July 9, 2004

To: Gerhard Salinger, NSF
From: Patricia Schank, SRI International
Re: Responses to questions by reviewers of NIMD Proposal No. 0436319

Dear Gerhard,

Thank you for providing us with the opportunity to address your questions and concerns. We address the seven primary areas of concern below, and also describe a working meeting on nanoscience and science education that we propose to host in the first year of the project.

**1) What is the impact (use) of the ChemSense activities and data showing what you know about their effectiveness in student learning? How will you do research on how the NanoSense activities can increase student learning and motivation to do science? How will you evaluate the success of the activities; i.e. convince us that more activities should be funded?**

Both qualitative and quantitative results (e.g., Michalchik et al., submitted; Coppola & Kiste, 2004) support our hypothesis that the use of ChemSense representational resources, within the social and physical contexts of collaborative investigations, can promote the development of a deeper understanding of chemistry.

Michalchik et al. (submitted) examine the impact of the use of ChemSense on the chemistry understanding of high school chemistry students learning about solubility by analyzing student discourse to elucidate the mechanisms by which ChemSense supports the development of representational capacities in students that help them build and communicate conceptual understandings of chemical phenomena. This analysis proceeds from the findings of Kozma (Kozma et al., 2000) and his colleagues that demonstrate the importance of the use of multiple representations—including iconic representations of particulate-level phenomena—to the professional work of practicing chemists. Quantitative findings from this study point to an overall increase in students' representational competence ($F_{1, 28} = 27.40$, $p < .01$; see Table 1). Specifically, at pretest students' representations tended to focus on depictions of physical observations at the macroscopic level. At posttest, students were much more able to use formal representations to stand for underlying, nanoscopic phenomena. These findings suggest that students developed their representational competence during the sessions in which ChemSense was used along with structured laboratory activities, a finding further supported by analyses of students' representative practices during laboratory sessions.

**Table 1.** Student Pretest and Posttest Mean Scores for Representational Competence

| | Representational Competence (Max score: 5) | |
|---|---|---|
| | Pretest | Posttest |
| N | 29 | 29 |
| Mean Score | 2.00 | 3.16 |
| S.D. | 1.08 | .97 |

Quantitative findings from this study also indicate that after using ChemSense along with structured laboratory activities for two weeks, students developed a deeper understanding of the geometry and connectivity-related aspects of solubility ($F_{conn\ 1,\ 37} = 88.83$, $p < .01$; $F_{conn\ 1,\ 37} = 26.41$, $p < .01$; see Table 2). Specifically, at pretest few students were able to correctly represent the shape or charge distribution of a water molecule, able to correctly show the alignment of water molecules with ions and with each other, or adequately discuss relevant connectivity issues. At posttest, students were much more able to show the shape and alignment of water molecules with each other and with dissolved ions, accurately represent correct bonding changes and connections between the macroscopic and nanoscopic levels, and use formal representations to represent the underlying, nanoscopic-level solubility phenomena.

**Table 2**. Student Pretest and Posttest Mean Scores for Connectivity and Geometry

| | Connectivity (Max score: 4) | | Geometry (Max score: 4) | |
|---|---|---|---|---|
| | Pretest | Posttest | Pretest | Posttest |
| N | 38 | 38 | 38 | 38 |
| Mean Score | .41 | 1.05 | .53 | 2.18 |
| S.D. | .31 | .51 | 1.06 | 2.11 |

Video analyses provide evidence that from the outset, students in a group that we closely followed began move away from focusing on the observable features of chemistry activity within their classroom and towards using appropriate graphic representations of the underlying aspects of the phenomena they were investigating. We see evidence that having a representational tool such as ChemSense that readily makes iconic representations available to students helps them: 1) use these representations meaningfully in their classroom practice, in ways more analogous to practicing chemists, and, 2) conceptualize chemical phenomena in scientifically valuable ways.

In a separate study, we matched carefully for teacher and student characteristics to get a preliminary sense of how students who used ChemSense activities throughout the year might compare against more standard control group that did not use ChemSense (Stanford & Schank, 2004; Schank et al., 2003). Students in both groups were administered a 30-question end-of-the-year conceptual exam. Fifteen "visualization questions," pulled (with permission) from the ACM 1996 college level conceptual exam, involved identifying an appropriate diagram amongst a variety presented of particle representations of chemical concepts. Fifteen "traditional questions" were written to represent the same concepts, but in a word problem manner. We found that students who used ChemSense activities throughout the year achieved significantly better scores than the control group on this exam ($p < .05$; see Table 3).

