NanoSense: The Basic Sense behind Nanoscience

First Year Report
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Project Activities and Project Findings attached as separate sections.

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SECTION 1: PARTICIPANTS

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
Jennifer Chiu—University of California, Berkeley, Berkeley, CA
Doris Mourad—Teacher, Castilleja School, Palo Alto, CA
Britt Hammon—Teacher, Antioch High School, Antioch, CA
Irene Hahn—Teacher, Miramonte High School, Orinda, CA
Carolina Sylvestri—Teacher, Gunn High School, Palo Alto, CA
Geri Horsma—Teacher, Gunn High School, Palo Alto, CA
Joan Carter—Teacher in Residence, San Jose State University, San Jose, CA
Nancy Day—Teacher, Menlo-Atherton High School, Menlo Park, CA

Robert Cormia—Faculty member, Foothill College
Brian Coppola—University of Michigan

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 relevant and standards-based nanotechnology curriculum for high school science classrooms. Dr. Scharberg provides expertise in curriculum design and teacher training, and will lead the development of 1-2 curriculum units and host teacher training workshops at SJSU. Dr. Scharberg is also working with SRI and our external evaluator to help coordinate testing and revision of units. She and her student assistant are developing a database of high school science teachers that will be used for NanoSense workshops and for updating teachers on the project.

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 will help 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.

NanoSIG, La Honda, CA. NanoSIG is an international special interest group for people both committed to nanotechnology and those interested in the business of nanotechnology. NanoSIG provides a variety of services to those interested in nanotechnology through business and technology oriented forums, news, jobs/career center, and other programs. Adolfo Nemirovsky and Bo Varga at NanoSIG collaborated with the NanoSense team to organize NanoSIG meetings on programs, ideas, and projects on nanoscience education for high school students and meetings with high school teachers to map nanoscience concepts to California high school standards. NanoSIG also helped organize the March 2005 Advancing Nanoscience Education workshop.

Foothill-De Anza Community College District (FHDA), Los Altos, 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, "Nanotechnology Program Curriculum Articulation (PCA)".

NASA Ames Research Center, Moffitt Field, CA. 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

Six 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. These schools represent a range of low- to high-performing students from culturally diverse populations.

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 initial NanoSense teacher meetings, and plans to use activities from the NanoSense introductory unit with her chemistry students for one week starting 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, and Geri Horsma, biology teacher, attended our initial NanoSense teacher meetings and provided feedback on our early materials. They also pilot tested our science fiction nanostory with a few of their students. Both Ms. Sylvestri and Ms. Horsma plan to use NanoSense activities with their students in fall 2005.

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, attended the initial NanoSense teacher meetings and provided feedback on our early materials. Ms. Mourad also attended the March 2005 Advancing Nanoscience Education workshop, and will be working closely with the NanoSense team over the summer to help us develop activities and assessments for our units that focus on optical properties at the nanoscale (e.g., quantum dots and clear sunscreen).

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 plans to use some NanoSense activities with her students in fall 2005.

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 initial teacher meetings and used the NanoSense introductory unit with two classes of chemistry students over the course of two weeks in late 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 include:

Dr. Brian Coppola—Professor of Chemistry at the University of Michigan. Dr. Coppola was Co-PI of the ChemSense project, and collaborates on a variety of chemistry education projects around the country. He is also co-authoring a new high school textbook that brings a more holistic and investigate approach to science learning. 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 has also attended our initial NanoSense teacher workshops and provided feedback on our early materials.

Robert Cormia—Faculty member at Foothill-De Anza College (FHDA). Mr. Cormia teaches courses in Internet projects, XML, informatics, bioinformatics, and starting in fall 2005, a new nanotechnology survey course. We have consulted with Mr. Cormia on his "Atlas for Nanoscience" effort to build a topic map for the domain of nanoscience, as well as maps for required skills and concepts and a curriculum map of courses taught in the San Francisco Bay Area.

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 a National Science Foundation Advanced Technological Education (ATE) proposal entitled "Nanotechnology Program Curriculum Articulation (PCA)" in October, 2004. This project proposed to define, create, test, refine and disseminate a nanotechnology *curriculum articulation model*, a set of modules and an infrastructure to facilitate a coherent, modular set of nanotechnology courses to be offered by Community Colleges and Universities. The proposal was not funded, and is currently under revision for a future submission.

Alyssa Wise—Graduate student, Indiana University. Ms. Wise is a PhD student in Learning Sciences at the School of Education, with a Masters in Instructional Systems Technology. Ms. Wise attended the March 2005 Advancing Nanoscience Education workshop and is working with the NanoSense team over the summer to develop a curriculum unit around optical properties at the nanoscale (clear sunscreen).

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 Patricia Schank and Tina Stanford have also attended several professional development seminars and workshops on nanoscale science at Stanford University.

NanoSense funding supports a graduate student from Indiana University at Bloomington who is interning with the project to help develop curriculum activities, and a student assistant at San Jose State University (SJSU). We are also working closely with a graduate student at the University of California at Berkeley who is working to integrate ChemSense and the Molecular Workbench using Pedagogica, with funding from the TELS Center for Learning and Teaching. The aim of this work is to create a nanoscience activity that uses Molecular Workbench to simulate a nanoscience concept and ChemSense to gather student assessment data. By partnering with SJSU and Berkeley/TELS, we are supervising and supporting graduate students who will become the teachers, designers, researchers and educational policy makers of tomorrow.

Additionally, we have worked closely with six 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. Two of these teachers are interning with the project during the summer months, in addition to attending our general meetings and workshops. 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 was developed in spring 2005 to provide public access to NanoSense activities, information about our workshops, presentations and publications, research findings, and project contact information.

NanoSense was presented at the Advancing Nanoscience Education workshop (Menlo Park, March 2005). Materials from the workshop were also posted on the NanoSense web site. NanoSense was also presented at the Gordon Research Conference (GRC) on Visualization in Science and Education (Oxford, July 2005) were Dr. Schank was an invited speaker.

Tina Stanford presented an invited guest lecture on nanoscience to a chemistry class at Acalanes High School in Lafayette, CA on May 19, 2005.

The ChemSense software—a constructivist representational environment that will be paired with some NanoSense activities—was released to the public at http://chemsense.org in January 2005. The software was also submitted to the Journal of Chemical Education (JCE) Digital Library upon request from JCE staff.

SECTION 3: PUBLICATIONS AND PRODUCTS

Publications

Technical Reports

Sabelli, N., Schank, P., Rosenquist, A., Stanford, T., Patton, C., Cormia, R., & Hurst, K. (in preparation). *Report of a workshop on science and technology education at the nanoscale*. Menlo Park, CA: SRI International.

Conference Presentations and Workshops

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.

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.

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 one full curriculum unit, and is currently developing two other units that will be tested in fall 2005.

All activities will be made available to the public on the NanoSense Web site at http://nanosense.org and distributed at teacher workshops at national conferences and at training facilities at San Jose State University.

1. *Size Matters* (6 lessons/sections, plus suggested extensions). This unit introduces students to the field of nanoscale science through readings, presentations, discussions, and lab activities around the size and scale of various objects, unusual properties of the nanoscale, and example applications.

2. *Clear Sunscreen* (under development, draft expected August 2005). 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.

3. *Quantum Dots* (under development, draft expected August 2005). This unit explores issues related to size and aggregation, specifically, how the size and aggregation of nanocrystals can effect physical properties (e.g., reflect different colors of light). Nanogold, for example, can appear orange, red, or green depending on the size and spacing of the gold atom aggregates. Quantum dots can be used as fluorescent labels in biological imaging and drug discovery research.

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 has been made freely available for download on the ChemSense web site at http://chemsense.or/download as of January 2005, and is also being made available through the Journal of Chemical Education (JCE) Digital Library.

Instruments

At this early stage of development, the outside evaluator for NanoSense is observing classroom 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 experiences with the activities. As the units undergo revisions and are implemented in additional settings, the evaluator will co-develop with the NanoSense team assessments of student learning and rubrics to analyze conceptual elaboration in classroom discourse.

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 2^{nd} 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—two graduate students and one undergraduate—and are working closely with six 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 1 ACTIVITIES

Activities conducted during the first 9 months of the NanoSense grant (September 2004 – June 2005) are described below, as well as plans for activities for the remaining 3 months of Year 1. We categorize the work in terms of 10 activities.

Activity 1: Teacher Meetings

In the first year of the NanoSense project, we held four meetings with our partner teachers. Primary objectives of the meetings included introducing the teachers to the project, gathering feedback on activities as they were being developed, and planning pilot use of materials with their students. Meetings lasted from 2 to 4 hours.

Project overview: November 20, 2004

Patricia Schank presented an overview of the NanoSense project, and Maureen Scharberg, San Jose State University, presented on the Understanding by Design approach to curriculum design (Wiggins & McTighe, 2001). Following these presentations and discussion, Tina Stanford and Anders Rosenquist presented an overview of some core concepts of nanoscale science and activity development ideas. Participants discussed our plan for activity development and teachers' impressions of topics and issues of most importance to them. We distributed folders with introductory readings on nanoscience and the Understanding by Design approach, instructions for using our internal project Wiki for group collaborations, instructions on how teachers should prepare and submit invoices for their time spent working with the project, the full NSF proposal and responses to reviewers' questions, and a CD with all of the folder materials and the ChemSense software. Materials presented were also posted to the group Wiki for future access. Contact information for all NanoSense team members and collaborators was also made available on the group Wiki.

Review early draft of Size Matters materials: March 5, 2005

In the second teacher meeting, the NanoSense team presented the initial materials for our first Size Matters unit for teacher review and feedback. The materials included the learning goals and road map for the unit, a science fiction story developed by our team illustrating how nanotechnology could affect our lives 40 years in the future, and PowerPoint slides for teachers to present the Unique Properties and Applications of Nanoscience lessons. We provided folders with these materials at the meeting and distributed the materials for review a week before the meeting on our internal group Wiki. At the meeting, we also presented the new NanoSense Web site and described the upcoming Advancing Nanoscience Education workshop. The teachers seemed quite engaged, asking many good questions and providing recommendations for changes to the materials, as well as ideas for additions such as worksheets and a more basic set of introductory slides. Two teachers, Geri Horsma and Carolina Sylvestri, volunteered to pilot-test our science fiction nano story with some of their students and faxed student feedback to the NanoSense team 2 weeks after the meeting. This feedback was used to revise the story.

Review first complete draft of Size Matters materials: April 25, 2005

In the third teacher meeting, we reviewed the first complete draft of the Size Matters unit, which has a week or more of activities (see Activity3: Instructional Materials Development). The teachers said that they were very impressed with how much progress we had made since the last meeting. Most of their recommendations focused on the Size and Scale lesson (e.g., there was much discussion around the card sort activity) and the Unique Properties lesson, which they felt still needed more elaboration to be understandable by the teachers and the students. Two teachers, Geri Horsma and Doris Mourad, also sent written comments on the activities (via a supplied FedEx mailer) 2 weeks after the meeting. During this meeting, we also gauged teacher interest in using one or more activities in the spring and fall, so that we could schedule pilot testing and a spring visit by our external evaluator, Ellen Mandinach from the Center for Children and Technology division of the Education Development Center (EDC) in New York. Teacher partners Irene Hahn and Britt Hammon committed to using this introductory unit with their students in mid May and early June, respectively. Other teachers expected to use some of the materials but indicated that the fall would be better for them. The NanoSense team spent the beginning of May implementing revisions to the materials based on teacher comments so that Ms. Hahn and Ms. Hammon would have the revised versions for use in their classrooms.

