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.

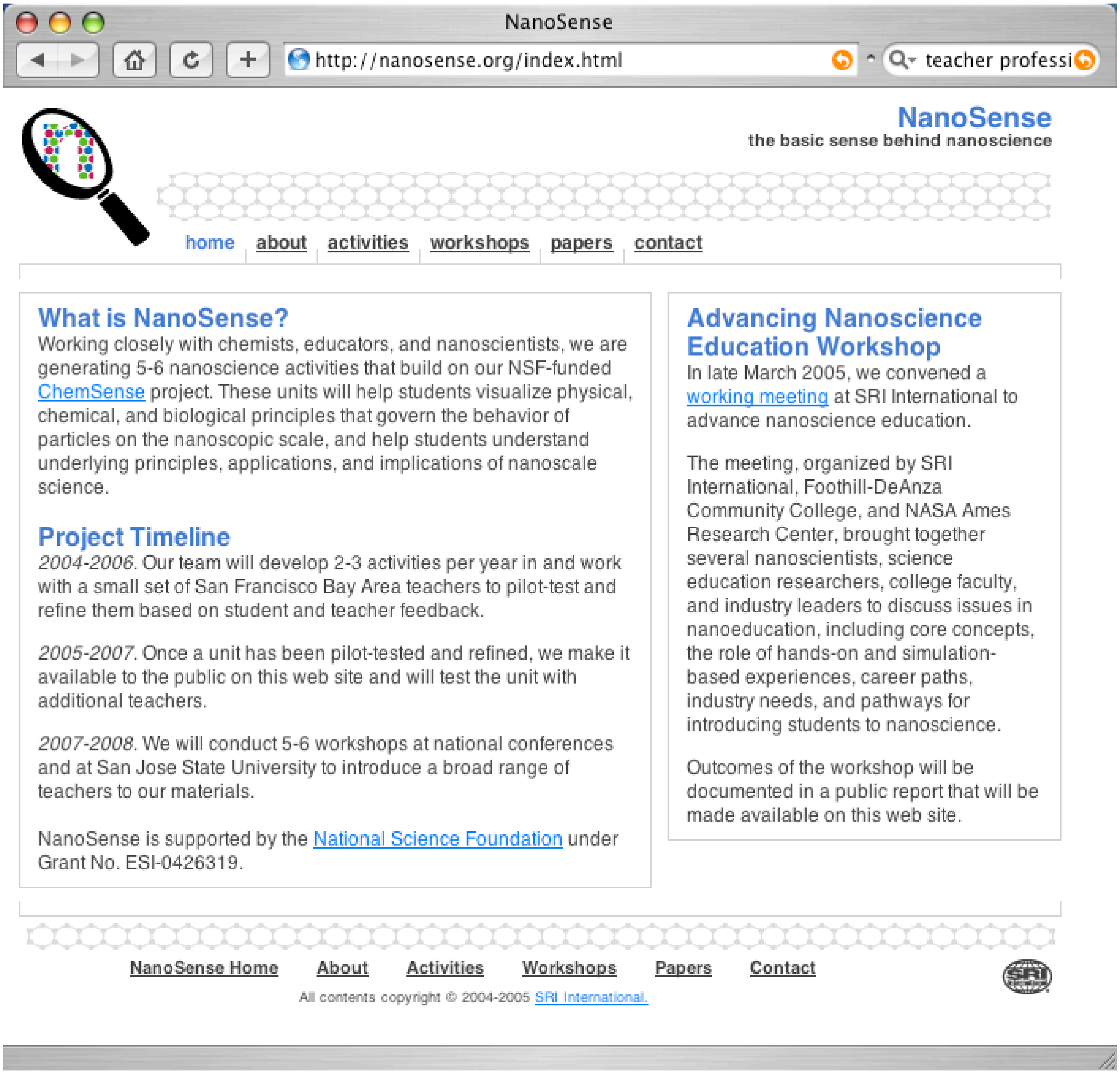
Situating the science. Regarding the second challenge, our intent is to develop curriculum to embed in a typical high school college-preparatory chemistry class. Given the interdisciplinary nature of nanoscience, as we develop our materials, what other science concepts (if any) can we assume such students 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.



What is NanoSense?

Working closely with chemists, educators, and nanoscientists, we are generating 5-6 nanoscience activities that build on our NSF-funded ChemSense project. These units will help students visualize physical, chemical, and biological principles that govern the behavior of particles on the nanoscopic scale, and help students understand underlying principles, applications, and implications of nanoscale science.

Project Timeline

2004-2006. Our team will develop 2-3 activities per year in and work with a small set of San Francisco Bay Area teachers to pilot-test and refine them based on student and teacher feedback.

2005-2007. Once a unit has been pilot-tested and refined, we make it available to the public on this web site and will test the unit with additional teachers.

2007-2008. We will conduct 5-6 workshops at national conferences and at San Jose State University to introduce a broad range of teachers to our materials.

NanoSense is supported by the National Science Foundation under Grant No. ESI-0426319.