**Table 3**. Descriptive statistics for end-of-year exam scores for each group.

| | Mean scores | | |
|---|---|---|---|
| | Entire exam (max=30) | Visualization questions (max=15) | Traditional questions (max=15) |
| ChemSense Group (N=205) | 14.41 | 7.17 | 7.21 |
| Control Group (N=76) | 12.60 | 6.35 | 6.25 |

We are currently analyzing results from an extended, controlled study of five general chemistry classes over the 2003-2004 school year. All five classes received the same curriculum, with the exception that for the lab portion of 12 textbook chapters, 3 classes used ChemSense activities and two classes did traditional lab activities. All classes were taught by the same teacher, and all activities (ChemSense and traditional) were developed by that teacher. Data collected from this work include a conceptual pretest to establish baseline student chemistry understanding, a parallel posttest administered at the end of the school year, short (roughly 10 min) tests before and after lab activities, video of one pair of students from each class during labs, and think-aloud data as students interacted with a pre-made animation while verbally describing what they are doing. Preliminary results of our analyses should be available in fall 2004, and will be reported fully in our ChemSense final report.

At the college level, Coppola & Kiste (2004), building on Lemke's (1990) work thematically analyzing science discourse, have developed techniques of analyzing student representations to be able to compare responses from students using ChemSense and students using traditional (e.g., paper and pencil) methods. In this analysis, student drawings are transformed into "thematic diagrams"— meta-representations that facilitate comparisons of student work—and network analysis software is used to compute the degree of similarity between the maps. Student work was obtained from approximately 150 students in an introductory undergraduate chemistry course. Students were evenly divided and randomly placed into groups that did all of their work in ChemSense or that did their work in traditional pencil and paper. A similarity analysis of the thematic diagrams produced for student work and quizzes from these ChemSense and non-ChemSense students showed that visually, the representational drawings created by chemistry students who used ChemSense are more similar to textbook and expert (junior and senior chemistry majors) drawings than they are similar to drawings by the chemistry students who did not use ChemSense.

To assess the usefulness and value of the NanoSense activities, we will apply similar qualitative and quantitative methods as those described above, with additional help from EDC to collect and analyze indicators of student learning. EDC's efforts will be both formative and summative, providing ongoing and iterative feedback to shape the development effort. Data collection will include classroom observations, interviews with teachers and students, and student outcome data from assessments developed by SRI in conjunction with the curriculum units. The student assessment instruments developed by SRI and EDC will tap the expertise in science assessment that exists in both organizations. We will also measure changes over time in scientific attitudes of students using validated questionnaires such as the Changes in Attitudes about the Relevance of Science (CARS) questionnaire (Siegel & Ranney, 2003). One would expect an attitude change about science if a curriculum were sufficiently activity-based and engaging, yet it is rare to find dramatic changes in attitudes in a short time. Research has also shown a decline in positive attitudes toward science as students reach high school level. Although attitude change is not easy to achieve, the design of the NanoSense (interdisciplinary, activity-based, real-world examples of science in action) leads us to expect attitude enhancement to be possible.

### 2) How are ChemSense and NanoSense to be disseminated so that others can know about using the activities?

Our ChemSense activities are available for download on our web site (http://chemsense.org), and NanoSense activities and materials will similarly be made available for public download. Beginning in early fall 2004, the ChemSense software will also be made available for public download (up to the present, it has only been used by our research partner schools). In the final year of the NanoSense project, we will conduct four to six half- or 1-day teacher workshops with scores of teachers at national conferences (such as BCCE, NSTA, NARST, CACT, ACS), and at training facilities at San Jose State University. The software and activities will also be distributed on CD-ROM at these events. We will also present our software and activities in the After School Online forum in Tapped In, a well-established community of more than 15,000 K-12 teachers, faculty, graduate students, and education researchers engaged in professional development and education reform. Finally, we will work with the Stanford Center for Probing the Nanoscale (CPN; see letter of support) outreach program, and are discussing collaborations with the University of Michigan, Texas A&M University, San Diego State University, Southern University of Baton Rouge, Virginia Polytechnic Institute, and Miami University Middletown to use our activities in their workshops for chemistry teachers.