Review of pilot testing and summer development plans: June 16, 2005

In the fourth teacher meeting, findings from observing the use of NanoSense materials in Ms. Hahn's and Ms. Hammon's classes will be reviewed. We will also present our development progress and plans for the summer. In particular, learning goals and activity and assessment ideas will be presented for our Clear Sunscreen" unit, under development by Maureen Scharberg and SRI summer intern Alyssa Wise. Alyssa is a doctoral student at Indiana University at Bloomington, focusing on instructional design. She has an undergraduate degree in chemistry and has taught high school physics. Partner teachers Doris Mourad and Irene Hahn will each be working with the NanoSense team for 4 weeks during the summer to contribute to activity development and development of teacher support materials. At the meeting, they will discuss their plans for this summer work.

Meeting participants

Attendees of the meetings above included the following:

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

- Partner Teachers:
  - Doris Mourad, Castilleja School, Palo Alto, CA
  - Carolina Sylvestri, Gunn High School, Palo Alto, CA
  - Irene Hahn, Miramonte High School, Orinda, CA
  - Geri Horsma, Gunn High School, Palo Alto, CA
  - Britt Hammon, Antioch High School, Antioch, CA
  - Joan Carter, San Jose State University (Teacher in Residence)

Activity 2: Advancing Nanoscience Education Workshop

On March 28-30, 2005, NanoSense hosted a workshop at SRI International to discuss conceptual issues and needs related to incorporating the science and technology of the nanoscale in science education. NASA Ames Research Center, Foothill-De Anza Community College District (FHDA), and NanoSIG (http://nanosig.org) were cosponsors. Educational researchers and science educators (spanning high school, community college, and university levels), nanoscientists, science museum/informal-learning specialists, and workforce development staff came together at this workshop to identify and document core nanoscience concepts and how to bring them to students, and to uncover needs, gaps, and research questions for the field of nanoscience education. Additional information, including the list of workshop participants and all presentations, is available at http://nanosense.org/workshops.html.

The primary goals of the workshop were to plan for the integration of concepts of the nanoscale into science education and to move beyond the show-and-tell nature of many nanoscale education activities. In particular, we expected to:

- Identify representations of the core nanoscience concepts.
- Explore the role of hands-on and simulation-based experiences in the learning process.
- Discuss how to prepare teachers to teach in this new area.
- Identify and document industry needs, career paths, and pathways (both formal and informal) for introducing students to nanoscience.
- Recommend needs and directions for research related to nanoscience education.

Prior to the workshop, participants were asked to complete a 10-question online survey that was used to drive the focus of the small-group work at the meeting. At the workshop kickoff dinner, Larry Dubois from SRI International, Martha Kanter from FHDA, and Meyya Meyyappan from NASA Ames gave their perspectives on nanotechnology innovations in the industry in general and at SRI in particular, nanoscience education at FHDA, and NASA Ames's collaboration with FHDA to support development of a new nanoscience certificate program and internships for students participating in the program.

The following day, Robert Cormia kicked off the working meeting with a summary of FHDA's Atlas of Nanotechnology effort to build topic maps for the domain of nanoscience, including maps for the required scientific skills and concepts and a curriculum map of more than 500 courses taught in the San Francisco Bay Area. The Atlas was used to stimulate and organize the workshop discussions. Participants then gathered in working groups to address the workshop goals and prepare a summary of their recommendations for next steps. Examples of driving questions for each working group included:

- Concepts: What are the foundational concepts of nanoscience and key examples that illustrate them? Should more focus be placed on disciplinary or emergent concepts?
- Hands-On Experience: What is the role of lab experiences and simulation, what are good examples, and how can we best deliver them to students?
- Pathways/Careers: What are some possible career paths? Are there nanotech jobs or just "nanoskilled" workers? What are industry needs? What are ideal pathway(s) and timeline(s) by which students should be introduced to nanoscience education concepts in K-12, community college, university, and on-the-job training?

- Teacher Professional Development: How do we best train teachers? What are good models for teacher training?

See the Findings section for a summary of the workshop findings. A complete report of the workshop will be disseminated in summer 2005.

Activity 3: Instructional Materials Development

Overview

In the development of our nanoscience curriculum, we are applying the Understanding by Design approach (Wiggins & McTighe, 2001). Our initial efforts have been to address the challenge of identifying important big-picture ideas, or *enduring understandings* about nanoscience*,* for our high school students to take away with them. To achieve this goal, we consulted and brainstormed with nanotechnology scientists and science education experts. We also conducted an extensive review of the literature, Web sites, and other curricula to help us define our focus. We then aligned our goals with the National Science Education Standards. We established the *essential questions* to guide our unit development, followed by *key knowledge and skills* to be developed by students as a result of experiencing this unit.

Our next step in the process was to identify a set of assessments that would provide the teacher with enough information to evaluate students' understanding of these central ideas. Once this was accomplished, we developed a set of classroom activities to move students toward the goal of understanding. We met with teachers on multiple occasions to review these materials and refined them on the basis of their feedback. By May 2005, we had a complete draft of our introduction to nanoscience unit, Size Matters, consisting of multiple lessons and a week or more of activities. We piloted many of the activities with one teacher in two classes and will pilot a subset of the activities during the week of June 6 with another teacher.

On the basis of the insights of our evaluator, our own observations, and teacher and student feedback, we are currently revising this set of introductory materials and developing more in-depth teacher professional development materials to accompany the unit. The revised unit materials will be posted to the NanoSense Web site at http://nanosense.org/activities/sizematters/ in summer 2005. In fall 2005, we will test the refined introductory unit with additional teachers. We are also beginning development on two new units on the topics of clear sunscreen and water purification. The water purification unit will build on a ChemSense unit that focuses on solution chemistry. We plan to pilot-test these new units with teachers during fall 2005.

Determining a focus for our learning goals

Determining our learning goals was an iterative process that involved the NanoSense team members, partners, and advisors. Our first draft involved identifying seven enduring understanding*s* that we wished students to achieve. In November 2004, we asked for comments on the accuracy and centrality of these goals from our nanoscientists at SRI, Markus Krummenacker, Marcy Berding, and Yigal Blum, as well as Maureen Scharberg and one of our advisors, Deb Newberry.

We held our first teacher meeting in November to share resource material and the initial draft of our learning goals. We brainstormed topics and the possible sequence of these to develop for the first few units. We met again in January with Deb Newberry. On the basis of comments from the teachers, partners, and advisors, we revised our initial set of goals to include a more refined and focused list of four enduring understandings, with complementary essential questions and key knowledge and skill*s*, as follows:

- What enduring understandings are desired?
  1. Nanoscience is an emerging science that 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. The nanoscale is 1-100 nanometers, and small macro- and even microscale objects (e.g., a grain of salt, bacteria) are still orders of magnitude larger than nanoscale objects.
  3. Nanosized particles of any given substance exhibit different properties than larger particles of the same substance.
  4. Nanotechnology focuses on manipulating matter at the nanoscale to create structures that have novel properties or functions.

- What essential questions will guide this unit and focus teaching and learning?
  1. How small is a nanometer, compared with a hair, a blood cell, a virus, or an atom? How do we see things that are very small?
  2. How do the properties of nanosized particles compare with those of larger particles or bulk materials?
  3. Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. What scientific and engineering principles will be exploited to enable nanotechnology to be the next big thing?

- What key knowledge and skills will students acquire as a result of this unit?
  1. Students will be able to distinguish between some commonly known objects (e.g., atom, cell, protein molecule, human hair strand) in terms of their relative size, using metric units appropriately.
  2. Students will be able to predict whether certain sizes of aggregations of matter will exhibit bulk properties or nanoscale properties.
  3. Students will be able to describe two or more applications (or potential applications) of nanoscience and their possible effects on society OR compare a current technology solution with a related nanotechnology-enabled solution for the same problem.

Developing assessments and content

We outlined assessment possibilities for each of the enduring understandings. After a careful review of candidate assessments, we chose a small subset to develop fully. Some assessments we embedded within student activities, and others we developed as formative and summative evaluation items. We developed one performance assessment, accompanied by a scoring rubric. Instructional activities for students were developed simultaneously.

During our first teacher meeting in November 2004, Maureen Scharberg introduced the Understanding by Design approach. As part of the iterative development process, at the second teacher meeting we presented our initial set of introductory slides and readings to the teachers for their critique. On the basis of their comments, we significantly revised and continued to fill out our content. A few teachers pilot-tested the science fiction nano story with their students. We received feedback from the students and revised the story on the basis of their comments.

We presented the first complete draft of our readings, slides, activities, and assessments to our partner teachers during a third teacher meeting in April 2005. We collected the teacher comments on each of our pieces other than the readings. They were to review the readings and send their written comments within the next 2 weeks. We continued to revise our materials on the basis of teacher feedback at the end of April and during the first few weeks of May.

Our first teacher pilot occurred in the two Advanced Placement chemistry classes of one of our partner teachers. She devoted a full week to the topic of nanotechnology. We observed each of her classes during this week with our evaluator. We also interviewed the teacher and some of the students. The observations and recommendations are summarized in Findings 2: Evaluation of Initial Implementation. In addition, Tina Stanford presented an overview of nanotechnology, using an amalgam of our curricular materials, to another AP chemistry class of a teacher who is not a NanoSense partner. Impressions of student reactions to this presentation are provided in Findings 3: Evaluation of Feedback on Outreach Presentation.

Another NanoSense teacher partner, Britt Hammon, plans to use the NanoSense curricular materials in her classroom the week of June 6. We plan to collect observations in her classrooms and interview the teacher and some of the students.

Size Matters curricular materials

Below is a brief outline of the introductory curricular materials in the Size Matters unit. The materials can be used individually or together as a unit.

- Introduction to Nanoscience (addresses enduring understandings 1 and 4)
  - Introductory science fiction short story, "The Personal Touch," involving nanotechnology applications in 2045, accompanied by a questions sheet developed to stimulate student discussion of the story. The novel applications of nanotechnology within the reading are paired with a column by the side of the story, providing more factually detailed information on the applications.
  - A reading that introduces students to the topic of nanoscience.
  - A PowerPoint slide presentation with accompanying teacher notes and a student worksheet. The worksheet is designed to help students highlight key points within the slide presentation.

- Size and Scale (addresses enduring understanding 2)
  - A student reading on visualizing the nanoscale, with examples involving powers of 10.
  - A diagram that compares dominant objects, forces, and laws at a various scales.
  - Two activities designed to help students develop a sense of scale from 10^1 meters to 10^{-10} meters. The first involves sorting cards with familiar pictures and pairing them with measurement units of decreasing value on a number line. The second activity, Cutting It Down, guides students in their ability to conceive objects at the nanoscale.
  - A quiz that allows students to pair objects with appropriate number units.

