NanoSense: The Basic Sense behind Nanoscience

Final Report
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Contents:

Project Activities and Project Findings attached as separate sections.

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SECTION 1: PARTICIPANTS

Core Participant Individuals

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

Partner Organizations

Research and Development Partners

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

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

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

Foothill-DeAnza Community College (FHDA), Los Altos Hills, CA. FHDA is one of the largest community college districts in the United States, providing credit classes for about 44,000 students per quarter. Faculty member Robert Cormia helped the NanoSense team organize the

March 2005 Advancing Nanoscience Education workshop. Faculty member Dr. Singh collaborated with the NanoSense team to develop and submit a National Science Foundation Advanced Technological Education (ATE) proposal entitled "Nanotechnology Program Curriculum Articulation (PCA)".

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

School Partnerships

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

Fremont High School, Sunnyvale, CA. Fremont's student population is approximately 37% Hispanic, 27% White, 18% Asian, 13% Filipino, and 5% African American; 17% of the student body qualifies for free or reduced-price lunch, and 22% are English language learners. The school's 2006 API score was 706 out of 1000, and its API rank is 6 out of 10. Tina Stanford, co-PI of the NanoSense project, took a position as a chemistry teacher at Fremont High School in late 2007 and used NanoSense curriculum materials in some of her lessons. She also conducted workshops with her fellow teachers at Fremont High School.

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

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

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

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

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

Other Collaborators or Contacts

Advisory Panel

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

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

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

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

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

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

Other Collaborators

Larry Woolf—A physicist at General Atomics in San Diego, California. Dr. Woolf advises on the science content of our units and performs an annual site visit review of the project. He has been involved in K-12 education for years, developing and reviewing K-12 curriculum activities and critiquing state and national science standards.

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

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

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

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

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

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

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

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

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

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

SECTION 2: ACTIVITIES AND FINDINGS

(See also attached files)

Opportunities for Training and Development

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

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

Additionally, we have worked with at least dozen high school chemistry teachers who have provided useful and frequent feedback on the Nanosense activities and are using some or all activities in their classrooms. In addition to attending our teacher meetings and workshops, two of these teachers have interned with the project during the summer months. We have also sponsored and worked closely with a high school teacher through the Industry Initiatives for Science and Math Education (IISME; iisme.org) Fellowship Program for Teachers. IISME is a nonprofit collaborative of San Francisco Bay Area corporations, universities, and local educators working to improve mathematics and science education. IISME Fellowships provide K-16 teachers with meaningful professional development by exposing them to industry and research environments, giving them direct experience with applications of science, inspiration to infuse their lessons with relevance, encouragement to stay in teaching (IISME teachers stay in teaching at more than twice the rate of their colleagues) and better understanding of career needs. By working closely with teachers, we are providing teacher professional development opportunities and creating a teacher-researcher model that scaffolds procedures and activities necessary to co-design research in schools.

Outreach

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

NanoSense activities and findings have been presented in numerous forums, including the annual meeting of the American Education Research Association (AERA), the International Conference of the Learning Sciences (ICLS), the Exploratorium, the Boston Museum of Science, the Workshop on K-12 & Informal Nanoscale Science and Engineering Education, the Gordon Research Conference on Visualization in Science and Education, the Advancing Nanoscience Education workshop (Menlo Park, March 2005), and the Nanoscience Learning Goals workshop (Menlo Park, June 2006), and annual NSF IMD meetings. PI Patricia Schank has co-authored a book chapter with Joe Krajcik on nanoscience education (published by Wiley) and an article, with Alyssa Wise, for the APS newsletter.

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

SECTION 3: PUBLICATIONS AND PRODUCTS

Publications

Articles

- Schank, P. & Krajcik, J. (2007). Can Nanoscience Be a Catalyst for Education Reform? In F. Allhoff, P. Lin, J. Moor, J. Weckert (Eds.), Nanoethics: The ethical and social implications of nanotechnology. Hobeken, NJ: Wiley Publishing.

- Schank, P., & Wise, A. (2006). Introducing high school students to nanoscale science. *Forum on Education of The American Physical Society Summer 2006 Newsletter*. http://www.aps.org/units/fed/newsletters/spring2006/index.html

Technical Reports

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

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

Conference Presentations and Workshops

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

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

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

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

- *Schank, P. (2006, February). Overview of the NanoSense and ChemSense projects. Presented at the* Nanoscale Informal Science Education Network (NISE) Visualization

Laboratory Meeting. *February 17-18, San Francisco, CA.*

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

- Schank, P. (2005, October). The NanoSense project: Design challenges and opportunities. Presented at the *Workshop on K-12 & Informal Nanoscale Science and Engineering Education* sponsored by the National Science Foundation. October 19-20, Washington, DC. Available online at http://nanosense.org/documents/presentations/NIMDWorkshopOct2005.ppt

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

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

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

Web Sites

The NanoSense web site, http://nanosense.org, 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, pilot-tested, and revised four curriculum units. All units are available to the public on the NanoSense Web site at http://nanosense.org under a Creative Commons license, and are distributed at teacher training workshops.

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

2. *Clear Sunscreen.* This unit explores issues related to size and scale, specifically the effect of the size of nanopowders on the interactions of energy and matter (e.g., the absorption of light, addressing the electromagnetic spectrum and associated wavelengths). For example, old sunscreens use "large" zinc oxide particles, which block ultraviolet light but scatter visible light, giving the cream a white color. If nanopowders of zinc oxide are used instead, the cream is transparent, because the diameter of each nanoparticle is smaller than the wavelength of visible light. The unit spans up to twelve 50-minute classroom periods if all lessons are used. Available lessons and activities include a UV protection lab, ChemSense animation activities, Flash animations, an investigation of sunscreen labels activity, and a consumer information pamphlet project, PowerPoint slides, readings, and worksheets.

3. *Clean Energy.* This unit explores the issue of energy production as a pressing global issue and how nanoscience could enable important breakthroughs in energy generation and conversion. The unit spans three 50-minute classroom periods if all lessons are used. Available lessons and activities include a solar cell lab, animation activity, PowerPoint slides, quizzes, readings, and worksheets.

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

Software

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

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

The ChemSense software is also available under an open source license on Sourceforge at http://sourceforge.net/projects/chemsense

Instruments

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

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

SECTION 4: CONTRIBUTIONS

Nanoscience and Related Disciplines

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

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

Contributions to Other Disciplines

- A different lens through which students can revisit core concepts from physics, chemistry, and biology, as well as related areas such as materials science and engineering to support student understanding and (eventually) move these fields forward through interdisciplinary research.
- An improved understanding of the importance that constructivist representational environments can add to science learning—especially for students who have been less well served by traditional approaches to science education.
- An improved understanding of how teachers model and assess representational and collaborative practice to support student representation, discourse, and understanding, and what types of tools and activities support teacher practice.
- A general software environment for representation building and sharing animations that can be used in domains other than chemistry. For example, for nanoscience learning, students could animate concepts such as hydrogen filtration by carbon nanotubes, representing details such as hydrogen and tritium gas, the introduction of nanotubes, and tritium becoming trapped in the nanotubes over time. If adapted for physics learning, students could animate concepts such as Newton's 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—one graduate student and one undergraduate—and are working closely with several high school chemistry teachers. In doing so, we are supervising and supporting graduate students and teachers 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.