Advancing Nanoscience Education Workshop

In late March 2005, we convened a working meeting at SRI International to advance nanoscience education.

The meeting, organized by SRI International, Foothill-DeAnza Community College, and NASA Ames Research Center, brought together several nanoscientists, science education researchers, college faculty, and industry leaders to discuss issues in nanoeducation, including core concepts, the role of hands-on and simulation-based experiences, career paths, industry needs, and pathways for introducing students to nanoscience.

Outcomes of the workshop will be documented in a public report that will be made available on this web site.

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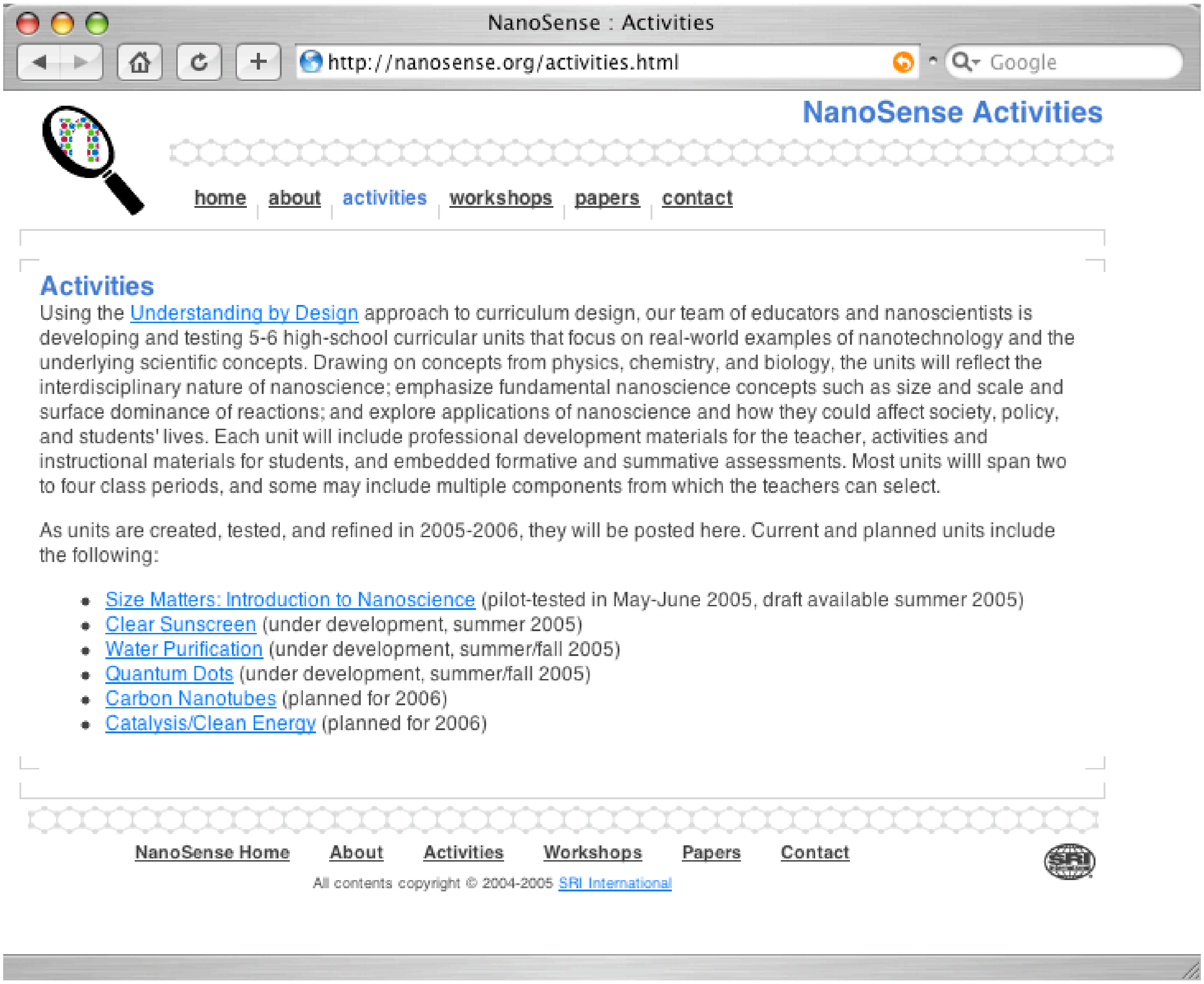
Exhibit 2. NanoSense Web site: activities page.