- Unique Properties at the Nanoscale (addresses enduring understanding 3)
  - PowerPoint slides that illustrate examples of unique properties at the nanoscale, with accompanying teacher notes.
  - A general reading on unique properties at the nanoscale and three specific readings on electrical, mechanical, and optical properties.

  - Lab station activities designed to demonstrate central concepts about properties, with accompanying teacher directions and student lab sheet.
  - A quiz on unique properties of nanoscale objects.

- Nanofabrication Techniques (addresses enduring understanding 4)
  - A reading on nanofabrication techniques and tools of the nanosciences.
  - A quiz on the reading.
  - Optional extension activities using model atomic force microscopes, ChemSense software, and Molecular Workbench software.

- Applications of Nanoscience (addresses enduring understandings 1 and 4)
  - PowerPoint slides illustrating approximately a dozen examples of applications, with accompanying teacher notes.
  - A performance activity in which students research a current or possible application of nanotechnology and prepare a poster or presentation. The activity includes student instructions, a list of topics and references, and a scoring rubric.

Summer development plans

Our student intern, Alyssa Wise, joined the team in mid-May 2005. She reviewed our existing materials, and has begun to develop a unit on the topic of clear sunscreen. Two partner teachers, Irene Hahn and Doris Mourad, will work with the NanoSense team for 4 weeks during the summer to help with development of new units and support materials. In particular, Ms. Hahn has expressed interest in working on teacher materials and a unit on quantum dots or tools of the nanosciences. Ms. Mourad may help with the development of our water purification unit. The team is also completing revisions to the Size Matters unit, including professional development materials to help teachers understand nanotechnology in general and specific support materials to help teachers work with the curricular materials we have developed.

Activity 4: Evaluation Planning

Planning for the formative evaluation of our materials began in February and March 2005 with teleconferences with our external evaluator, Ellen Mandinach. Members of our development team, Patricia Schank and Anders Rosenquist, also met with Dr. Mandinach at AERA in Montreal on April 13, 2005. During these meetings, we discussed our expectations and framework for the evaluation. It was decided that we would ask one or two of our teachers to commit to implementing some or all of our introduction to nanoscience unit, Size Matters, in May or June, and Dr. Mandinach would conduct an initial formative evaluation of one or both teachers' implementation. We also scheduled several phone conversations to further discuss objectives and to jointly draft initial instruments, including student questionnaires, observation protocols, and interview frameworks. We also agreed on several overarching issues for the evaluation. Telephone conversations with Ellen in April and May helped us refine our approach and plan the logistics of the evaluation. The core issues for evaluation include:

- *Implementation variables*. Is the unit difficult to implement? Are the kids engaged? Are they doing what was intended? Were activities omitted that we thought should be included? Why did the teacher omit or adapt specific activities? Did the teacher use the teacher notes?

- *Curriculum alignment*. How well do our activities match the learning goals? Where do they fall short? Are some goals over- or underrepresented? Are activities related to certain goals skipped by some teachers? How well do our assessments (formative and summative) measure students' understanding related to all learning goals? How might the activities/assessments be changed to align better with the learning goals?

- *Learning outcomes*. What kinds of evidence are we seeing for key learning outcomes? What assessment strategies will work best for gathering evidence regarding student learning outcomes?

Schedule of implementation

Two of our participating teachers, Irene Hahn (Miramonte High School) and Britt Hammon (Antioch High School), volunteered to implement the NanoSense Size Matters unit in their classrooms at the end of the 2004-05 school year. Together, these classes represent a diverse range of students with respect to demographics and overall levels of academic achievement.

Activity 5: Evaluation of Initial Implementation—Miramonte High School

Ellen Mandinach spent Monday through Friday, May 16-20, 2005, observing the initial implementation of Size Matters in two of Irene Hahn's AP Chemistry classes at Miramonte High School. Ms. Hahn's class met every day of the week for approximately 50 minutes. The following outlines her schedule for the unit:

- *Friday, May 13*. She assigned the NanoSense science fiction story and accompanying worksheet.

- *Monday, May 16*. She presented the NanoSense Introduction to Nanoscience PowerPoint slides, had students do the NanoSense card sort activity, and assigned the NanoSense introductory reading on nanoscience. She collected the story worksheet but did not go over it in detail, other than to discuss which elements of the story seemed most and least realistic to the students.

- *Tuesday, May 17*. She presented her own, custom-developed introduction to tools of the nanosciences—in particular, atomic force microscopes and scanning tunneling microscopes.

- *Wednesday, May 18*. She presented the NanoSense slides on unique properties at the nanoscale and attempted to supplement them with some lecture material spontaneously developed in response to student questions. An interesting, though unresolved debate ensued regarding how light is emitted from solid objects.

- *Thursday, May 19*. The students completed an MRSEC nanogold lab activity instead of implementing the NanoSense Unique Properties lab stations.

- *Friday, May 20*. She handed out the NanoSense Nanofabrication Techniques reading but did not formally assign it or discuss it. She also handed out a compilation of student responses to the science fiction story that summarized what applications the students found most/least believable, and a list of the questions they wrote on their worksheets. Next, she presented the NanoSense slides on applications of nanoscience. After the presentation, she assigned the NanoSense performance assessment, which had students research and prepare a presentation comparing a current technology with a related, new nanotechnology application. She handed out the NanoSense list of possible topics, which also included topic summaries and links for more information. Students self-selected into small groups (three or four per group) and selected topics for their presentations.

- *Monday-Wednesday, June 6-8*. The students presented and explained their chosen applications of nanoscience.

Dr. Mandinach attended all class sessions from May 16 through 20. She took extensive field notes, conducted interviews with the teacher and students, and collected student worksheets. NanoSense team members also observed the classes each day except May 19.

Activity 6: Evaluative Activities for Outreach Presentation—Acalanes High School

NanoSense team member Tina Stanford presented an introduction to nanoscience to AP chemistry students at Acalanes High School on May 19, 2005 (see also Activity 10: Dissemination and Outreach Activities). On the basis of discussions with the teacher and feedback from students after her presentation, Ms. Stanford documented student interests and understandings regarding nanoscience, presented in Findings 3: Evaluation of Feedback on Outreach Presentation

The style of presenting was a combination of lecture and class discussion. The presentation materials were selected from among those developed for the longer NanoSense Size Matters unit. The presentation began with a definition of nanotechnology, followed by the first few PowerPoint slides from the unit. The NanoSense scale diagram was given to students to help guide their thinking about the relationship between matter, tools and dominant forces at different scales. The NanoSense unique properties slides were used as an organizer for comparing the optical, mechanical, and electrical properties of bulk materials with those of nanoscale materials of the same substance. Samples of red and blue nanogold were passed among the students to focus the discussion of optical properties. The NanoSense applications of nanoscience slides were shown last. Students were asked questions throughout the presentationand in turn asked several questions regarding the applications of nanotechnology.

Activity 7: Evaluation of Second Implementation—Antioch High School

Britt Hammon used several activities from the NanoSense Size Matters unit in her chemistry class at Antioch High School on June 2 and during the week of June 6-10. Ms. Hammon's class meets every other day for approximately two hours each day (the school is on a block schedule). The following outlines her schedule for the unit:

- *Thursday, June 2*. She discussed nanoscience as an aggregate of chemistry, physics, and electronics, and had students read the NanoSense Introduction to Nanoscience.

- *Monday, June 6*. She presented the NanoSense Introduction to Nanoscience slides and had students complete the accompanying worksheet. Students then completed the Cutting it Down activity. Students also read the NanoSense science fiction story and completed the accompanying worksheet, working in pairs. Finally, she assigned the Unique Properties reading.

- *Wednesday, June 8*: She presented the NanoSense slides on Unique Properties at the Nanoscale, and students completed the Unique Properties lab stations.

- *Friday June 10*: She presented the PowerPoint slides on Applications of Nanoscience and assigned the NanoSense performance assessment to prepare a poster comparing a current technology with a related, new nanotechnology application.

Members of the NanoSense team observed the classes on June 6 and June 8, taking field notes and conducting brief interviews with teacher and students.

Activity 8: Synergistic Activities

Gordon Research Conference on Visualization in Science and Education

Patricia Schank was invited to give a presentation on ChemSense and NanoSense at the 2005 Gordon Science Education & Policy Conference on Seeing and Understanding: Guiding Research for Visualization in Science and Education in Oxford, England, in July 2005. Dr. Schank's talk will focus on how student-created drawings and animations can support nanoscale science learning, discourse, and assessment. Anders Rosenquist will also present a poster on the NanoSense project (see Activity 10: Dissemination and Outreach Activities) that will highlight NanoSense activities and their use of visualization.

Scaling and sustainability of large-scale science education innovations

In March 2005, we submitted a joint IERI proposal with the Concord Consortium to adapt ChemSense to run under Pedagogica, a scripting and data acquisition/analysis tool that will allow ChemSense to support structured problem-solving activities and collect student performance data, and use this framework to collect data in multiple school settings. If funded, we will develop activities using ChemSense and Molecular Workbench together to help students learn nanoscale science and will place these interactive curriculum and assessment materials in as many schools as choose to download our software and register their students with us. These schools will receive real-time reports analyzing what their students are doing with the software. The reports will assess the students' inquiry and modeling skills in science, as well as their content knowledge. The activities themselves will provide formative feedback to students, and we will study the effect of this feature on their learning. We will also study how the teachers use the reports, in order to gauge the effect of cognitive feedback on teachers' practice. Finally, we will select as case studies a group of schools that have been successful in implementing our innovation, as well as others that have failed to do so. This work will enable us to identify the critical factors that affect success in the adoption and/or adaptation of a technological innovation by schools that have no other contact with the creators of the innovation.

Collaboration with TELS and UC Berkeley graduate student

In April 2005, we began discussions with members of the TELS Center for Learning and Teaching—in particular, with Marcia Linn and her graduate student Jennifer Chui at UC Berkeley—about creating chemistry-learning activities that integrate Molecular Workbench simulations and ChemSense within Pedagogica. This work would build on the different strengths (e.g., simulation versus assessment) of these very different tools. Jennifer has developed initial sketches of several possible interactive activities and will be designing one or more activities as part of a graduate project. This work would integrate nicely with the proposed IERI work (above) to support more structured problem-solving activities and automated logging of student performance data.

Women in Engineering speaker event

On June 1 2005, the NanoSense project and the IEEE SF Bay Area Nanotechnology Council cosponsored a talk by Robert Cormia, from Foothill College, titled "Angstromology: A Tour of the Universe at the Nanoscale Level and Beyond" (see http://ewh.ieee.org/r6/scv/wie/upcoming-events/20050525-angstromology.html). This talk was free and open to the public, with about 40 participants attending. This talk provided a tour of the universe at the quantum scale, shedding some light on what is, isn't, or might be nanotechnology.

Center for Articulation project

In October 2004, the NanoSense team collaborated with Robert Cormia (Foothill College) and Sukhjit Singh (De Anza College) to develop an NSF Advanced Technological Education (ATE) proposal for a Nanotechnology Program Curriculum Articulation (NPCA) project. The goals of this project are to develop a "Center for Articulation" to train faculty in developing a rigorous practice of defining and declaring learning outcomes in terms of knowledge and skills and, more importantly, to document the method by which a student learning outcome is produced. Funding for this proposal was not awarded, but we plan to submit a revised proposal, addressing reviewer contents, in a future ATE round.

