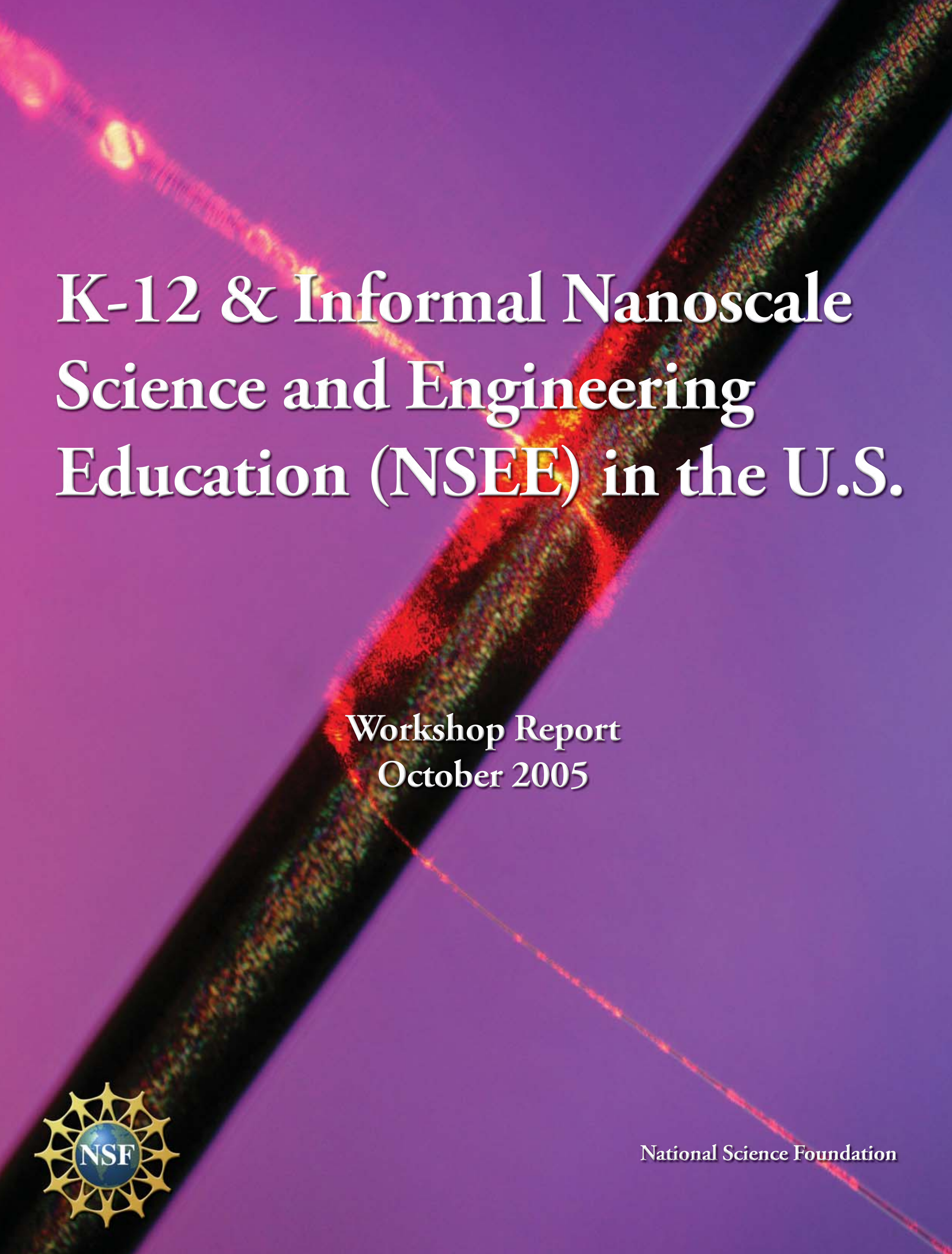

K-12 & Informal Nanoscale Science and Engineering Education (NSEE) in the U.S.

Workshop Report
October 2005

National Science Foundation

Cover Image:

Wrapped around a human hair, a 50nm silica nanowire conducts red light.

