The depth of understanding of the pertinent science concepts (bold headings) is inferred based on the observable descriptors described below each heading.

Understanding of UV Blocking Mechanisms

Question 1: How do you think the absorption of UV light is different for organic sunscreens, inorganic sunscreens and single atoms?

For this question, many students gave superficial or incorrect answers. The twelve answers scored as a “1” generally gave superficial and global explanations such as “inorganics are better” without enough supporting detail to infer any understanding or incorrect attributions such as “organics scatter and inorganics absorb UV light”. The seven answers scored as a “2” reported that organics blocked “only some parts” while inorganics blocked “the whole range” but did not explain in detail what was being blocked or what the range referred to. The twelve answers scored as a “3” reflected some understanding of the UV spectrum as a range of wavelengths and the fact that organic ingredients absorbed only some wavelengths in this range while inorganic ingredients blocked (via scattering and absorption) the full range of UVA and UVB rays. No students gave answers earning a score of “4”; such answers would have needed to include a reference to the structural differences between organic and inorganic compounds and why they exhibit different absorptive properties.



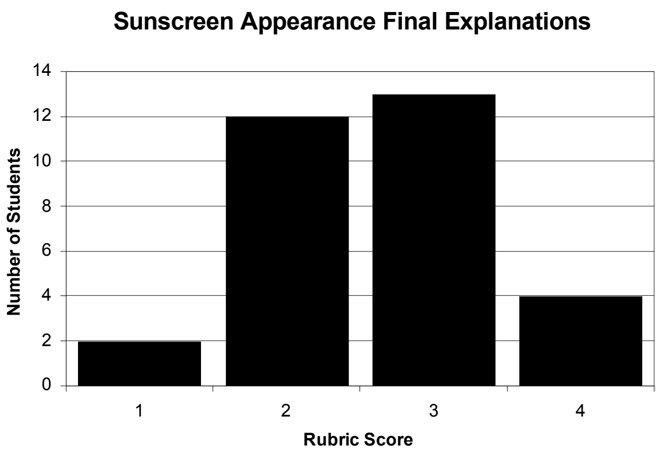
Based on their answers, many students seemed able to grasp the idea that organic substances absorb in bands (with peaks and ranges) while inorganic substances absorb all light up to a certain wavelength. Students were able to discuss the implications of this for combining organic substances to protect against the whole UV range and the fact that inorganic substances could block this range on their own. However, no students connected these properties to the structure of the substances involved or the fact that absorption of light was related to changes in the energy state of the substance (the differences in absorption result from the differences in energy level spacing patterns for organic molecules and inorganic crystals).

One possible cause for this disconnect is that the curriculum materials had been designed based on the assumption that students would be familiar with different kinds of substances such as organic molecules and inorganic crystals and this turned out not to be the case. Students were confused by the terms “organic” and “inorganic” and did not readily distinguish between molecules and crystal lattice structures which would necessarily make the discussion of their different energy level patterns hard to comprehend. Greater background and support for the basic differences between inorganic and organic substances will need to be included in future revisions.

Understanding of Sunscreen Appearance

Question 2: What are the different factors that help determine whether or not ZnO and $Ti0_2$ particles suspended in sunscreen appear clear or not and why?

For this question, most students grasped that the size of the sunscreen ingredient particles was an important factor in determining if the sunscreen would appear transparent, answers differed greatly, however, in the depth to which students explained why the size of the particles mattered. The twelve student answers scored as a "2" all referenced the importance of the size of the particles but gave no explanation as to why this was important or attempted an incorrect explanation (two students referred to particle size affecting absorption and one student referred to particle size affecting the wavelength of light). The thirteen student answers scored as a "3" also referenced the size of the particles as being important and provided some explanation relating to scattering, visible light, and skin color as resulting from the skin's absorption of blue/green wavelengths of light. Such explanations contained very few incorrect statements but were not scored as "4"s because they were not complete, generally referencing some but not all of the concepts described above. The four answers scored as a "4" presented integrated explanations including reference to scattering, visible light and different wavelengths of light. (Only two of the four directly referred to the color of the skin as a result of selective absorption, but since this was not explicitly asked for in the question, this was not counted as an omission to the core explanation).