Engineering education

We are also beginning discussions around a project to improve student understanding in undergraduate and graduate engineering education under the NSF Engineering Education Program (EEP). This work would involve the development of software to help students visualize and manipulate processes of nanoscale science on six different, but related, levels—atomic, molecular, nano, micro, and macro—and application of this software to the study of student understanding of size, scale, and nanoscale science. This work would be partly modeled after the the GenScope project (Horwitz, Neumann & Schwartz, 1996), which gives students a way to investigate scientific and mathematical concepts in genetics through direct manipulation and experimentation at multiple levels (DNA, chromosome, cell, organism, pedigree, and population).

Activity 9: Advisory Activities

Several of the NanoSense advisory board members have met with our research team during the past year. Deb Newberry visited SRI in January 2005 and brainstormed with the NanoSense team around activity development. She suggested that we reduce the scope of our learning goals for the first unit, and highlighted the importance of the interface (i.e., surface-to-surface) level of material interactions. Dr. Newberry also visited SRI in March to review our current set of nanoscience activities; she gave valuable comments on our introductory slides and readings and provided ideas for assessment.

Another advisory board member, Michael Ranney, visited SRI in February 2005 to discuss our introductory story, which he was able to pilot-test with his high-school-age daughter. He provided detailed comments and suggestions for improvement. In April, Dr. Ranney visited SRI again to help us refine and focus our properties slides and readings.

Maureen Scharberg and advisors Marcy Berding and Brian Coppola were solicited to give their input on our learning goals and the accuracy of the science concepts and ideas. They each gave timely feedback, which was incorporated into our next iteration of the activities. Robert Cormia also gave feedback, focusing on key concepts of nanoscience based on thinking at Foothill College on development of the Atlas of Nanotechnology.

At our Advancing Nanoscience Education workshop in March 2005, advisory board member Larry Dubois gave the opening presentation at the workshop's kickoff dinner. Dr. Dubois gave an insightful overview of nanoscience, current developments, and educational challenges moving forward. One advisory board member, Christine Peterson from the Foresight Nanotech Institute, was unable to attend the workshop, but Scott Mize, President of the Foresight Nanotech Institute, attended in her absence. Advisor Robert Tinker attended the workshop via phone and discussed the use of Concord Consortium's Molecular Workbench for teaching nanoscience and possible collaborations with Concord Consortium to integrate ChemSense and Molecular Workbench through Pedagogica (see Activity 8: Synergistic Activities). Robert Cormia presented the Atlas of Nanotechnology at the workshop and led a discussion on the development of the tool and its application to nanoscience program articulation.

Activity 10: Dissemination and Outreach Activities

Papers and presentations

NanoSense activity development progress and current findings were presented at two conferences this year, the Gordon Science Education & Policy Conference in Oxford, England, and the Instructional Materials Development Conference at NSF. The Gordon conference work, presented in both a discussion session (Patti Schank) and in a poster session (Anders Rosenquist), highlighted the overall goals of the project and our findings to date. At the IMD conference, Patti Schank and Tina Stanford highlighted the conceptual challenges of developing nanoscience learning activities, presented the NanoSense goals and research questions, gave an overview of the ChemSense environment, summarized candidate nanoscience activities, and discussed our implementation approach.

In May 2005 we also presented our NanoSense work at an internal Center for Technology in Learning (CTL) meeting to discuss NanoSense progress, findings, and challenges, and to gather recommendations and ideas from other content developers in CTL. We also presented our NanoSense work to SRI senior staff to obtain internal funding to support workshop report writing. This funding was used to write the technical report for the Advancing Nanoscience Education workshop that was held at SRI in March.

Publication citations

- Schank, P., Sabelli, N., Cormia, R., Stanford, T., Hurst, K., & Rosenquist, A. (in preparation). *Report of a workshop on science and technology education at the nanoscale*. Menlo Park, CA: SRI International.

Presentation citations

- 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.

- 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.

Outreach presentation at Acalanes High School

NanoSense team member Tina Stanford presented an introduction to nanoscience to AP chemistry students at Acalanes High School on May 19, 2005. The goal of the presentation was to introduce the students and the teacher to nanotechnology and to those aspects of the science that make it unique compared with the study of larger scale materials. The materials used were selected from among those developed for the longer NanoSense Size Matters unit. On the basis of discussions with the teacher and feedback from students after her presentation, Ms. Stanford documented student interests and understandings regarding nanoscience. See Findings 3: Evaluation of Feedback on Outreach Presentation for more information on the evaluative activities and findings related to this presentation.

NanoSense Web site

The NanoSense web site (http://nanosense.org) was established in spring 2005. We worked with an interaction designer to address branding, color treatment, text layout, icon development, and logo treatment to help establish a sense of identity for NanoSense. The site provides an overview of our project activities and links to more detailed information about the goals of the project, NanoSense activities, past workshop materials and planned workshops, papers and presentations, and project contact information. Sample screenshots of the NanoSense web site are provided in the Findings section of this report.

Activities developed by the NanoSense team will be made available to the public on the NanoSense Web site as they are pilot-tested and vetted by our partner teachers. In the final 2 years of the project, activities will also be distributed at teacher workshops at national conferences and at training facilities at San Jose State University.

References

Horwitz, P., Neumann, E., & Schwartz, J. (1996). Teaching science at multiple levels: The GenScope program. *Communications of the ACM, 39*(8), 127 - 131.

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NanoSense: The Basic Sense behind Nanoscience

YEAR 1 FINDINGS

We categorize our observations, conclusions, and recommendations from the first 9 months of the NanoSense grant (September 2004 – June 2005) in terms of four findings.

Finding 1: Advancing Nanoscience Education Workshop

Pre-workshop survey

Prior to the meeting, participants were asked to complete a 10-question online survey used to drive the small-group work at the meeting. The survey questions were:

1. In your own words, what do you think nanoscience education should be? Specify the education level that you are most interested in.
2. What knowledge should students have prior to starting a nanoscience program in college?
3. In high school, what concepts should students understand before going into a college nanoscience program?
4. Do you think nanoscience is better taught as interdisciplinary, integrated courses or through traditional, discipline-specific courses (i.e., biology, chemistry, physics, math)? If both, what would you emphasize?
5. What foundational concepts from nanoscience do you think are most crucial to teach? For example, scale and energy are often cited. What others can you suggest?
6. What are a few of your favorite examples that illustrate the concepts mentioned in question 3?
7. What do you think is the role of laboratory experiences and demonstrations in nanoscience education? Can you give a few examples and specify how they contribute to student understanding?
8. What tools, in general (including modeling tools) do you know of or you can recommend that can be adapted for labs or demonstrations?
9. What nanoscience education materials are you aware of that you think are particularly good?
10. In a nanoscience program, what do you see as the balance between academic learning, laboratory training, and on-the-job training?

Sixteen workshop participants completed the survey prior to the workshop. A summary of the responses follows. Complete results of the survey are given in the workshop report that will be published on the NanoSense Web site. Numbers in parentheses following a response indicate approximately how many respondents gave this response.

Question 1. Many participants indicated that nanoscience education should be a true cross-disciplinary effort and an exciting way to teach traditional science concepts. A wide range of target audiences were mentioned, with almost equal interest in undergraduate (6), high school (5), and museum/informal learners (4). Teachers (1) were also mentioned as a target audience.

Question 2. A variety of sciences were mentioned as required knowledge for starting a college nanoscience program, including an introduction to chemistry (8), physics (6), biology (6), math (3), computer science (2), engineering (2), and earth science (1). One participant mentioned the National Science Education Standards (NSES) and an appreciation for practice and implications. A few participants mentioned specific concepts (such as bonding, forces, atomic structure, friction, solubility), and several others mentioned more general skills, including problem-solving and communication skills (3).

Question 3. A variety of concepts were mentioned as ones that high school students should be exposed before going to a college nanoscience program. These included concepts from chemistry (e.g., atomic structure, bonding, oxidation and reduction, adhesion, absorption, electrochemistry, periodic table), physics (e.g., electronic and magnetic properties, electro-optical interaction, density, energy, forces), biology (e.g., cells, molecules, DNA, proteins), and math (e.g., calculate forces, metric system, scientific notation). More generally, concepts of size and scale, knowledge of applications, and skills in problem solving and "how to learn" were also mentioned.

Question 4. Regarding whether nanoscience might be better taught through interdisciplinary, integrated courses or through traditional, discipline-specific courses, most respondents said both were appropriate or "it depends" (8), but that they would prefer an interdisciplinary approach in an ideal world (8). It was noted that an interdisciplinary approach may be easier at upper levels and may be more interesting for students, particularly females. However, participants said that more examples within the disciplines are needed (3), especially in chemistry (2). It was noted that change is slow in academia, so the best bet may well be to integrate nanoscience education into the existing disciplines. One participant noted that we lack research on whether an integrated or independent approach is most effective.

Question 5. Regarding the foundational concepts that are most important to teach, many participants cited the unique properties at the nanoscale (4) and, in particular, surface technology/surface effects (4). Size and scale in time and space (5), self-assembly (3), and methods and tools for fabrication and measurement (2) were also mentioned. A sense of statistics and averaging was also noted (2), as were some domain-specific concepts (e.g., bonding, forces, energy, quantum states, magnetism). Two respondents noted that practical applications and jobs were also important to know about, as were ethics and implications of nanoscience.

Question 6. Favorite examples given by participants included often-cited examples such as self-cleaning clothes/nanofabrics (3); quantum dots, gold nanoparticles as sensors (3); clear sunscreen (2), and energy from nano solar panels and clean hydrogen fuel (2). Also mentioned were examples involving nanofilters, nanotubes, ferrofluids, and scanning tunneling microscopes. It was noted that everyday hooks (e.g., clothes, hobbies, cool stories, curious phenomena) were often best to motivate students and informal learners.

Question 7. Everyone said that lab experiences were critical for learning nanoscience, and demonstrations were also considered useful. It was noted that such experiences assist deep learning and also facilitate soft skills, such as interacting with others. Two respondents called for an interactive "playground" approach in which labs and lectures are integrated with computers, instruments, group tables, and remote cameras. Favorite lab examples included atomic force microscope (AFM) tools and models, self-assembly demonstrations with magnets or foam, and the nanoManipulator tool to explore surfaces.

Questions 8-9. Recommended tools and materials included Molecular Workbench tools (5), Wisconsin's MRSEC materials (3), actual or model (e.g., wood or LEGO) AFMs (2), the nanoManipulator tool (2), Lawrence Hall of Science's nanoZone (2) the "It's a Nano World" exhibition, and NanoKids. Two teacher-developed units were also mentioned (2), as were UCLA nanotechnology labs, Visual Quantum Mechanics materials, and ChemSense and NanoSense.

Question 10. Regarding the balance between academic learning, lab, and on-the-job training, many respondents felt that they were all equally important and should be tightly integrated (5), while others mentioned that the ratio in which they should be integrated depends on the level of the learner (5). For example, one respondent recommended a 40:50:10 ratio for high school students, and another noted that college/adult learners should gradually integrate more job training. A couple of respondents indicated that they were unaware of (and would like to learn about) what jobs and internships are available to students.