Photo credit:

Dr. Eric Mazur
Harvard University.

K-12 & Informal Nanoscale Science and Engineering Education (NSEE) in the U.S.

Workshop Report
October 2005

K-12 & Informal Nanoscale Science and Engineering Education (NSEE) in the United States

In October 2005, the National Science Foundation brought members of its nanoscale science and engineering education (NSEE) projects to Arlington, VA for a 2-day workshop to explore the status of on-going efforts and to forge collaborations at the national level that would facilitate future efforts. NSF currently funds NSEE projects through the Division of Elementary, Secondary, and Informal Education (ESIE), the Directorate for Engineering as part of the Nanoscale Science and Engineering Centers (NSEC), National Nanotechnology Infrastructure Network (NNIN), the Network for Computational Nanotechnology (NCN), and the Division of Materials Research as part of the Materials Research Science and Engineering Centers (MRSEC). This report refers to projects developing instructional materials for inclusion in grades 7-12 science courses, providing professional development and research opportunities for secondary teachers, and engaging in multiple forms of outreach to schools and general audiences through exhibits, media presentations, and traveling programs. NSEE workshop participants included project leaders, scientists, instructional materials developers, museum designers, professional development providers and NSF program directors. The workshop agenda focused on several basic questions:

- What are the core NSEE ideas?
- Who are the audiences for NSEE?
- What are appropriate NSEE goals for each audience?
- What evidence of impact exists for current NSEE efforts?

Dr. Mihail C. Roco, Senior Advisor at the National Science Foundation, in his opening address, established the themes that framed the workshop. Research is rapidly advancing knowledge about nanoscale phenomena, in contrast to the scant progress in bringing nanoscale science into school curricula and public awareness. Fueled by 2006 government funding of over $1 billion, research on matter at the nanoscale will “lead to a revolution in technology and industry” according to Dr. Roco. Emphasizing that a robust nanoscale science and engineering infrastructure depends on greater progress in education and public outreach, Dr. Roco stressed the importance of early education to prepare American students for future careers in nanoscale science, engineering, and technology. He proposed several objectives for NSEE:

- Developing a coherent longitudinal learning sequence extending from K-12 to college and graduate programs.
- Stronger collaboration between NSE researchers and educators.
- Focusing on better preparation of teachers.
- Enhancing public outreach efforts.
- Partnering across institutions working on NSEE.
- Increasing emphasis on engineering and systems.

Prior to the workshop, participants identified their major areas of interest. These topics were the subjects of plenary sessions and provided framing questions for the discussion groups. A plenary presentation by Dr. Angelica Stacy, University of California-Berkeley, offered design principles for effective secondary science instructional materials. She described her new learning-goals oriented secondary chemistry program in which students are introduced to organic functional groups by experiencing characteristic aromas and solubilities rather than memorizing structural formulas. She shared research supporting its positive impact on student understanding. Dr. Frances Lawrenz, University of Minnesota, delivered a plenary presentation on design principles for program evaluation. Citing evaluation plans of three current NSEE projects as specific examples, Lawrenz described several evaluation strategies, stressing the importance of aligning the evaluation plan with program goals. Dr. Robert Chang, Northwestern University, described international efforts in NSEE based on his recent travels in Europe and Asia.

Participants from the nano research centers met for in-depth discussions with those from the materials development projects during the Day 1 breakout sessions. The topics were: Design and Development of Instructional Resources; Teacher Professional Development; and Nanoscience Education beyond the Classroom.

During the Day 2 sessions, attendees regrouped for further networking and exchange of ideas. Participants from the nano research centers[1] met together to discuss the content and design of their education outreach efforts, while attendees from the projects funded through the Division of Elementary, Secondary, and Informal Education[2] shared their experiences and concerns related to bringing nanoscale content into classrooms and public venues and proposing topics for future research. Both groups discussed strategies for increasing collaboration across formal and informal NSEE programs.