It should be noted that in these explanations, students often interchanged the terms "scattering" and "reflection" and only one student mentioned the importance of the thickness of the sunscreen applied.

Based on their answers, many students seemed to grasp the idea that if the particles are small, they don't block the light and thus the sunscreen appears transparent, but almost half did not refer to the notion of scattering and many referred to reflection or "blocking" instead of scattering. This is surprising given that all students either created or spent a half an hour viewing animations focused on scattering. This implies a lack of perceived difference among students between these concepts and a need for greater clarity and emphasis on distinguishing them.

Student Misconceptions

Overall, student responses to the final explanation questions displayed more of a problem with superficial explanations than with misconceptions per se. Again, one of the major sources of confusion resulted from a lack of organic / inorganic distinction and which type of substance absorbed and/or scattered the different kinds of light. Many of the misconceptions appeared to be a matter of confusion as to which concepts applied in which situations. A clearer mapping of the situations (in terms of substance type, particle size and wavelength of light involved) to the appropriate kinds of energy-matter interactions would help to address this issue.

Student Statements Indicating Misconceptions Related to the UV Blocking Mechanism

- "Organic sunscreens are worse b/c they mostly scatter"
- "Organic and inorganic sunscreens absorb light well up to 380 nm"
- "Inorganic sunscreens absorb the UV light whereas organic sunscreens refract light so it appears white"
- "Inorganic absorbs and organic doesn't absorb (scatters)"
- "Organic sunscreens refract and scatter light and inorganic sunscreen absorb light"
- "Inorganic substances absorb differently depending on their size"
- "Single atoms give off an emission/absorption spectrum"

Student Statements Indicating Misconceptions Related to the Appearance of the Sunscreen

- "If the particles are small enough and the light absorbs through the particles"
- "The size of the molecules determines the wavelength of the light"

Conclusions

As the analysis of initial ideas showed, students came to the unit with few well-formed ideas about how nanosunscreens and sunscreens in general work. By the end of the unit, they had developed a set of understandings, many correct though some not, about how these products interact with light in terms of blocking and appearance. Given this situation, a traditional a pre-post comparison of the "amount" students learned is not particularly meaningful. More important and more interesting for this formative evaluation are the questions of what kinds of understandings students developed and what concepts caused difficulties of led to misconceptions.

Summary of Student Understandings Developed

Overall, most students did not have difficulty understanding that nanosunscreen ingredients are small inorganic (ZnO and TiO2) particles that are different in some way from most organic sunscreens on the market. Students also seemed to readily understand that nanosunscreens are better blockers than organic sunscreens because they block a greater range of the UV spectrum and not because they were "stronger" blockers of the same part of the spectrum[1]. Many students pointed out that organic substances absorb in "peaks" while inorganic substances absorb UV universally (up to a certain wavelength) showing a basic understanding of the idea that the substances interact with light in different ways. Related to this, students moved away from their initial idea that SPF was the primary (or only) thing to consider in picking a sunscreen to talk about choosing a sunscreen with UVA blocking abilities and that this was not captured in the SPF. One concerning thing seen was that students seemed to almost completely drop mention of SPF indicating an over reliance on the ingredients of a sunscreen without consideration of the other factors (dispersion, coverage etc.) that contribute to SPF. Students seemed to fall into binary categorization that either UVB or UVA must be "more" important to block. Finally, in relation to transparency and the appearance of sunscreen, students seemed to understand that nanosunscreens appear clear because they let the visible light "pass through" to the skin.

[1] One minor area of confusion related to what to compare nanosunscreen to – organic sunscreens or large inorganic ones.