Working group reports

The workshop report includes a complete report from each of the working groups. Below we briefly summarize some of the challenges and recommendations for nanoscale science education as identified by each working group.

Concepts. This group focused on identifying the foundational concepts of science at the nanoscale that seem most crucial to teach students. There was strong agreement that nanoscience is an interdisciplinary science and would benefit from inclusion in all or most relevant discipline courses. The following concepts were generally agreed on as being central to nanotechnology:

- Surfaces (e.g., surface chemistry, surface physics, interfaces)
- Unique properties at the nanoscale (e.g., electromagnetic, mechanical, optical)
- Self-assembly (e.g., bionanotechnology, crystal structures)
- Quantum principles and probability (e.g., quantized energy, quantum numbers)
- Scale (e.g., size, number, forces, properties, time)
- Energy (e.g., role in interparticle interactions, scale of energy and power)
- Nanostructures (e.g., nanotubes, colloids, thin films, quantum dots)
- Fabrication (e.g., tools, processes, metrology).

The group agreed that the concepts that underlie nanotechnology are difficult ones to teach, and that we also need to address ethical and safety issues directly because we don't fully understand the behavior of matter at this scale and the use of nanomaterials has implications for safety and privacy that are socially relevant. Communicating the science behind nanotechnology will require creative thinking about how better to convey to students the fundamental conceptual ideas in a way that is comprehensible and thus require new methodologies that account for the cognitive development of students.

Hands-on experiences. The hands-on group focused on identifying ideal practices and resources, needs and gaps, research questions to assess the impact of hands-on activities, and grand challenges for the field. Ideal practices and resources identified by the group fell into three categories:

- *Authentic, transparent tasks,* such as self-assembly with bubbles, dilution with Kool-Aid, LEGO and wooden models of AFMs, and the "pouring tea" exhibit at the Exploratorium that illustrates problems with pouring at a tiny scale.
- *Use of stories and narratives,* such as books like *Alice in Quantumland* (Gilmore, 1995) and *Mr Tompkins in Paperback* (Gamow, 1993); goal- and problem-based scenarios; and even movies such as *The Incredibles,* in which Jack-Jack, the superhero baby, "tunnels" around the room.
- *Using simulations and online modeling,* such as virtual AFMs, the nanoManipulator tool, and Molecular Workbench software.

The group also generated a number of research questions for the field, a subset of which are summarized below (see the workshop report for the longer list).

- How much (and in what sense) does authenticity matter for learning? How critical is hands-on experience in learning? How should a lab infrastructure be organized to support this experience? What aspects of lab experience are key to capture/preserve/replicate in virtual experiments?
- What leads to better understanding: demonstrating individual concepts or incorporating them into one realistic example?
- What are the everyday concepts and intuitions (e.g., stickiness, smelliness) that can be leveraged for nano understanding?
- How do you elicit and make explicit students' conceptions of nanoscale phenomena?

Teacher professional development (TPD). Keeping classroom instruction current in any technology-driven content area is difficult, given the constantly changing landscape of discoveries, methods, and applications. It is increasingly challenging for teachers, even those with a reasonable level of content knowledge, to keep up with new developments in their content areas, and national and local standards and assessments lag even farther behind than many teachers. States where thematic teaching is prevalent (e.g., Virginia) seem to address the curriculum issue slightly better than do states that base their curricula on specific science standards (e.g., California), but there is still a significant lag at the testing level. The TPD group addressed such issues and outlined two potential models of TPD for nanoscience educators.

One potential model involves the creation of a local professional teaching community focused on nanotechnology topics and activities. This could be modeled after local biotechnology teaching programs and consortia, such as Access Excellence, Gene Connection, and the Santa Clara County Biotechnology Education Partnership. These consortia include extensive local networks of teachers and provide packaged hands-on units on key topics and authentic techniques. These units are designed to be short (1 week or less) and to be easily adapted into regular and advanced high school biology courses.

Another promising model is the creation of summer research internships for teachers, who then adapt their experience into classroom lessons. These could be modeled after the successful local industry-teaching partnership, Industry Initiatives for Science and Math Education (IISME). Teachers who receive IISME fellowships participate in a 6- to 8-week research project in a local industry, government, or university lab setting, with a stipend. Teachers network through weekly meetings and design and critique lessons developed from their research projects. Teachers then present these lessons at their schools or districts during inservice training. A key issue for discussion was how to measure the learning outcomes from such programs, since many have focused on teacher interest and satisfaction rather than more concrete measures of classroom success.

Participants felt that basic unifying chemistry, physics, and materials science concepts should be presented to earlier-grade-level teachers, along with grade-level-appropriate classroom activities and assessments. These concepts and activities may not necessarily cover nanotechnology topics but could address issues of scale and the different types of forces that come into play at different scales. More advanced and specific nanoscience concepts, along with current developments in technology, could be presented to secondary teachers.

Careers and educational pathways. To develop effective pathways to education and training for careers in "nanoskilled industries," educators need to develop a clear understanding of career opportunities and requirements. Where are nanoskilled jobs, and what are these nanoskills? As a result of this NSF-sponsored workshop, a small group including Center of Excellence (COE) at West Valley College, the California Employment Development Department (EDD), and Foothill-De Anza Community College District (FHDA) will develop one or more survey instruments to determine what industries are working to employ nanoscience and engineering in their products and what typical job titles are associated with that work. Using an environmental scan, a thorough description of nanoskilled work, including the knowledge and skills required for those jobs, will be developed and will help map work skills to curriculum standards. As FHDA develops a program for both academic and workforce development in nanoscience and technology, we will need to ensure that educators' foundational knowledge in science is sufficient for building a specialized set of training materials and programs to meet the growing needs of industry.

Workshop evaluation

Participants were asked to complete an evaluation survey at the end of the workshop. The full survey and summary of participants' written comments are available in the workshop report. Fourteen participants responded to the survey, representing a wide variety of backgrounds (high school, community college, and university faculty, as well as nanoscientists, museum professionals, and education researchers). Most evaluations were quite positive. For example, participants were asked to indicate their agreement with several positive statements on a scale from 1, strongly disagree, to 5, strongly agree, and all mean ratings fell between agree and strongly agree, as shown below.

	Mean	**Max**	**Min**	**N**
The workshop was well organized.	4.64	5	3	14
The workshop met my expectations.	4.08	5	3	13
Presenters communicated effectively.	4.21	5	4	14
The content presented was of value to me.	4.07	5	2	14
The working sessions were of value to me.	4.36	5	2	14
I identified new collaboration opportunities that I plan to pursue.	4.38	5	3	14

Finding 2: Evaluation of Initial Implementations

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, most of which echo the conclusions we drew from our own observations and interviews at the participating high schools.

Preliminary Report on the Formative Classroom Observations by External Evaluator, Ellen Mandinach, Center for Children and Technology – May 16-20, 2005

Categories for classroom observations were determined a priori. It was important to keep in mind that the purpose of the week of observations in the middle of May was to provide formative feedback to the development team, trying to determine what the teacher thought "worked," did not work, was confusing, was easy to use, and the like. We wanted to get feedback from the students as well. The focus on the investigation was the introductory unit on nanoscience that was being beta tested in two Advanced Placement (AP) chemistry classes at Miramonte High School in Orinda, CA. The teacher was an energetic and experienced woman who has been providing feedback to the development team and agreed to try out the materials once the AP curriculum and examination were completed.

There are a few global comments that require mention as they are likely to skew the results, not matter how formative, and the interpretations. First is that the two classes that were observed are not typical of chemistry classes. Even for AP chemistry classes, the students in the two classes are likely to be more adept than the norm. The students are smart. The second factor is the teacher. Ms. Hahn is a very gifted teacher. Her knowledge of chemistry is quite far-reaching. She does, however, lack knowledge of biology, which she admittedly has not had since her high school freshman course. The third factor is the timing of the observations within the academic calendar. The middle of May was ideal for Ms. Hahn to test out new curriculum materials because the students has already completed their AP course and taken the examination. However, the timing was not ideal for two reasons. First, because the students had completed the course, there is little motivation for them to do much of anything at all. Second, half the students were seniors who apparently suffered from severe cases of senioritis. Not that the seniors did not take the task of helping to provide feedback seriously, but the juniors had much more to gain by providing valuable information.

In terms of the structure of this report, I will first outline the categories I used to approach the formative work. I will then describe briefly the observations, linking them to the general categories.

Categories for Observations and Interviews

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 and Readings
- Activities
- Ease of Implementation

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

Student Understanding

Students in both classes seemed to grasp the concepts contained in the materials and activities. In terms of the three laboratory exercises, they easily understood the concepts engendered in the scaling, box, and gold activities. Students had no trouble with the content, interacted in their dyads and small groups, questioning one another and debating ideas. In the classroom discussions, students asked incredibly sophisticated questions, often finding answers among themselves, not just from the teacher. As an example, in one of the debriefing sessions about scaling, Ms. Hahn asked one girl about the size of a particular phenomenon and they disagreed. The student then proceeded to lay out a logical set of statements to rationalize her answer to the question. The response was not only plausible but also correct.

The only time that there seemed to be difficulties with the students understanding the concepts occurred on Wednesday when Ms. Hahn used the prepared slides on the unique properties that occur at the nanoscale. It was clear from the questions, blank looks, and Ms. Hahn's reactions, that the students did not understand the entire discussion. In fact, Ms. Hahn also was experiencing difficulties with the content.

Specifically, optical properties and electrical properties caused the most difficulties for both students and teacher. In trying to explain the optical properties, students tried to apply the idea of photon emission by gaseous atoms, but did not consider the limitations of the model and when it would and would not be applicable. The surface plasmon wave phenomenon was not understood at all by the students or the teacher. For the electrical properties, students were hindered by the large amount of new terminology (e.g. semiconductor and superconductor), some of which was also new to the teacher (e.g. ballistic conductor). Students also tried to apply their knowledge of the electrical conductance of materials to the different electrical properties of substances being described. The teacher corrected this to some extent, but did not have a complete alternative explanatory framework to offer them.

Overall, the students wanted to use their existing knowledge to explain the novel effects at the nanoscale level and were frustrated by the combination of a disconnect between what they had learned in class previously and the lack of a complete alternative explanation. They were unclear about how general physical and chemical principles could apply to these objects; how and why smaller objects had different properties was confusing to them. While students were able to correctly state that things "work differently" at the nanoscale level, with a lack of alternative scheme for understanding, they continued to draw on their macroscale-level knowledge to try and explain specific phenomenon. This section needs to be rethought and reconceptualized.

Student Interest and Level of Engagement

Given that the nanoscience unit was totally ancillary and given at a time when student motivation to do anything other than bide their time until graduation or the end of the school year was lower than low, it was quite surprising to observe the high level of engagement that most students exhibited. The students appeared to be engaged and on task for most of the time that the classroom and laboratory activities were ongoing. The students seemed particularly interested in the scaling and gold laboratory activities, engaging in sometimes heated debate within their groups. One student even stayed after class to continue the gold activity. The students went right to work, completed the tasks, and were able to answer questions about the exercises and link the content to other things they have learned.