**3) Consider developing a reduced set of NanoSense activities that build on your ChemSense activities, that build on one another and that can be used to answer some of the research questions you posed. The Instructional Materials Development (IMD) program has moved from the funding the development of interesting activities to asking developers to consider the design principles described by Grant Wiggins and Jay McTighe in their monograph, Understanding by Design. This approach focuses the developers on the learning goals and not on the activities. Applied at the course level, it helps students attain a coherent understanding of science concepts and an idea how science is done. What are the learning goals for your activities and how will students learn them?**

We appreciate the importance of principled design of learning activities based on learning goals. Our existing ChemSense curriculum is designed around a set of five key time-dependent dimensions that we have identified as associated with the particulate nature of matter and chemical reactions: change in (a) connectivity, (b) molecular geometry, (c) aggregation, (d) state, and (e) concentration (Schank & Kozma, 2002). These time-dependent dimensions are essentially learning goals that cut across traditional high school chemistry topics, such as acid-base reaction, electrochemistry, solubility, kinetics, and thermodynamics. In the development of activities, we focused on addressing these dimensions, and assessing student learning along these dimensions (Michalchik et al., 2004). For example, our ChemSense module on solubility was developed to address elements of all of the dimensions, focusing on geometry and connectivity.

We will apply a similar approach to reduce and refine the set of proposed NanoSense activities and assessments and more clearly align with the Wiggins and McTighe backward-design approach. Members of the NanoSense team in SRI's Center for Technology in Learning are familiar with the approach, and our collaborator Maureen Scharberg at San Jose State has applied the Understanding by Design strategy in three of her projects, including her work with a graduate student in chemistry to develop lesson plans in nanotechnology.

Regarding learning goals, we will promote student understanding of the following big ideas:

1. An understanding of *size and scale*, including the challenges of measurement and manipulation at different scales, and the dominant laws, objects, and forces at different scales (see Figure 1, below).
2. An understanding of *aggregation and number*, including mechanisms of aggregation (organizing principles and molecular engineering strategies such as self assembly,

crystallization, and assisted assembly by catalysts), the emergence of bulk properties, and how the size of aggregates can make differences in the properties of materials.

There are a few key areas in which physical properties change from the bulk properties of microscale aggregations or larger to nanoscale properties: surface-area-to-volume ratio, the size of the particle moving into the realm where quantum mechanic effects dominate over classical mechanical effects, and the fact that nanosize particles have dimensions below the critical wavelength of light, making them transparent. Further, at the nanoscale level, particles have properties that are not entirely predictable. The properties can change according the size and aggregation of the particles. In other words, the properties are 'tunable' by size rather than the consistent average of the bulk aggregation of particles.

These "big idea" concepts of size, scale, aggregation and number reside at the heart of nanoscience. They are also concepts that students struggle with, yet they offer a great deal of potential for engaging students. These concepts (and the activities that support their learning) can also be mapped to related national standards (e.g., science in personal and social perspectives, structure and properties of matter, interactions of energy and matter, understanding about science and technology, the cell, chemical reactions). They are also concepts that are typically under-explored in traditional chemistry curricula. Chemistry instruction almost always focuses on two distinct levels—the macroscopic and particle levels—and how things react with each other. The continuum between the macro level and the nano level is rarely discussed. In NanoSense, our goal is to expose high school students to the "in between" part as well, to make them aware of that a continuum exists, and that there is a lot of interesting science and technology in this in between (meso) level.

We will use a combination of traditional assessments (e.g., quizzes, tests) and performance assessments and projects (e.g., design activities, construction of representations) that will serve as evidence of student understanding. For example, students will be asked to sketch and appropriately place items on a wide scale (such as that sketched in Figure 1, below), depict an aggregation process such as self assembly using the NanoSense tools, critique peer (and other) animations to identify accurate and inaccurate features, identify bulk vs. discrete properties (e.g., a bulk mass may tend to move in a particular direction even though individual atoms are moving in various directions), identify when aggregation levels are not great enough to produce bulk properties, and illustrate and compare properties of different allotropes of carbon, including nanoparticles of carbon.