As reported in the closing session both groups, although serving different audiences and educational purposes, share their commitment to the value of nanoscale education programs for introducing both students and the general public to contemporary science. The interdisciplinary nature of the topic, its myriad applications, and the economic impact of nanotechnology provide an excitement that has great potential for engaging learners of all ages and interesting students in career opportunities. Although challenges abound, participants reported some success, including workshops for educators, research opportunities for high school teachers, teacher-graduate student collaborations to develop classroom materials, traveling exhibits for elementary students, computer simulations to aid in visualizing nanoscale phenomena, and recently developed instructional packages currently in pilot test mode in secondary classrooms.

However, more discussion time was devoted to challenges than to successes. The general public and students, in particular, lack fundamental background knowledge upon which to build an understanding of nanoscale phenomena. While exhibits focus on public awareness, there is no evidence that they are promoting understanding. Instructional materials developers are keenly aware of the difficulty of introducing any new topic in existing science curricula, particularly an interdisciplinary topic that cannot be readily linked to state or national standards. The informal education community emphasized concern over combating public misconceptions and fears resulting from science fiction accounts of nano critters who take over the world. Ultimately, most discussions turned to seeking:

♦ Entry points for an introduction to nanoscale phenomena
Do units have to start with a discussion of scale and/or new behavior?

♦ Instructional resources that would appeal to secondary teachers
Will two week units or1-day lessons be more acceptable?

♦ Strategies that emphasize the uniqueness of nanoscale properties
Must students understand atomic, molecular and supramolecular structure and properties first?

♦ Representations and models to make nanoscale phenomena visible
Will virtual representations of nanoscale behavior and self assembly be meaningful?

♦ Strategies to share materials and expertise across programs
Will NSF support a national clearing house for nano education resources?

1 Nanoscale Science and Engineering Centers (NSEC), National Nanotechnology Infrastructure Network (NNIN), Network for Computational Nanotechnology (NCN), and Materials Research Science and Engineering Centers (MRSEC).
2 Nanoscale Instructional Materials Development (NIMD), Nanoscience Center for Learning and Teaching (NCLT), and Nanoscale Informal Science Education Network (NISE).

- Assessment strategies to evaluate current efforts

Where will projects find funding and expertise for assessment?

Participants articulated a common set of needs to move current efforts forward more rapidly, including:

- Quality instructional resources that would engage students and support meaningful learning goals.
- Content-rich professional development programs for teachers.
- Guidelines for a standards-based K-12 nano learning sequence.
- Innovative technologies to support visualization of nanoscale phenomena.
- Strategies for integrating interdisciplinary nano content in discipline-oriented curricula, and better connecting researchers and educators.
- "Hooks" that capture public interest and combat negative misconceptions.
- Clearinghouse to disseminate resources and share best practices across projects

Summaries of all of the workshop sessions follow.

Day 1

Session I. Instructional Materials: Designing and Developing Classroom Resources

Framing Questions:

- What nano topics and learning goals should guide the development of classroom materials?
- What areas of secondary (grades 7-12) science support the integration of nano concepts?
- How can instructional technology enrich nano classroom resources?

This session began with four formal presentations. Dr. Joseph Krajcik, University of Michigan, presented guidelines for the design of materials; Dr. Patricia Schank, SRI, talked about her group's early drafts of materials for secondary chemistry classes and the obstacles they encountered; Dr. Thomas Moher, University of Illinois-Chicago, focused on technology applications for middle school students that would enhance understanding of nanoscale phenomena; and Dr. Kenneth Klabunde, Kansas State University, reviewed nanoscale science content.

Krajcik emphasized three lessons learned through his work on a new middle school science curriculum that are directly applicable to developing instructional materials in nano science. First, focus on learning goals. Developers must help teachers recognize what it means to understand a scientific idea and answer the question, "how do we know if students understand?" Second, scaffold complex tasks. Krajcik emphasized the importance of helping students develop the skill of presenting evidence-based explanations and providing data to support explanations. As a scaffolding example he described a structure for student explanations: make a claim, provide evidence, present reasoning, and consider alternatives. His third lesson is that instructional materials must be educative for teachers. Krajcik emphasized the importance of providing teachers with adequate understanding of content and the appropriate pedagogy for introducing complex topics to their students.