Student Reactions

Students like the materials for the most part. In only one case—and admittedly he is an extreme and negative case—was one senior completely turned off by the unit. Admittedly, he did not care about anything except getting out of school. None of the other students expressed negative reactions towards the materials in general. The only part of the materials that did, however, receive negative, but constructive feedback, was the nano science fiction story. Several students thought the story was unrealistic and too elementary. One student commented that it was appropriate for second graders. The applications in the story were based on current or predicted applications, and contained footnotes that explained the applications in more detail as they were introduced, but did not give sources, which was probably a mistake. The space elevator application (based on carbon nanotubes) was the least believed. Several days after reading the story, SRI staff gave the students a handout with more information and references on the applications that the students indicated that they least believed, along with a summary of the questions they had after reading the story, gathered from student worksheets. After receiving the handout, one group of students chose to research the space elevator topic for their final presentation. Another student said she felt frustrated that they wrote down all of these questions as they read the story, and the teacher nor class never addressed or discussed them later. The teacher said that the student research project might be the best part of the unit for her students, since they could dive into the content and answer some of the questions that had been raised but not answered to their satisfaction during the week.

Student Individual Differences

Ms. Hahn noted that the two classes have different perspectives about the types of activities they prefer. The first class much prefers classroom discussion and interaction, whereas the second class prefers the hands-on active work of the laboratory. These differences were only somewhat apparent from student reactions and responses to the class and lab experiences. Other differences could be observed between the juniors and seniors in both classes, and again this is reflective of senioritis and the time of the year. It follows logically that the juniors seemed to take the activities more seriously than did the seniors. Despite senioritis, most seniors were engaged by the lab activities and fully participated in the classroom discussions. The other individual difference noted was gender. Both classes had slightly more males than females. In one class, the males completely dominated discussion and the females hardly said anything, other than when they were called on. In the second class, the females were much more vocal, asking excellent and insightful questions, volunteering information, and refusing to be dominated by the males.

Teacher Knowledge and Needed Level of Knowledge

It was clear from Ms. Hahn's interactions with the classes that in order for a teacher to effectively use these materials, she or he must have not only a deep understanding of chemistry, but also some understanding of physics and biology. Ms. Hahn admittedly did not have an appropriate grounding in biology. Her last class was as a high school freshman. Given the vast amount of biological concepts in the materials, she often looked to the AP biology students for guidance and confirmation of ideas. In a less confident teacher, this would have been a real problem, but with Ms. Hahn, she actually used her lack of knowledge to an advantage. She empowered the students by looking to them for expertise. She could also have used these events as teachable moments, allowing the class in a constructivist manner to explore the areas where there were deficits in knowledge.

A major point to be made is that these materials require substantial breadth and depth of knowledge on the part of the teacher. Ms. Hahn is probably two to three standard deviations out beyond the typical chemistry teacher, and yet she still struggled with necessary fundamental knowledge. It is important to keep in mind that no matter how accomplished a teacher is, she or he is not a content expert. And professional development must take that fact into consideration.

Another issue that must be raised is teacher pedagogical style. It was clear from Ms. Hahn's behavior that her level of confidence and her pedagogical style were highly correlated. The more she felt confident and comfortable with the content, the more likely she was to engage in constructivist activity. The less confident, the more didactic she became, working directly from the slides and the materials that had been provided. She did not feel comfortable diverting from the materials, had trouble fielding questions, and tended to lose control of the class. She in fact could have used those moments as teachable events, but she was clearly too flustered by her lack of knowledge and familiarity with the content to capitalize on the situations. These are highly complex issues that must be dealt with as SRI moves forward and rethinks the professional development activities and the kind of knowledge teachers need to bring to the classroom for effective use of the curriculum.

Teacher Response

In general, Ms. Hahn felt positive about the materials, with the exception of the unique properties lesson. As noted above, she did not know how to tie this lesson to previously learned materials, and there were some ambiguities in the materials themselves. This lesson was a somewhat superficial treatment of the topic, and her frustration was apparent, despite the fact that she has done substantial research on her own to prepare for the class.

Ease of Use and Confusions. As mentioned above, the laboratory exercises were easy to use but the PowerPoint slides tended to be confusing and superficial, particularly the unique properties lesson. The scaling lesson was easy, but two comments resulted from it. First, the objects used in the scaling activity should be laminated rather than presented on paper that can easily fly away. Second, the students were confused whether there should be a one-to-one correspondence between the specific scale size and the object. For example, students noted that the basketball player neither fit one meter nor ten meters and wanted to know what to do. Students thought that parts of the nano science fiction story were hokey and contrived, and too far from the potential reality of the future. This confused some students and turned off other students. Students were thoroughly confused by the unique properties lesson. They just did not understand the ideas and were unable to concretize it.

Misconceptions. While the teacher could clearly state that electrical, optical and material phenomena operate differently at different size scales, she had an incomplete picture of how things work at the nanoscale level and thus reverted to her knowledge of macro phenomena to try and explain the nano phenomena. She was unclear to what extent and what level of general physical and chemical principles would apply to these situations.

While her AP students had mostly taken physics and had no problem understanding how and why different forces dominate at different size scales, she feared that some of her regular chemistry students would have problems with this. Regular chemistry students will not have had a physics class and she thought that without this theoretical background, many would think that the forces would only exist at particular scales, rather than at all scales.

Materials

Accuracy. This is difficult to discern, given the newness of the field and the increasing amount of material available. It was clear that Ms. Hahn spent a great deal of time doing research and preparing for class. Yet she still experienced difficulty. Both she and the class questioned the accuracy of some of the material, especially when connecting the information to topics previously covered in class. Take the example cited above when the female student questioned Ms. Hahn about the scaling lesson and showed logical connections to why the research might be incorrect. Issues like this will arise and there needs to be some sort of crib or answer sheet or way that the teacher can rectify inconsistencies as they arise, short of going to the research in the classroom and on the spot.

Slides and Readings. The slides seem problematic due to their superficiality. Ms. Hahn seemed to struggle with the slides and not know really what to say, other than reiterate what was on the slides, and could not or did not elaborate. Additionally, the teacher did not give the students the prepared reading on properties at any time. Her lecture did not seem to be coordinated with the reading or the slides. As mentioned above, the unique properties slides were particularly troublesome for the students and the teacher. The use of the reading and the slides need to be rethought, especially in light of how they are intended to be used, how they will be integrated, and for what audience.

Activities. The activities went well. The students seemed to enjoy them and they were linked to the educational objectives. The presentation of the scale items might be made more durable, rather than just on paper.

Ease of Implementation. The laboratory activities were easy to implement and took only a short bit of time. This should make it easy for the teacher to work the lab in and put sufficient introductory materials and discussion around it to support learning. Keeping the lab activities short seems to work well to maintain student interest and continuity with the classroom work. The slides were easy to implement and Ms. Hahn moved between the PowerPoint and web-based presentations nicely. A couple of students complained about having to endure a PowerPoint presentation.

Other Issues

Fit in Curriculum and Integration. A question was raised whether chemistry is the appropriate spot in the curriculum to introduce nanoscience. Should it be used in biology, physics, introductory science, or even integrated into thematic science courses? In addition to where in the curriculum nanoscience is appropriate, there also is the question of how it is best integrated. Should there be a lengthy introduction as we saw in Ms. Hahn's class or should there be a short introduction with the remaining ideas integrated across the curriculum in appropriate niches?

AP versus Traditional Chemistry. It is obvious that the AP classes we observed and Ms. Hahn were not typical of AP chemistry classes or traditional chemistry classes in general. This fact resulted in the question of appropriateness of fit. The AP students grasped the concepts easily and asked sophisticated questions, but one has to wonder how the traditional chemistry students would do. There also is the issue of timing of integration. For AP, the only time that is possible to introduce nanoscience is after the AP curriculum is completed and the AP examination has been taken. There is no flexibility in the calendar. The problem with this is, as mentioned above, the lack of motivation for students once the formal AP parts of the course are over. The teacher has about a month of dead time to fill and nanoscience is a good fit. Yet, nanoscience and anything that would be used in this month is not likely to be taken seriously by the students, particularly the seniors. Traditional chemistry classes suffer a different problem, namely where and when to integrate nanoscience. These courses are completely jammed with content and teachers have little wiggle room in which to integrate anything, especially an introduction to nanoscience that requires a week of time. The developers need to give serious consideration to these issues and get feedback from teachers about the most effective ways to integrate the materials, given the specific type of course.

Other Possibilities. The teacher suggested that a more topic-based approach—for example, one that introduces the idea of clear sunscreen and then dives deeply into the nanoscale properties and scientific explanations for this topic over the course of 1-3 days—may have been better for her students. Looking back, she said that she would probably have done a one-day introduction, then spend a day delving into the tools of the nanosciences (AFM, STM, etc.), and finally delve more deeply into a particular topic (e.g., clear sunscreen). The teacher was also interested in the wooden AFM model mentioned in the optional extension activities, and thought this would be a nice hands-on experience for her students.

The NanoSense team had already planned that their remaining units would be topical (instead of a more general survey, as the introductory unit was), and teacher reaction suggests that this approach is a good way to proceed. The NanoSense team might also consider separating out sections of the introduction to more clearly indicate that each section is an optional lesson, and index each section better to the teacher's curriculum. For example, the size and scale activities would easily index to the measurement topic common in chemistry classrooms. The team also mentioned that a unit involving that wooden AFM model was discouraged by their program officer because the model had limitations (it is a superficial model that gives students an idea of how an AFM works, but not in sufficient detail to explain the forces in action). Perhaps the model could be used in conjunction with additional activities or discussion about the limitations of models and the forces that are at work with the AFM.

NanoSense team member observations

NanoSense team members observed Ms. Hahn's classes and reached conclusions similar to those cited by Dr. Mandinach. We also observed student presentations in early June, after Ms. Mandinach had completed her observations. Approximately 18 student groups (3-5 students each) gave 20 minutes presentations on research that they had conducted on a group-chosen nanotechnology topic. Example topics included a space elevator constructed from carbon nanotubes, clean energy, nanobots, self-cleaning surfaces, and nanopaint to improve air quality. Though not entirely uniform, the presentations overall were very good in terms of content and clarity. They were well researched and reflected a high degree of sophisticated scientific concepts from both chemistry and other sciences. For example, the presentation on self-cleaning surfaces was well-grounded in chemistry that dealt with both hydrophilic and hydrophobic surface coatings and the relevance of contact angles of surface beads on hydrophobic surfaces. The students had also visited Nano-Tex in nearby Emeryville, California and brought back examples of a water resistant fabric.

Presenters seemed engaged and anxious to share what they had learned and the audience asked probing questions. The level of questions asked by the student audience indicated close following and understanding of the scientific content presented. Students seemed most interested in real-world practical concerns, such as: Does this exist? Who is doing it and where? How much does it cost? Where will it be used next? When will I be using it? Despite the difficulty of the material, students seemed to have good answers for most questions. In sum, the research projects seemed to engage the students and give them some of depth they had been wanting. Most students seemed engaged in other's presentations as well.