We will develop a subset of the activities summarized in the proposal, focusing on five or six activities that clearly provide more depth to the issues of scale and aggregation. The activities will bring in some concepts from biology and physics (as is the nature of nanoscience), but will focus on fit with chemistry curriculum, and build on existing ChemSense activities, where possible. The "big ideas" will be introduced early in each activity, and will be reinforced across the set of activities. Our top candidates for this subset of activities include:

- "Size Matters" (size and scale). Illustrate and discuss the size and scale of various objects, unusual properties of the nanoscale, and transitions between levels.
- "Quantum Dots" (size and aggregation). Explore how the size and aggregation of nanocrystals can effect physical properties (e.g., emit different colors of light).

- “Clear Sunscreen” (size and scale). Explore 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).
- “Biomolecular Motors” or a unit on catalysis (aggregation and scale). Address aggregation by nature’s nanomachines that perform self-assembly, assisted by catalysts like ribosomes; how catalysis causes agents to aggregate in a particular way and build things that become visible on the macro scale.
- “Carbon Nanotubes” (aggregation and scale). Explore interesting physical properties of unique shapes of carbon when aggregated at the nanoscale.
- “Water Wiggles” (aggregation and number). Extend an existing ChemSense unit on phase change that would address the number of water molecules needed to undergo phase change at a specific temperature and pressure.

We chose this subset of activities because they clearly address the proposed learning goals; we also believe that these activities will engage students by providing compelling, real-world examples of science in action, and help them uncover how nanoscience could affect society, policy, and their lives.

**4) Provide the design considerations for the development of activities. Who is going to do it? What is the role of practicing scientists, science educators, educational researchers and teachers? How will the activities be used in classrooms nationally, especially with the constraints of the accountability movement? How can they be integrated into established curricula? How will teachers learn to use them? What supports can be provided? Why would they come for professional development?**

Activity development will be led by Tina Stanford, an educational researcher at SRI, veteran chemistry and biology high school teacher, science teacher trainer, and assessment developer and coordinator, and Dr. Maureen Scharberg, professor and director of science education in the chemistry department at San Jose State University. Four content experts (spanning physics, biology, and chemistry) in SRI’s Center for Technology in Learning will aid in activity development, and three nanoscientists at SRI will consult on content accuracy and application of nanoscience. Dr. Sabelli and Dr. Coppola will also consult on chemistry content and activity development. Our five partner high school teachers will advise us on where activities might best fit in their curriculum, pilot-test our activities in their classrooms, review and score student work, reflect on their experience through journals, and generally provide feedback on their experiences. Based on their feedback, we will iterate our materials to improve them. Only after they are pre-piloted and piloted will we disseminate our curricular materials more generally.

Chemistry will be the main domain area in which activities will be developed. Each activity will be associated with our learning goals (see above) as well as a major area of the established curriculum in chemistry. It is anticipated that student learning will deepen around tradition areas of the curriculum as a result of integrating the nanoscale perspective in various spots throughout the curriculum (properties of matter, catalysts, quantum mechanics, etc.) Learning objectives and applicable National Science Education Standards (NSES) Grades 9-12 Science Content Standards will be indicated for each activity to enable integration into established curricula. Because most of our pilot teachers are located in California, the activities will be identified with the appropriate California State Science Curriculum Standards as well.

A variety of materials will be provided to classroom teachers. These materials will support the teachers' professional understanding of the area of nanoscience concepts and nanotechnology ideas. We are very aware of the multiple demands on teachers' time and will take care to design our professional development materials to be respectful of their time. It is our goal to make the integration into their regular teaching curriculum as painless and as minimally disruptive as possible to their regular curriculum. As a team, working with the ChemSense teachers, we have had several opportunities to iterate the professional development components of existing activities. We feel that we have an easy-to-learn, participant-friendly model.

The essential core of the professional development will be interactive, hands-on experiences with the materials that the teachers will be using with their students. A teacher professional development workshop should not take more than 1/2 day. In the final year of the project, we will conduct four to six workshops with scores of teachers at national conferences and at San Jose State University (see dissemination above). We will plan these workshops for early enough in the final year to be able to give teachers support through their initial implementation efforts. Our original core teachers will be serving as mentor teachers in the workshops, and through an online teacher community forum in Tapped In. We're confident that this is an effective approach due to the extensive use of Tapped In by our own and other NSF grants over the past six years. Our partner, San Jose State, will also provide follow-up supports through their subgrant.