Summary of Student Difficulties and Misconceptions

While students were able to understand the general whys and hows discussed above, when it came down to what was actually happening at the particle level mechanism wise, many difficulties and misconceptions were encountered. Perhaps the most basic confusion was between organic and inorganic substances. While the difference in bonding structure between molecules and ionic compounds is a core topic of the chemistry curriculum, it is one that many students struggle with. Student often interpreted an ionic formula unit as indicating a discrete molecule as shown in the student-generated animations. The core difference in bonding structure between molecules and ionic compounds underlies how they interact differently with light so the lack of distinction here contributes to other misunderstandings as well. One such area involves what it means to make a "nanosized" particle. Students had many different misconceptions here, but none seemed to understand that a smaller particle is simply a cluster of fewer ions. This indicates a need to make better connections between the particle and molecular level.

Another area of confusion related to how nanosunscreens block UV rays. Students gave answers including scattering, absorption, reflection, and refraction. The terms scattering and reflection were often used interchangeably and students didn't seem to distinguish between how light would interact with a bulk substance and a small particle (a key nanoconcept) showing light being "reflected" directly by small particles. Students also referred to both scattering and reflection as "refraction" in some instances. Despite these confusions, students seemed to be much more comfortable with the "scattering" explanations than with the absorption ones. In part because of the lack of distinction between organic and inorganic structure, but primarily due to the lack of deep background knowledge of atomic absorption, students were not able to build up to the concepts of molecular absorption and band gap absorption. Students were also unclear whether particle size would affect absorption leading to a need to distinguish between physical properties / processes and chemical ones.

The final area of confusion related to what happens to visible light at the skin's surface. Interestingly, the group that viewed the pre-made animations had no troubles here – they saw the green and blue wavelengths absorbed by the skin and the red, yellow and orange ones reflected and were able to talk about this process clearly afterwards. The group that made their own animations however did not intuit this and created a wide variety of incorrect versions of what happened at the skin's surface. This indicates that while this may not be a difficult concept per se, it is also not intuitive and some form of instruction on these issues should be included for all students.

Exhibit 6. Workshop evaluation survey for students. (Spacing reduced to save space.)

NanoSense Workshop Evaluation for Students
February 11, 2006

Your feedback about what you learned in this workshop, how you interacted with the materials, what you liked and didn't like is very important to help use improve the materials. Please help us by answering the following questions about yourself and your thoughts about the workshop.

Personal Information

1. Grade:
2. School:
3. Current science class(es):
4. Current math class(es):
5. Past science classes:
6. Past math classes:
7. Technology classes taken (please name):

Tell Us What You Learned

8. How do you think the absorption of UV light is different for organic sunscreens, inorganic sunscreens, and single atoms?

9. What are the different factors that help determine whether or not ZnO and TiO_2 particles suspended in sunscreen appear clear or not, and why?

Workshop Feedback

10. Why did you come to this workshop?

11. Did you like the workshop?	Yes	Sort of	No

If you circled "Sort of" or "No", please explain why:

12. Was it interesting?	Yes	Sort of	No
13. Did the material make you want to learn more?	Yes	Maybe	No

14. Were there parts that were confusing?	Yes	Sort of	No

If you circled "Yes" or "Sort of", what parts were confusing?

15. Was the workshop a good use of your time?	Yes	Sort of	No

If you circled "Sort of" or "No", please explain why:

16. Would you take another workshop like this?	Yes	Maybe	No
17. Is the content relevant to your school work?	Yes	Maybe	No

18. What did you like the most? (Check all that apply)

__ The introductory lesson	__ The afternoon lesson
__ The lab activities	__ The animation activities
__ The guest speaker	__ Other (what: ________________)

Please explain why you liked these parts most:

19. What did you like the least? (Check all that apply)

__ The introductory lesson	__ The afternoon lesson
__ The lab activities	__ The animation activities
__ The guest speaker	__ Other (what: ________________)

Please explain why you liked these parts least:

20. What was the most important thing you learned?

21. Is there anything you would suggest to make these workshops better or more interesting?

Thank you for your help! We hope you enjoyed today's workshop.