In early June, NanoSense team members also observed two classroom sessions in Britt Hammon's AP chemistry classroom at Antioch High School. We observed high student engagement with the nano science fiction story, the Size and Scale Cutting it Down activity, and the Unique Properties laboratory activities. We also observed occasions where directions were unclear, and saw different methods of using the PowerPoint presentations and the readings with students. Although the students were not at the same level as those in Ms. Hahn's class, the discussions still focused on deeper "how and why" questions related to the presented examples. However, inappropriate application by the teacher of scientific concepts to situations was an issue. For example, physics (particularly electromagnetism) concepts seemed especially challenging for the teacher, and she sometimes reinforced science fiction notions. It was unclear to students what nanotechnology applications existed, which were being developed, and which were still many years off.

Recommendations from Dr. Mandinach's findings and the team's supplementary findings are summarized below and will be used to revise the NanoSense materials.

- Topical and methodological approaches could unify and deepen the approach to the material presented during each class session. An understanding of the tools and methods for studying nanoparticles is one that students could benefit from greatly.

- Modularity for activities and units (self-contained quality) with clear indexing to topics within the normal course curriculum would allow teachers greater flexibility in using the units. This is especially important in light of differences in implementation (student level, course topic, integration with curriculum, etc.).

- Teachers need a road map and additional educative materials with a "drill down" structure for progressively greater depth of understanding and ready adjustment for different levels of students. Teachers do not necessarily emphasize the aspects of the science or technology that are most important. Also, teachers' lack of familiarity with content makes it difficult for them to stimulate discussion by asking follow-up questions and to identify and address student misconceptions.

- Students and teachers would benefit from a glossary that includes all potentially new terms.

- It would be helpful to have a page of reference material to explain the science behind each idea mentioned.

- It is important to motivate the teacher to assign student readings, and to motivate the teacher to read the provided reference materials.

- Reducing differences in gender participation in class discussion during our observations might require the creation of curricular strategies to increase girls' involvement.

- Students generally should be able to identify which forces dominate the nanoscale, and the implications for technological applications. That is, students need to know the "why" behind all the interesting applications.

- In their research presentations, students were able to make connections to other disciplines (e.g. biology, physics) that they were familiar with and share this knowledge with others. Leveraging student knowledge of other disciplines could be a useful way to deal with the interdisciplinary nature of nanoscience and reduce some of the burden on the teacher.

Overall, our own findings from the first implementation make clear that it is important to provide means for the teacher and the students to understand how the concepts they know do or do not work at the nanoscale and what alternative concepts can be applied.

Finding 3: Evaluation of Feedback on Outreach Presentation—Acalanes High School

Although most chemistry students in this classroom said they had heard of nanotechnology, few were able to describe its meaning accurately. Many students at the start of the class had misconceptions about nanotechnology. For example, some thought that nanobots (miniature robots) were currently being used in health care and as biological weapons to transmit disease. These technologies are considered by most scientists to be possible developments, but not in the near future. However, students had a good working understanding of most of the scientific concepts necessary to understand the presentation. The concepts that were most foreign to students were electron tunneling and the principles of optics.

The students appeared actively engaged in the presentation from the presenter's and the teacher's viewpoints, and seemed to enjoy learning about this new field. They asked several questions regarding the applications of nanotechnology. They wanted clarification about which applications were in the research stage and which were in the production stage of development. There were several spontaneous discussions among the students about some of the potential applications of nanotechnology. After the presentation, a few students mentioned that they would like to work in some aspect of the field.

Despite high student engagement, the presentation felt a bit rushed as a result of introducing several nanoscience concepts and examples. The presenter, Tina Stanford, felt that it would have been helpful to have at least 20 more minutes in which to present the material. Synthesizing the introductory NanoSense materials into one coherent 50-minute (length of a standard class period) presentation could better serve the needs of teachers who would like to spend only a day introducing this topic to their students.

Finding 4: Instructional Materials Development

A summary of the Size Matters unit is given in Activity 3: Instructional Materials Development. Sample materials for this unit are available on the NanoSense Web site at http://nanosense.org/activities/sizematters, including the Card Sort: Number Line Activity, which worked well in the classroom; lab station activities for the Unique Properties of the Nanoscale lesson; and the performance assessment for the Applications of Nanoscience lesson. We are currently revising remaining materials for this unit on the basis of our initial implementation findings, and will post all Size Matters materials at the above URL in summer 2005. Exhibits 1-3 show screenshots from the NanoSense Web site, including the activities page that links to the developed materials as they are posted.

Challenges designing nanotechnology education curricula

Designing curriculum on the cutting edge of scientific research and applications is both exciting and challenging. Three challenges we have faced are:

- Defining the curriculum for a new and evolving area of scientific study.
- Situating an inherently interdisciplinary science within a typical high school classroom that focuses on one discipline (i.e., chemistry).
- Developing teacher support materials for content that is novel for teachers.

Defining the curriculum. An illustrative example of the first challenge comes from our preliminary work on the Clear Sunscreen unit. In our searches to understand the science behind sunscreens containing nanoparticles of zinc oxide (ZnO), we found nine different explanations, which contradicted each other on various fronts. For example, whereas several explanations claimed that zinc oxide blocks UV radiation by absorbing (not reflecting/scattering) the radiation, multiple other sources attributed the blocking action to both absorptive and reflective processes; and one explanation highlighted the scattering of UV radiation by zinc oxide, as compared with the absorptive processes used by organic sunscreens. In addition, there was disagreement as to whether the size of the ZnO particles affects the UV blocking process and effectiveness, and none of the explanations gave a satisfactory account of why nanosize ZnO particles do not scatter visible light. After more research and discussion with science content experts Yigal Blum at SRI and Maureen Scharberg, it appears that the preponderance of evidence supports the absorption model—that is, UV radiation is absorbed by ZnO particles over a broad wavelength range. A primary issue is that, as with any emerging science, our understanding is still evolving. Much is still unknown about the regularities of behavior of nanosize objects. Information about the properties of nanoscale materials includes data from experiments with particular materials that may not be generalizable. There are many scientific papers and articles on such experiments, but there are few common frameworks for understanding the critical science at this level—particularly ones that are understandable at a high school level.

More generally, determining the core concepts that should make up a nanoscience curriculum is a challenge. A main focus of our Advancing Nanoscience Education workshop was for science educators, researchers, and nanoscientists to arrive at a consensus about the concepts that are central to understanding nanoscience. Many hours of discussion and debate were required to agree on a few central nanoscience concepts. Further, some of the science concepts important to understanding nanotechnology are quite difficult to understand. For example, electron tunneling is a characteristic of the quantum mechanical model of atomic structure and behavior. It is important to understand this concept, because this phenomenon is involved with the explanation of how we gather data (scanning tunneling microscopes) at this small scale and why there are unique problems for studying and using objects this small. High school students do not normally encounter the phenomenon of tunneling in their regular curriculum. We decided to include the conceptual description of electron tunneling in our materials, as it appeared to be an important one. We included conceptually based explanations of this phenomenon in our slides and our readings.

Situating the science. Regarding the second challenge, our intent is to develop curriculum to embed in a typical high school college-preparatory chemistry class. Given the interdisciplinary nature of nanoscience, as we develop our materials, what other science concepts (if any) can we assume such students have? A typical high school college preparation science course of study begins with a year of biology, followed by a year of chemistry and a third optional year of either physics, physiology, earth science, or environmental science. Thus, in most cases, we can assume that our target chemistry students have had biology (although we can't assume this of the teacher) but not physics. However, we have also found that our partner teachers want to use the curricular materials in AP chemistry, regular chemistry, biology, physics, and interdisciplinary science classes. To further complicate matters, all of these disciplines use different terminologies and focus on different aspects of phenomena. For example, consider again the clear sunscreen example from above. In chemistry, high school textbooks typically talk about absorption and transmission of light by gas-state moledules. However, in physics, textbooks typically talk about light being transmitted (passed through) or refracted or reflected (bounced back) when it reaches a boundary between mediums. There is occasional talk of absorption in physics, but effectively no mention of reflection in chemistry.

To what degree can we accommodate teachers' requests for materials that work in different disciplines and even interdisciplinary science classes? We decided to develop the introductory Size Matters unit to be useful in almost any high school science classroom by providing descriptions in terms of core concepts and ample professional development materials. However, to focus our development and testing effort, our remaining topical units (such as the units on clear sunscreen and water purification, currently under development) will each focus on one core discipline, per our original intent—even though it is clear that some topics could easily fit into multiple disciplines (e.g., clear sunscreen could fit into chemistry or physics, since the interaction of light and matter are core concepts for both disciplines). The alternative—creating units that provide sufficient depth for different disciplines—would require the development of a separate set of materials for each discipline to account for significant differences in terminology and prior knowledge. We will continue to focus on chemistry, our core expertise, although we also have expertise in biology and physics in our team. However, some of our partner teachers have expressed interested in adapting our units for use in other disciplines. If partner teachers adapt any units for other disciplines, we will make these adaptations available, with their consent.

Developing teacher professional development materials. Clearly, a core challenge is to develop appropriate support materials for teachers. We found that our material on unique properties of the nanoscale lacked sufficient detail to present the key concepts adequately to the AP chemistry students in our pilot classroom. We developed three readings carefully describing electrical, mechanical, and optical properties of nanoscale objects, but the teacher felt that there was still not enough explanatory information for her or her advanced students. She did feel confident, however, that the level of description would be sufficient for her regular chemistry students.

More generally, we are working closely with our teachers to design and pilot-test activities. Our regular meetings, collaborative review of materials, and efforts at classroom implementation provide the teachers opportunities to reflect on and receive individual feedback regarding their experiences and practices using the new materials. Throughout the process, in order to make the materials as useful as possible, we have ensured that they are aligned with national (NSES) content standards and include embedded assessments and rubrics for scoring student work. Our assumption in this regard is that teachers' learning is likely to be best supported by materials that they co-design and believe to be highly valuable for their students.

Exhibit 1. NanoSense Web site: home page.