Supportive material will be provided online and in a hardcopy binder provided at our workshops. The materials will include activity guides, succinct readings, and instruction regarding the content of the curriculum covered by the activities. We will also provide written and online references for teachers who wish to explore the topic further on their own time. Classroom curricular activities, instructional materials, sample student work products, and formative and summative assessments (many times embedded within the activities themselves) will be provided to teachers. We will facilitate team meetings with our core teachers, and encourage them to meet independently to share implementation stories and strategies. We will also encourage site and district administrators to be informed and supportive of their teachers' efforts to implement activities in this exciting new area.

Because nanotechnology is beginning to be featured in a variety of information forums (and even in advertising), we anticipate that students will have the basis for interest and questions about this new area. We expect that teachers will come for professional development mainly because they want to be able to answer student questions about this new area; to improve student learning about science in general by encompassing the nanoscale view of properties, materials, and technology; to prepare their students for further study in this emerging field; and to help them understand the interplay between science, technology, and their lives. Since most high school teachers have limited familiarity with nanoscience and its applications, we expect they will seek out professional development to learn about this new field. Some teachers also seek out professional development as a means of feeling like they are advancing in their field and honing their craft. Because of its importance, we anticipate that an understanding of nanoscience principles and applications will take a similar trajectory in terms of classroom integration as did genetic technology: Local colleges will begin to offer professional development courses, districts will start to bring professional developers to staff development days for science teachers, resources will become increasingly more available until the new field is a regular topic area within standard high school text books, and national and state standards will be revised to incorporate the new field.

**5) When an object is magnified to less than about 100,000 times, the reality stays the same. You can believe that you are seeing part of the macroscopic object. Using prepared samples, there is a second reality at about 1,000,000 times magnification at the cellular level. But for magnifications of 100,000,000 or more, Reality changes a second time to particles. These transitions are very difficult for students. Has anybody studied how student deal with these reality changes? Can the NanoSense activities help students make the transitions through the reality changes? Can the NanoSense activities be appended to ChemSense activities to demonstrate the continuum from molecules up to at least nanoscale structures?**

We view "reality changes" as referring to the changes in dominant laws, forces, and objects different scales (e.g., see Figure 1). One example of how "reality changes" is offered by surface tension and viscosity. You can't walk on water, but a spider can, because surface tension is not a dominant force at the human scale but it is at the scale of spiders and bugs. Viscosity is even more important to a bacterium moving through water—for a human, it would be like being thrown in a tub of Vaseline. In either case, at smaller scales, the intramolecular forces in fluids become as significant or more significant than gravity and inertia. An important related idea is that the exact nature of what happens on the atomic scale has big macro consequences; bulk properties follow from what happens at that scale.

In chemistry, the most important conceptual difficulties that students face is that they must come to construct understandings of complex, real-world phenomena that are impossible to see with the naked eye and typically quite hard to imagine (Gabel, 1998; Nakhleh, 2002). Many studies suggest that students do not relate phenomena they perceive in the laboratory (reagents precipitating or changing color) to underlying entities and processes (bonds being made or breaking between atoms) (Bunce & Gabel, 2002; Hinton & Nakhleh, 1999). At the same time, students are able to solve chemical equations but do not know how these connect these to the aperceptual chemical phenomena they represent (Dori, Barak, & Adir, 2003; Hinton & Nakhleh, 1999; Nakhleh, Lowrey, & Mitchell, 1996). Given that these levels are rarely talked about as a continuum in high school chemistry (instruction is almost always broken into two distinct levels—the macroscopic and the particle level—almost to the point that it seems that there really isn't anything in the middle), we expect that students will be unfamiliar with, and have difficulties with, these transitions.

The critical importance of students' being able to visualize aperceptual phenomena has motivated chemistry education researchers to investigate how various types of visualizations affect chemistry learning. These studies have produced promising results in helping students—especially lower-achieving students—improve their conceptual understanding (Barnea & Dori, 1999; Bunce & Gabel, 2002; Sanger & Badger, 2001; Stieff & Wilensky, 2002; Wu et al., 2001). We propose to extend particle-level visualizations to illustrate the relationship between different scales of aggregation of particles and their associated properties.