Exhibit 7. Workshop evaluation survey for teachers. (Spacing reduced to save space.)

NanoSense Workshop Evaluation for Teachers
February 11, 2006

Your feedback will help us improve our materials and future workshops. Please help us by answering the following questions about yourself and your thoughts about the workshop.

Background

1. Your school:
2. Grades and courses you teach:
3. Number of years teaching:
4. College Major:
5. Have you had other training in nanoscience? Yes No

   If yes, please describe:

Workshop Feedback

6. Did you like the workshop?	Yes	Somewhat	No
7. Was it interesting?	Yes	Somewhat	No
8. Was it well organized?	Yes	Somewhat	No
9. Was the content of value?	Yes	Somewhat	No
10. Were there parts that were confusing?	Yes	Somewhat	No
If so, which parts?			
11. Was the workshop a good use of your time?	Yes	Somewhat	No
If not, what improvements need to be made to make this workshop a better use of your time?			
12. Do you plan to use the materials in any of your classes?	Yes	Maybe	No
If you circled “Maybe” or “No”, what are your concerns?			

13. What did you like best or find most useful about the workshop?

14. What changes would you make to the workshop to make it better next time?

15. What one or two ideas from the workshop do you feel you will most likely apply, and how?

Student Engagement

16. Do you think the students were engaged in the workshop?	Yes	Somewhat	No

17. Where there particular sections in which the students were more engaged? If so, which?

18. Were there particular sections in which the students were less engaged? If so, which?

Student Understanding

19. Did your students have sufficient science background to understand the ideas being presented?	Yes	Somewhat	No

If you circled "Somewhat" or "No", please answer questions a & b below.

a. What additional background would they have needed?

b. Would you like to see that background provided in the materials,

___ For the teacher
___ For the students

20. Do you think the students generally understood the materials?	Yes	Somewhat	No

If you circled "Somewhat" or "No", please answer questions a & b below.

a. What sections or concepts were difficult for them to grasp?

b. What kind of support would your students need to better understand the concepts presented?

21. What was the most important concept you are taking away from the workshop?

Materials Feedback

22. How can the developers make the materials better for the next workshop?

23. We are interested in hearing about any experiences you have using NanoSense materials in your classroom. Would it be okay for us to contact you about this?	Yes	No
24. Would you like us to contact you with information about other NanoSense professional development opportunities for teachers?	Yes	No

If you answered "Yes" to either question above, please tell us your email address:

25. Are you interested in becoming more actively involved in developing nanoscience curriculum?	Yes	No

Thank you for your help! We hope you enjoyed today's workshop.

Exhibit 8. Detailed description of our recommended changes to the Clear Sunscreen unit based on workshop findings. These changes were implemented in April-May 2006.

Overall Structure

General Strategy

- Make more connection to topics that are currently covered in the curriculum.
- Have more hands on activities
- Break up the lectures more
- Show connections between the lecture(s) and activities

Planned Revisions

We are going to try to break up the "main" PowerPoint, which contains the bulk of the explanation of science concepts into several smaller presentations that are interspersed with the relevant activities. We are also going to move some of the "History of Sunscreens" part into the Intro presentation to give students more background and understanding of why this is a current issue. The new structure will run as follows: (current lesson # in ()s).

PPT: Introduction, Danger & the E/M spectrum (1) (3)
- Activity: UV Beads (2)

PPT: Sunscreens (History & Kinds) (org/inorg; phys/chem.; par. size) (3) (New)
- Activity: Sunscreen Labels w/ FDA Approved Sunscreens List (2)

PPT: How sunscreen block (absorption) (very optional) (3)
- Activity: Some sort of visualization?