Schank described her Nanosense project that is creating instructional units to use in high school chemistry courses. Each unit will emphasize core concepts underlying nanoscale phenomena and employ computer visualizations of the behavior of nanoscale particles to enhance student understanding. Schank convened a group of teachers, scientists, industry representatives, and education researchers who developed the following list of core concepts: scale, energy, quantum principles and probability, relation between structure and properties, surface phenomena, unique properties, self-assembly, and control of fabrication.

Shank also stressed the need for authentic tasks and tools to promote student understanding, citing as an example a virtual atomic force microscope (AFM). She emphasized the importance of teaching that properties depend on scale but cautioned that there are limitations to models and simulations that may be informative at one scale but irrelevant at another.

Schank presented several challenges she and colleagues are confronting: (1) defining a curriculum for nano science; (2) situating this inherently interdisciplinary field within traditionally single discipline courses; and (3) designing professional development for teachers. She concluded by posing a set of research questions related to the teaching of nano content:

- Will students' understanding of nanoscale science concepts (effects of size, significance of high surface-to-volume ratios, etc.) improve over time?

- Will students' understandings of the process of science and the interplay between science and technology improve?
- Will students' interest in science increase?
- Will students appreciate how technologies can alter their lives and society?
- How will teachers use these tools and activities to support student discourse and understanding?

Kenneth Klabunde, a Professor of Chemistry at Kansas State University and nano researcher, proposed that "nanotechnology is really an extension of chemistry, but it reaches into physics, biology, [and] earth science." As previous presenters, he emphasized the importance of presenting nano in the context of existing classroom materials at levels that are developmentally appropriate for different grades. He proposed several nano concepts that might become the basis for classroom materials:

1. Size-dependence of solid state properties.
2. Properties that change with nano-sizing.
3. Uses of nano-scaled applications and devices.
4. Changes in physical properties at the nano-scale (example–magnesium oxide).
5. Increase in surface area/volume at the nanoscale.
6. Chemical properties of nanoscale materials.
7. How changes in size and shape of nanocrystals affect chemical and consolidation properties of magnesium oxide.
8. Preparation and manipulation of gold nanoparticles.

Moher discussed the roles of virtual experiences in student learning and new technologies his group is developing for classroom use. He talked about the value of placing a student in the middle of phenomena, rather than as an external observer. Describing several successful simulations in which students use hand-held devices and interface with laptops, he emphasized that these technologies would offer students an affordable simulation of the nano world. Talking about the importance of providing students with an understanding of scale, Moher offered examples of simulations that would allow students to "control phenomena" at the nano scale.

These presentations were followed by a more global audience discussion about instructional resources: what content to include, how to link nano content to the standards, defining "understanding" in the realm of nano content. The discussion moved toward looking for "hooks' that might make nano "cool" to young audiences.

Session II. Teacher Professional Development

Framing Questions:

- What nano content should be included in professional development?
- What models of professional development can be scaled to meet the needs of a large and diverse teacher population?
- How can a teacher leadership cadre capable of supporting nano professional development be recruited and prepared?

This began with presentations by Nancy Healy (NNIN, Georgia Institute of Technology), Monica Plisch (NSEC, Cornell University), and Christine Morrow (NIMD, McREL and University of Colorado).

Healy described professional development projects sponsored by the NNIN at some of its 13 centers across the nation. One example was about teachers visiting nano research labs and, with the help of graduate students, designing materials for student use. At subsequent 1-2 day workshops, materials are shared with other teachers. A workshop was described to help teachers tie specific nano concepts to topics they currently teach in secondary science courses.

Plisch also described specific professional development offerings. With examples from the education outreach efforts at her research facility, she talked about an institute for physics teachers and a program combining lectures, laboratory tours and hands-on activities, all intended to build teacher content knowledge. She described a lending library created to provide materials and activities for classroom use.