In some of our existing ChemSense activities, students have created molecular and macroscopic animations that run in parallel with each other to illustrate (for example) the color change of a solution synchronized with depicted changes at the molecular level. We will extend this approach to NanoSense activities and assessments to more clearly address the macro-to-meso-to-micro continuum and related "reality changes." For example, if one begins from a single atom or molecule and successively aggregates atoms/molecules, at some point mass properties (e.g., boiling point) begin to be demonstrated. We will develop animations that start from the molecular level, depict aggregation and synchronized graphs of relevant bulk properties (typically, but not always, step-shaped graphs, as bulk properties emerge from aggregation), and "zoom up" to the macro scale to display the bulk properties. Plots of other interesting, relevant measures (e.g., surface area, ratio of surface area to particles) may also be linked to the animation as appropriate. Students will also be asked to create such representations in ChemSense to assess their understanding (e.g., from the bottom up, to "build water" by aggregating $H_2O$ molecules and depicting approximately when they form a liquid, or to show a crystal being formed; or from the top down by "cutting down" a solid until cutting does not give you a solid anymore). By design, creating animations in ChemSense forces students to clarify the steps and make their thinking visible. We will also ask them to provide explanations for observed phenomena to their peers, and watch and listen for evidence of understanding of the transitions.

**6) The model of an atomic force microscopes works for macroscopic objects, but does it really apply when looking at atoms. How does the probe work? If this is an issue the model does not work. If it is not an issue, why animate something that students can build.**

The model AFM that works for macroscopic objects was designed to demonstrate, through analogy, how a real AFM (which is generally expensive and unavailable to high school students) works. Building a model AFM is something we are considering as a complementary part of the relevant unit on Tools of the Nanosciences, which focuses on issues of size and scale and the challenges of measuring and manipulating structures on the nano scale. The model demonstrates the principles that enable an AFM to resolve molecules, and gives students an intuitive feel for the real AFM's imaging mechanism.

In general, the model AFM shows students how a tool is used to collect indirect evidence of a structure or phenomena. By having the model AFM scan a surface, a representation (plot) of the surface is generated. By comparing the real (macro) surface to the plot, students get an intuitive feel for how the data collected can help them visualize what a surface may look like, and for how imaging techniques such as AFM actually work. The model allows students to perform experiments on macro-level surfaces, record measurements, and ultimately, to reconstruct surfaces using the recorded data. We expect that giving students opportunities to build and use an AFM model will help them use representations to visualize surfaces and 3D shapes, and address students with different learning styles, especially those who are more visual thinkers or learn by working with their hands. The purpose of creating an animation is to deepen their understanding of the mechanisms of the AFM and to serve as a formative assessment tool.

It is appropriate to reiterate here that we are not committed to any particular piece of our proposed curriculum if we discover in our pilot testing that it does not promote and enhance student understanding of the major nanoscale topic concepts, or if our teacher or science consultants offer compelling arguments against the use of a particular model or activity. Given the reduced set of activities that we have been asked to create, it is likely that this particular activity will be cut, given reviewers' reactions.

**7) In the activities in which student are to design something, can you also teach about design?**

Design and science are often seen as separate activities, yet both require complex problem solving (Goel & Pirolli, 1992). Design tasks are prototypical complex problems that require extensive domain knowledge and a process of structuring and restructuring in which solutions (e.g., creation of an object that has some utility) emerge gradually through definition of external and internal constraints. Problem solving in design also has many similarities to scientific inquiry: It is an iterative process that includes identifying a problem or need, researching related work, creating a design proposal, developing specifications and criteria to evaluate solutions, implementing and testing ideas, and modifying the product (or "going back to the drawing board") as needed.

As in the teaching of scientific inquiry, teaching design requires significant hands-on experience and reflective activities (Kolodner, 1995). NanoSense design activities will include problem-oriented, collaborative, hands-on components, as well as facts and reflection. Central to NanoSense is the software that promotes collaboration and reflection by helping students make their thinking explicit and making student work available for viewing and commenting by others. We can augment our design activities to explicitly include metacognitive activities such as reflecting on design practice through discussion of design steps, asking students to "interview" each other to learn about their design process, having students build arguments as a design activity, and whole-class critique of design processes and solutions. We may also explore adapting a product design activity used by one of our collaborating teachers in her high school chemistry classes. In this activity, students propose, research, create, and evaluate products (e.g., foods, cosmetics) they create based on their cumulative understanding of chemistry (e.g., colligative properties, solubility) and principles of design.