PPT: How sunscreen block (scattering) (optional)
- Activity: Choice of Scattering (UV light) (4)

PPT: How sunscreens appear (3) (New) (optional)
- Choice of Scattering (visible light) (4-expanded)

PPT: Summary (3) (New)
- Activity: Consumer Choice Pamphlet (5)

In addition, students don't want to answer the same questions again and again, so the reflection questions after each unit need to be different. (The very beginning and very end can be the essential questions but the ones in the middle need to vary.) Also can have teachers go over the answers and "what I still want to know" questions.

PowerPoint Revisions

General Strategy

- Dedicate whole slides in presentations to the discussion questions to foster participatory "lectures"
- Work on the balance of text / images in the PPT slides by adding images and wordsmithing text down.
- Making slides simpler:
    - Split things into 2 slides if needed – avoid cognitive overload
    - Wordsmith to decrease # of words

  - Put stuff in the teacher's note – but depth, not connectors
- Need to move focus of language to "sunscreen ingredients" not "sunscreens"

Planned Revisions

The planned revisions are listed according to the new ppt structure.

Intro, Danger & EM Spectrum PPT:

- Old Slides: Intro PPT, 3-9, expand minimally
- Add in some single ppt slides with the big questions to try and promote discussion (i.e. give more motivation before diving in – why should I care.)
- Follow up with several slides addressing some of the issues that the Q raises
- Also add to teacher notes questions such as "Do you wear sunscreen?", "Why, why not?" & "Are there nanoparticles in your sunscreen? How do you know?"
- Old Slide 3: Show c=lf formula in multiple forms and deal with issue with Symbol Font
- Old Slide 8: Redo graph to get rid of confusing elements.

Sunscreen History & Kinds of Sunscreens (organic/inorganic) PPT:

- Old Slides: 10-13, 27, 17, 25, expand
- Be clear on what SPF is (a rating not a thing) and what it measures
- Focus on Blocking UVA and UVB and why SPF is important but not enough
- Clarify active vs. inactive ingredients
- Need to do something in the "story" – to deal with the question – are "old" inorganics still available?
- Add "history" parts from main PPT that discuss 1. Why we moved from inorganics to organics (appearance) and then 2. Why organics are no longer enough (will need to reorganize some)
- Add in section on sunscreen basics – including "colloidal suspension"
- Add content on organic vs. non-organic (carbon based, bond type, size, structure, relation to allergies…) make sure to use visuals of the molecules / crystal structures
- Make really clear what is organic and what is inorganic and need to be clear that "nano" only refers to inorganics because those are the ones that vary in size and thus need to be shrunk.
- Molecule versus the formula unit
- Use "Cluster" language versus particle language so they get that there are multiple ions involved
- Talk about if "particle" has meaning for molecules…
- Include answer to the question: How do we know if something has a nanoingredient in it?
- This section will also need to have sunscreen blocking basics (i.e. if they don't do any of the indepth ones…or this might go in the summary ppt). Need to divide "block" into absorb and scatter. With this - include the diagram that AFW drew on the board early on and then break it down.
- A "zoom" thing – switch from the "particle" level view to the "atomic" level view. Also bonding structure of inorganic substances.
- What does it mean to make a nanosized particle – the difference in "Bonding" (electron sharing) and ion's electrostatic attraction.

- Old Slide 11: Need to increase text size so it is readable and explain why UVA causes long term damage

How Sunscreens Block (absorption) PPT:

- Old Slides: 14-16, 21-24 (don't expand)
- Band gap is just too hard and draws strongly on stuff they only have a little bit of (atomic emission) just too big a jump – SUPER optional or eliminate
- Need to start with emission and then move to absorption noting the key differences. Also more explanation of band gap.
- With absorption, need to be clear what happens to the "jumping" electrons when they "fall" back down.
- Need to make it clear that Size and Absorption are not strongly related. Good opportunity to distinguish between "chemical" properties and "physical" properties (though band gap is slightly affected by particle size…)
- Include the diagram that AFW drew on the board early on and then break it down.