Morrow, representing the instructional materials development community, focused on the design principles for effective professional development and for the preparation of teacher leaders. With specific reference to her NanoLeap project currently developing a secondary curriculum covering properties of matter, forces, energy, measurement and size, ethical issues, and the interdisciplinary nature of nanoscale science, she reviewed standards-based teacher professional development guidelines. She emphasized the importance of a focus on essential understandings and learning goals for students in both teacher professional development and student materials. She described the multi-media teachers guide currently under development that would employ video clips illustrating demonstrations and animations, background information rich in content and pedagogy, and suggestions for embedded assessments of student learning.

These presentations introduced several critical issues that were, along with the framing questions, topics for the subsequent discussion. The SRI project adopted the approach of developing short focused lessons for key insertion points in the secondary curriculum, since high school teachers are reluctant to include longer units in an already over-crowded curriculum. Many were critical of existing high school curricula, describing its adherence to single discipline courses as “rigid” and “archaic”. Participants considered the option of introducing nanoscale science in middle school classrooms, as they have fewer constraints with respect to content and are more welcoming to interdisciplinary topics.

The education outreach efforts from the research centers mostly involve small numbers of teachers who volunteer for these programs. They have opportunities to visit research labs and participate in the design of instructional materials that they take back to their students and frequently share with colleagues. At the present time, these programs lack formal evaluations, and evidence of impact is largely anecdotal.

Participants suggested additional profession development strategies such as lesson study, classroom support for teachers, and peer study groups and emphasized the importance of better instructional materials, particularly those that would meet the needs of diverse student groups.

Session III. Nanoscience Education beyond the Classroom: Exhibits, Media & Special Programs

Framing Questions:

- What models of informal nano education have been successful in your projects?
- How can formal and informal efforts in nano education be integrated?
- What has been learned about making nano accessible to young students? To the general public?

The session began with introductory presentations by Anna Waldron, Cornell University, Chang Ryu, Rensselaer Polytechnic Institute, and Michael Melloch, Purdue University, describing outreach efforts in their projects and some of the obstacles associated with the work.

Waldron talked about *Too Small to See,* an exhibit designed for children and adults that is intended to engage viewers in thinking about atoms as building blocks. As part of the project evaluation audiences of different ages were interviewed about what they understood. Few were able to comprehend scale. High school students associated "small" with a spec of dust or a grain of sand. Some of the adults interviewed heard of "nano" and "nanotechnology", but, as Waldron noted, awareness is different than understanding. *It's a Nano World* is a traveling exhibit for children age 5-8. Like *Too Small to See*, the exhibit tries to push viewers' understanding from small to smaller, but, according to Waldron does not succeed in conveying understanding of the nano level.

Some of the challenges Waldron encountered in her work include engaging the public in the topic and providing interactive learning experiences that might enhance understanding.

Ryu described the Molecularium, a portable dome for presenting a musical simulation in which cartoon-like figures with facial features model atomic motions and molecular interactions to help K-5 students understand molecular behavior. The animation conveys the message that everything is made of atoms. A first installment features figures representing hydrogen, oxygen, and water. The next episode will focus on carbon and atoms in living things. There were several concerns about the implications of this approach, in particular the impact of anthropomorphizing atoms on a child's understanding of science. Ryu explained that this 7-minute show engages both children and adults.

Melloch described a LEGO simulation of a scanning probe microscope and an exhibit about The Science of Making Things Smaller.

A key challenge confronting the informal education community is finding ways to reach audiences with minimal knowledge of nano science or background on which to build meaningful understanding. Participants agreed that their work is complicated by the absence of a clear set of essential understandings and desired outcomes. The need for effective materials was stressed repeatedly—materials that are based on best practices and have been subject to rigorous evaluation.

Chemistry was mentioned as a possible introduction to nanoscale science. However, critics noted that since public understanding of chemistry is generally limited it is not an adequate entry point and properties of chemical systems are quite different from those of nano systems

Ultimately, effective resources for informal education must evoke a "wow" to attract audiences. There was general agreement on the goal of raising public awareness. Under this general heading, came issues such as using nano as a vehicle for showcasing the interdisciplinary nature of science and introducing the tools that are advancing the frontiers of science. Participants acknowledged the importance of developing age-specific learning goals and conducting systematic evaluations of informal education programs, reporting both what works and what doesn't.