As we design our nanoscience activities and consult with teachers, we can also use this opportunity to help the teachers better understand the science of pedagogical design (e.g., collaboratively discuss and work with them to apply best practices in pedagogical design, such as the backward design approach to planning curriculum, assessments, and instruction described by Wiggins and McTighe, 2001).

## 8) Proposed working meeting on nanoscience and science education

The *National Nanotechnology Initiative* highlights contributions to education made possible by advances in information technologies, such as the use of scientific visualizations that bridge the perceptual gap between the micro and macroscales. Nanotechnology implies (a) Novel phenomena, properties and functions at the nanoscale, *which are nonscalable outside of the nm domain*; (b) The ability to manipulate matter at the nanoscale in order to change those properties and functions; and (c) *Integration along length scales.*

Whereas numerous nanoscale science and engineering (and education) programs exist, there is a need for a more focused *conceptual* nanoscience understanding to increase students' scientific literacy and to prepare them for further technology study. Very few community colleges (and even four year colleges) working on nanotechnology projects have the internal capacity to cover the field, and are thus opportunistic in their approach. There is an urgent need, therefore, to re-examine aspects of science education to respond to the challenges posed by nanoscience, and a parallel opportunity to use the relevance of nanoscale to examine some fundamental science education issues. *Making the science curriculum more nano-friendly would make much-needed improvements in science education in general.*

We believe that an effective strategy for considering the impact of nanoscience in science education and its relationship to the science education standards is to integrate the knowledge of the science education research community with that of the researchers and educators whose expertise lies in nanoscale research. SRI International, working with Foothill/DeAnza Community College (Drs. Cormia and Sermon) and NASA Ames (Dr. Meyyappan), proposes to organize an invitational workshop in Fall/Winter 2004 to identify and prioritize a coherent set of concepts and potential ideas that underlie a full understanding of the scale continuum between nanoscale and macroscale on which an instructional materials R&D agenda and a certificate program can be built. The main goal of the workshop is to map a full range of nanoscience concepts into a few articulated skill sets required by different career paths. Outcomes of the workshop will include a certificate in nanoscience, supported by NASA, and a report that documents topics that comprise nanoscience education at the high school and community college level, mappings of these topics to national standards in science and technology, a list of nanoscience courses already being offered, and some possible career paths. The creation of the certificate and the report serve as partial evidence of the success of the workshop; a post-workshop survey will also be administered to assess whether the workshop met participants' expectations, and to gather participants' impressions regarding the accuracy, completeness, and utility of the workshop discussions and products.

Approximately 20 participants—10 nanoscale researchers and educators and 10 science and technology education researchers—will be invited to the workshop. Drs. Meyyappan and Sabelli will select the invitees, with the intention of integrating researchers in nanotechnology familiar with college education issues and researchers in science education interested in advanced uses of technology to expand learning. Besides participants from the partner organizations (SRI, Foothill, NASA), we will involve nanoscientists and educators from Stanford University, University of California at Berkeley, San Jose State University, local high schools, and the Bay Area NanoSig group (nanosig.org). NanoSense funds will facilitate the participation of two or three researchers from outside the Northern California area, in particular those whose work is supported by the NSF Nanoeducation Initiative. NASA will provide the site for the meeting, and FHDA will be in charge of the local arrangements.

Drs. Cormia, Schank and Sabelli are collaborating on a taxonomy of nanotechnology topics that will be used as starting point for the workshop discussions. Other participants will be asked to briefly present their work related to mapping nanoscience concepts to national standards (e.g., a NanoSIG education group has done work in this area, as has the NanoSense team), and existing or proposed courses, skills, and career paths. Core nanoscience concepts and skills will be compiled and prioritized (e.g., through voting and discussion) by the group. The workshop report will be presented at meetings (including the Bay Area NanoSIG meeting); distributed to workshop participants, NanoSense partners, and a variety of organizations interested in nanotechnology education and career paths; and be made available on the SRI Web site.