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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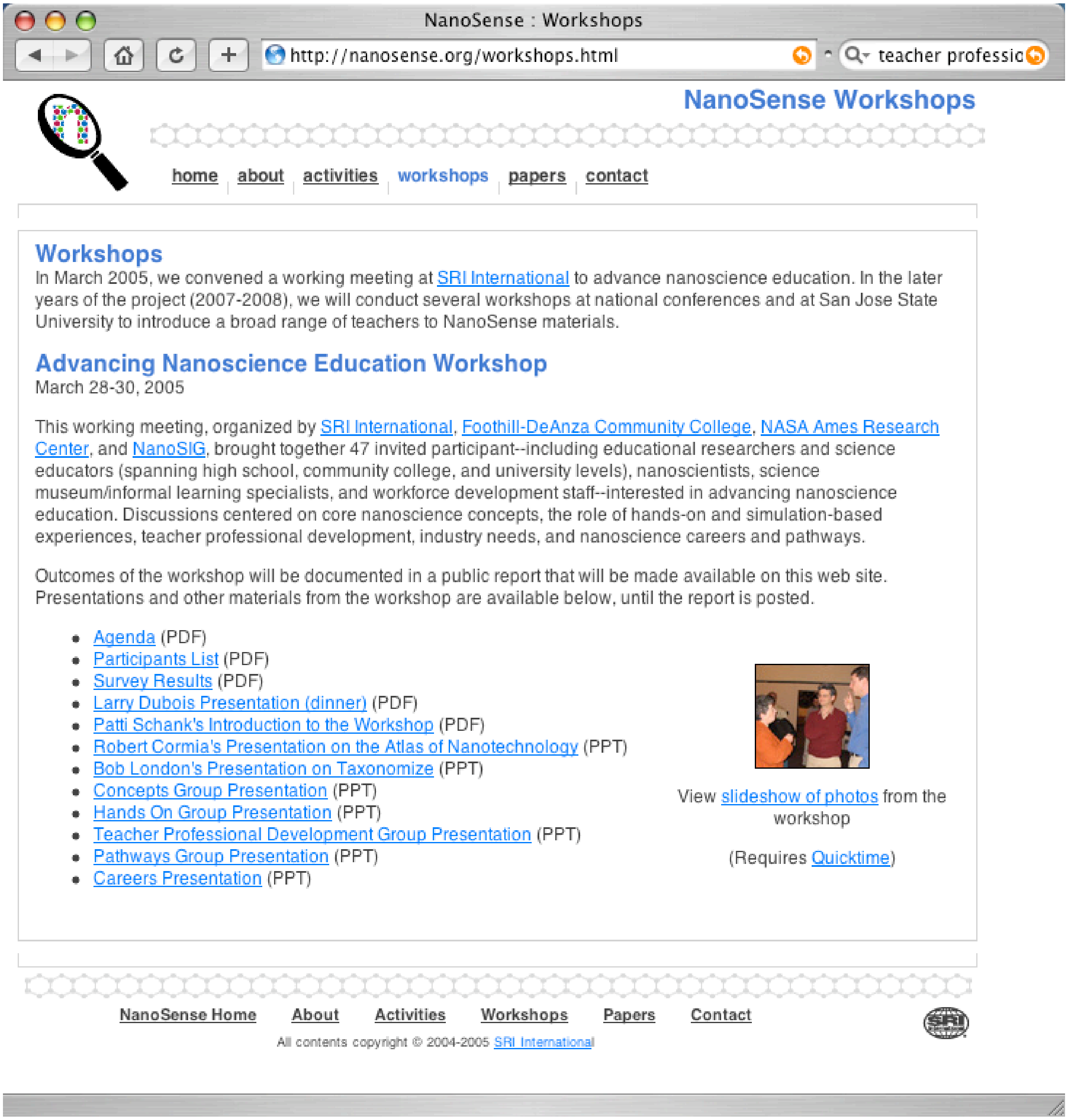
Exhibit 3. NanoSense Web site: Workshops page.



NanoSense Workshops

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Workshops

In March 2005, we convened a working meeting at SRI International to advance nanoscience education. In the later years of the project (2007-2008), we will conduct several workshops at national conferences and at San Jose State University to introduce a broad range of teachers to NanoSense materials.

Advancing Nanoscience Education Workshop

March 28-30, 2005

This working meeting, organized by SRI International, Foothill-DeAnza Community College, NASA Ames Research Center, and NanoSIG, brought together 47 invited participant--including educational researchers and science educators (spanning high school, community college, and university levels), nanoscientists, science museum/informal learning specialists, and workforce development staff--interested in advancing nanoscience education. Discussions centered on core nanoscience concepts, the role of hands-on and simulation-based experiences, teacher professional development, industry needs, and nanoscience careers and pathways.

Outcomes of the workshop will be documented in a public report that will be made available on this web site. Presentations and other materials from the workshop are available below, until the report is posted.

- Agenda (PDF)
- Participants List (PDF)
- Survey Results (PDF)
- Larry Dubois Presentation (dinner) (PDF)
- Patti Schank's Introduction to the Workshop (PDF)
- Robert Cormia's Presentation on the Atlas of Nanotechnology (PPT)
- Bob London's Presentation on Taxonomize (PPT)
- Concepts Group Presentation (PPT)
- Hands On Group Presentation (PPT)
- Teacher Professional Development Group Presentation (PPT)
- Pathways Group Presentation (PPT)
- Careers Presentation (PPT)

View slideshow of photos from the workshop

(Requires Quicktime)

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