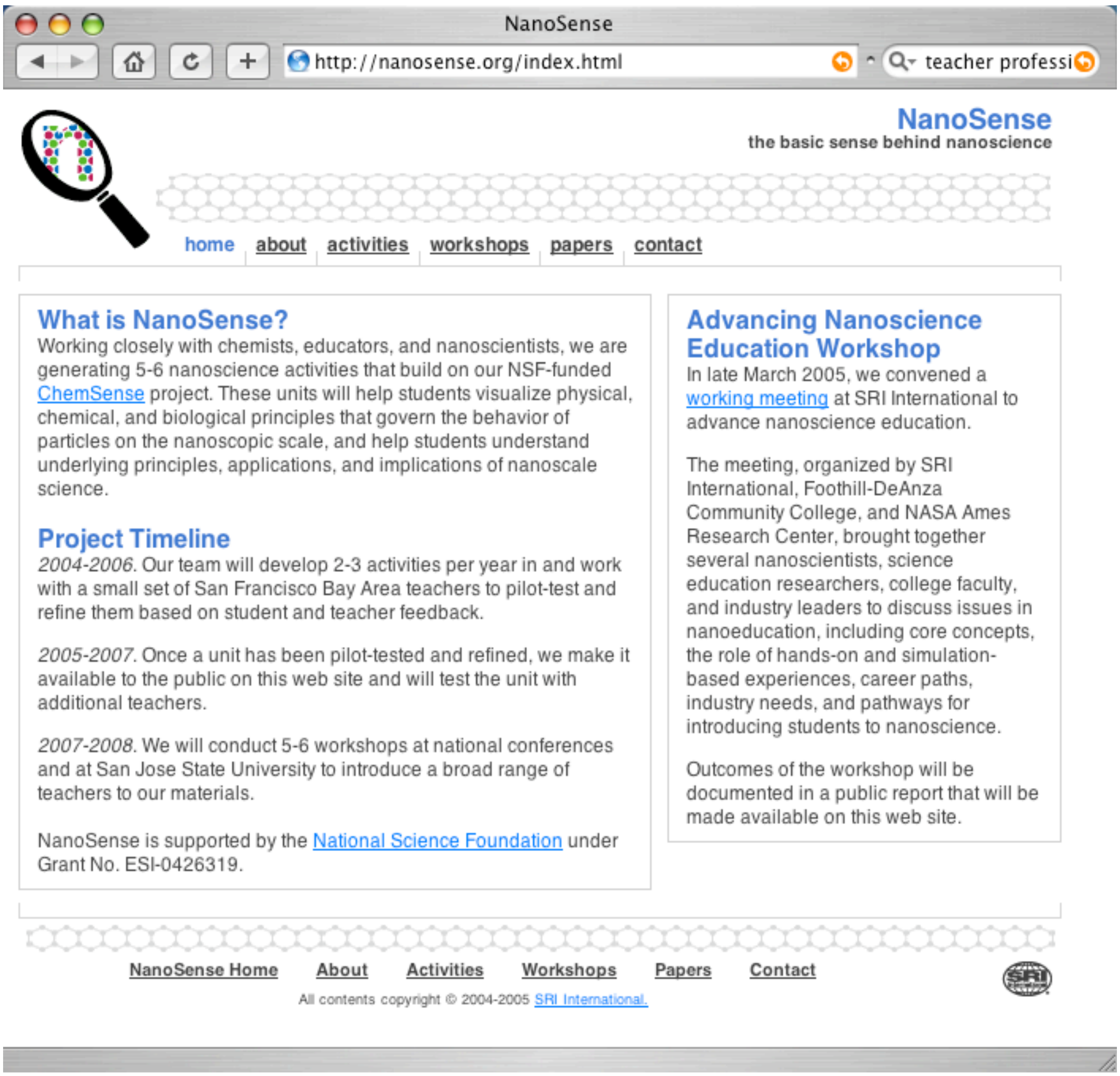
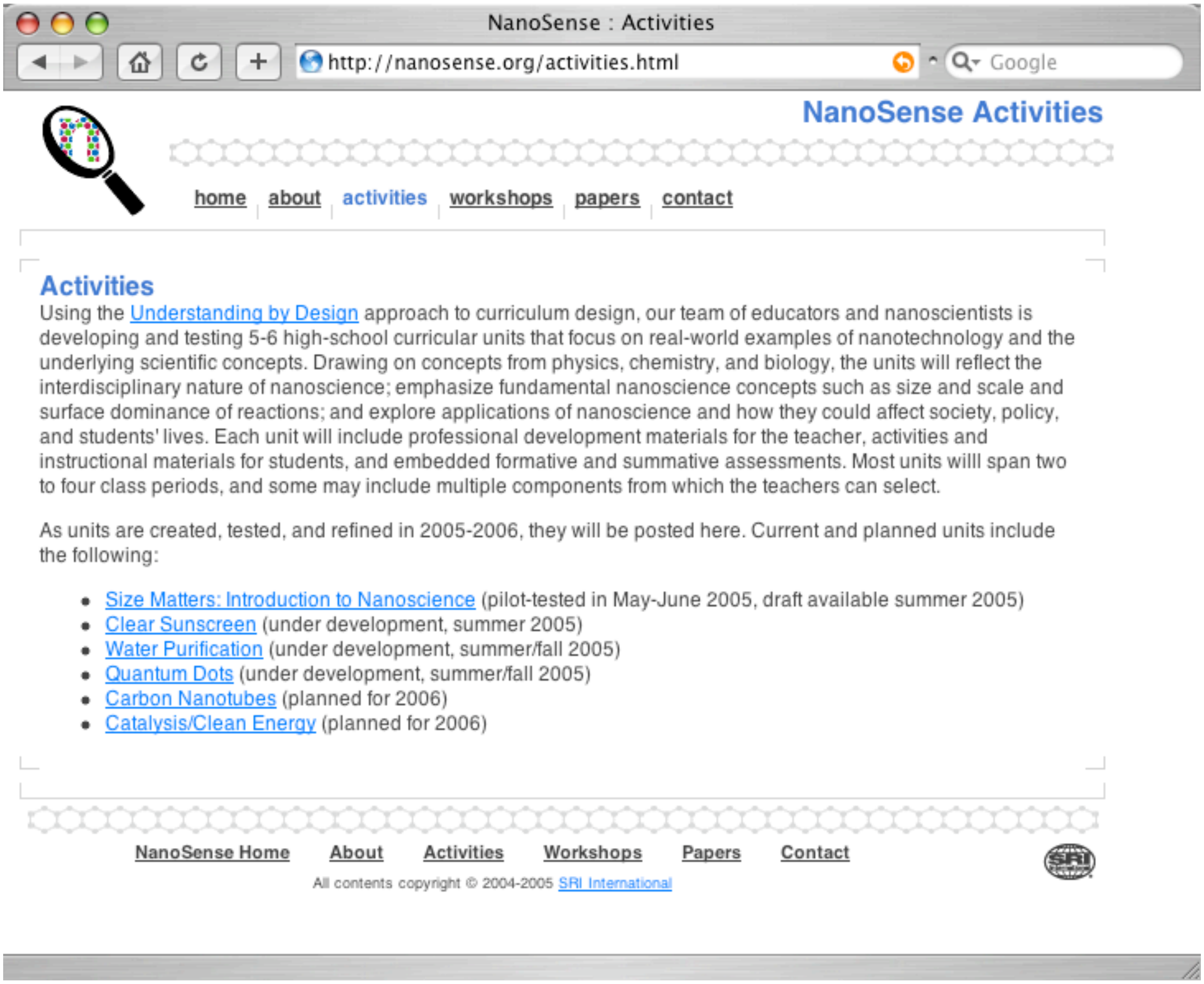


Exhibit 2. NanoSense Web site: activities page.


NanoSense : Activities

http://nanosense.org/activities.html

NanoSense Activities

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Activities

Using the Understanding by Design approach to curriculum design, our team of educators and nanoscientists is developing and testing 5-6 high-school curricular units that focus on real-world examples of nanotechnology and the underlying scientific concepts. Drawing on concepts from physics, chemistry, and biology, the units will reflect the interdisciplinary nature of nanoscience; emphasize fundamental nanoscience concepts such as size and scale and surface dominance of reactions; and explore applications of nanoscience and how they could affect society, policy, and students' lives. Each unit will include professional development materials for the teacher, activities and instructional materials for students, and embedded formative and summative assessments. Most units willl span two to four class periods, and some may include multiple components from which the teachers can select.

As units are created, tested, and refined in 2005-2006, they will be posted here. Current and planned units include the following:

- Size Matters: Introduction to Nanoscience (pilot-tested in May-June 2005, draft available summer 2005)
- Clear Sunscreen (under development, summer 2005)
- Water Purification (under development, summer/fall 2005)
- Quantum Dots (under development, summer/fall 2005)
- Carbon Nanotubes (planned for 2006)
- Catalysis/Clean Energy (planned for 2006)

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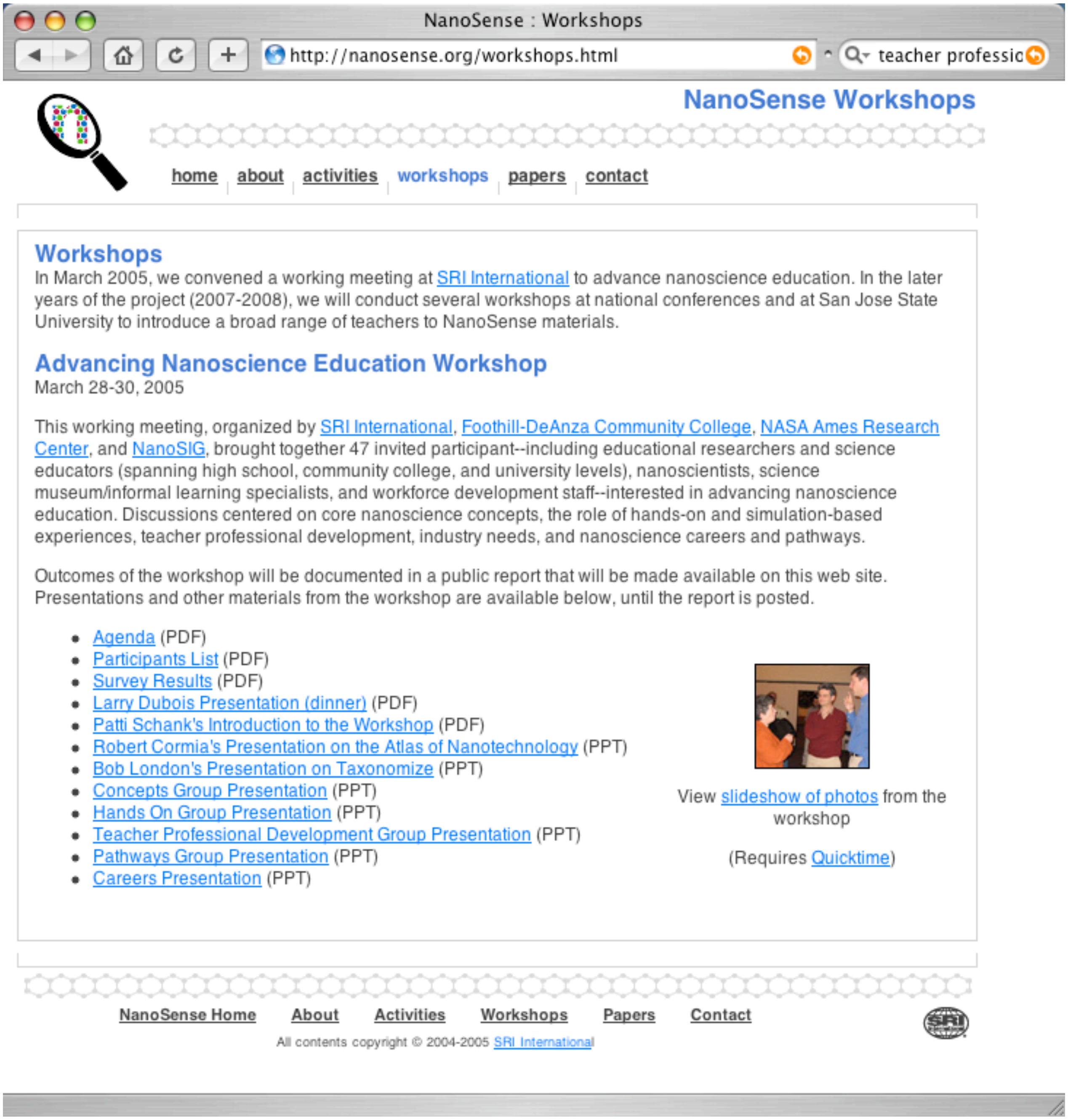
Exhibit 3. NanoSense Web site: Workshops page.



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