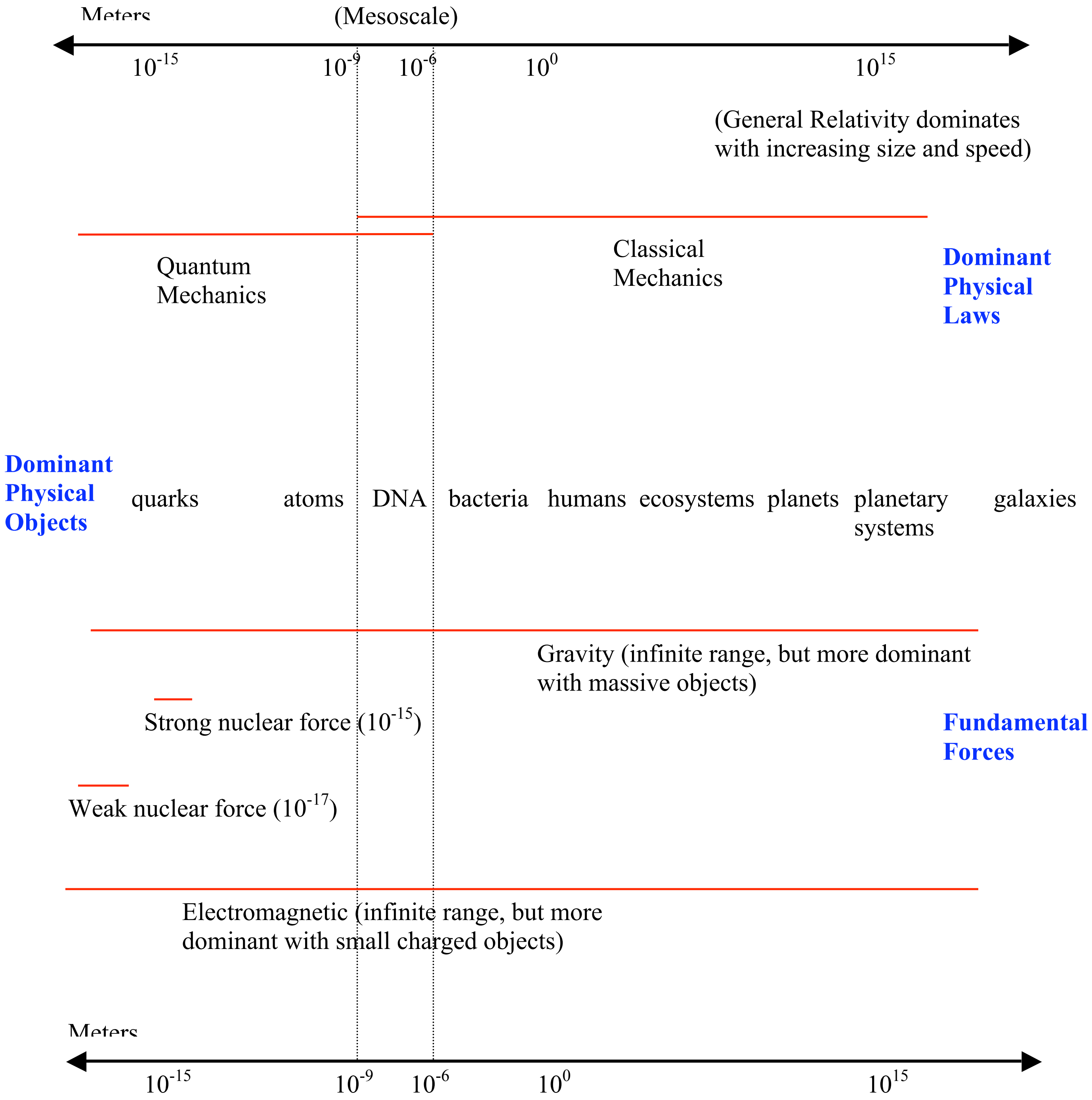

**Figure 1**. A rough sketch of dominant physical laws, objects, and forces at different scales. The mesoscale describes a range where both classical and quantum forces are important, and until recent advances in nanoscience and nanotechnology, has been difficult to access and manipulate technologically.

## References

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