How Sunscreens Block (scattering) PPT

- Old Slides: 18-19 (probably kill), 20, 29, expand
- Remove part about refraction and focus on how light interacts w/ different sized stuff differently (scattering by particles versus reflection by objects)
- Need to have clearer basic definitions of terms and relationships between refraction, reflection etc…
- Revisions to the unit plan to eliminate the discussion of refraction and present scattering as a property of small particles (as opposed to bulk substances), focusing on the similarities and differences between reflection and scattering

How Sunscreens Appear PPT

- Old Slides: 28-30, expand
- Expand the explanatory section in the PPT about how and why objects appear different colors to our eyes
- For the "appearance" part – can have demos showing how R, B & Y light add up to white (need to try this out) and shining lights of each of these colors on different objects to see what color they appear. E.g. in a dark room shine a white light on a green apple and it looks green. Shine a red light on a green apple and it looks black. (Demos w/ lights and color films)

Summary PPT

- Old Slides: 26?, 31?, 32?, 33?, 34
- Add specific explanation of why visible and UV light interact differently with each substance
- Clarify explanations in presentation slides related to scattering and absorption mechanisms and which occur when for what substances
- Clarify which absorbs and which scatters (and why do the different particles behave in different ways?)

- Need to answer question of "How do you know if you are using nano in a sunscreen?' and be very clear about mapping situation: substance type, particle size and wavelength of light involved to appropriate light-matter interactions.

Lesson 1: UV Bead Lab Revisions

General Strategy

- Increase range of substances tested in UV lab
- Add emphasis for students and teachers on the meaning of non-patterns

Planned Revisions

- Change opacity guide to be a black-white-grey thing (put the sunscreens onto black paper and make the opacity guide go black to white)
- Add extra columns to data table to record SPF (when applicable) and observations.
- Need to rethink the different kinds of substances used to get a better range in the chart (i.e. not a bunch of sunscreens that have the same appearance, maybe include some sunscreen gels and some different sunglass lenses)
- Pull the "didactic" part in the intro section out into the ppt that will come before it.
- UV light = required not optional material
- Make note to not put sunscreen on body (allergies issues)
- Don't do it through a window (window blocks) – UV light always
- Use + and – control for both extremes
- In analysis need to draw bigger dot
- Q2 – should have a small grid and ask them to color it in
- Deal w/ issue that SPF didn't correlate w/ blocking except for 1 group
- How should teachers combine results if more than one group tested a substance? Should still use all dots!
- What can we do to make it more exciting that there *isn't* a relationship between opacity and blocking? Maybe it has to do with wearing clothes (of course don't want to scare them) but does a thin (new) white t-shirt block UV or should we be wearing sunscreen underneath?

Lesson 2: Sunscreen Label Lab Revisions

General Strategy

- Shorten sunscreen label activity and connect to new lecture section on the differences between organic and inorganic chemicals

Planned Revisions

- Integrate FDA chart into end of Label activity and make the organic/inorganic distinction clearer.
- Have 2^{nd} part be a class discussion, not individual activity
- Best to use empty containers and store for future use
- Place sunscreens in stations and have kids move in groups of 2-3.
- Change name from 'lab' to 'activity'
- Add columns for price and smell

Lessons 4 & 5: Scattering Animations

General Strategy

- Add UV rays to the animation project

Planned Revisions

- Need more in the prior PPT presentation about how stuff appears to our eyes.
- Need to have both use UV and visible Groups. Can have sharing for the four groups or do 5 groups (one for no sunscreen).
- “Look at UV light, look at visible light, look at UV & visible light” options on pre-made animations - click on buttons to make it clear what they were using.
- Use of term “photon” – reference “light ray”
- Add to things to consider: How will you show a photon being absorbed?