The discussion moved to nano education in museum settings. Larry Bell, director of Boston's Museum of Science, emphasized that museums have fewer constraints than classrooms. Although most discussions of NSEE content started with teaching size and scale, Bell proposed a different starting point. At the nanoscale, the properties of matter are different than at the micro or atomic scale. Atoms can be manipulated and new molecules assembled atom by atom. Bell suggested that this is the "wow" that will attract the audience.

Teachers and parents bring children to museums to supplement what they learn in school. They want exhibits that are “cool” but can be related to the curriculum. Although emphasizing size and scale came up repeatedly, Bell proposed not focusing on size, but rather on the fact that the critical properties are different and things are manufactured in a different way---bottom up assembly, atom by atom.

Day 2

Session IV: NCLT, NIMD, and NISE projects

Framing questions:

- Finding a place for nano in the secondary curriculum: what have we learned?
- Preparing teachers for pilot and field-testing: what are we doing? What might we do better?
- What research projects are currently underway? What research questions are emerging?
- Collaboration among formal and informal efforts: how can they support one another?

The session began with each project summarizing current efforts. McREL's NanoLeap project in collaboration with Stanford University researchers is developing a multimedia guide for secondary physical science and chemistry teachers. It will incorporate text, activities, and simulations and provide web-based teacher support. The project is currently engaged in professional development of leader teachers who will participate in development and pilot testing.

SRI's NanoSense project shared the first volume of their curriculum series entitled *Size Matters: Introduction to Nanoscience*. It includes both teacher and student materials, reference readings, PowerPoint presentations, worksheets, and assessments. Noting that teachers must believe they have sufficient understanding to field students' questions before presenting a new topic, the developers start the volume with a segment *For Anyone Planning to Teach Nanoscience… Read This First!* It alerts teachers to challenges and opportunities associated with teaching nanoscience, and it encourages teachers to examine with students how to approach phenomena we don't yet understand. Early evaluation results indicate that transfer from a professional development session to an effective classroom lesson is challenging, even for master teachers.

The NCLT, housed at Northwestern University, offers a monthly web cast to share ideas among nano researchers and educators. The Center is forming interdisciplinary research teams that will study the extent to which new tools and technologies promote students' understanding of nanoscale phenomena.

NISE is a newly-funded network of major science museums in Boston, Minneapolis, and San Francisco. Ultimately 100 additional museums across the country will join the network. It will promote all forms of public engagement related to NSEE including exhibits, media programs, public forums, and professional development.

The conversation about the role of nano content in school science quickly turned to a discussion of obstacles:

- Guidelines for a coherent progression of nano concepts must be developed.
- Learning goals for students of different ages have not been articulated.
- The science standards do not encompass topics such as nanoscience.
- Tools and technologies to help students visualize and understand phenomena at the nanoscale are not available.

The classroom materials described in the workshop all begin with the concept of size and scale, but there is little research available on students' comprehension of this topic. Some questioned this starting point. There was overwhelming support for establishing a research based learning sequence to guide future materials development and education outreach efforts.

Teacher professional development is a challenge for all of the instructional materials projects. A small number of teachers have participated in existing programs. Few teachers have adequate content knowledge for learning or teaching nano, or for the roles they would normally play in materials development: consulting as experts in pedagogy and the needs of students from diverse backgrounds; conducting pilot and field tests; and leading professional development for peers as resources become available for dissemination. Participants suggested strategies that have been successful in other content areas: lesson study, engaging teams of teachers, rather than individuals, securing administrative support, internships with researchers, professional development in cross disciplinary teams, and mentoring.

Participants identified several system-related issues that inhibit change in school science:

- While research supports the need for 2-3 week focused instructional units to achieve content understanding, teachers are asking for 1-day lessons to insert in existing curricula.
- Neither teachers nor curricula are prepared to incorporate interdisciplinary topics.
- Middle school courses have greater content flexibility and fewer time constraints, but students and their teachers have limited prior knowledge on which to base instructional units.
- Secondary science curricula, already overburdened with content, do not welcome additional topics, particularly those not clearly linked to standards and high stakes assessments.
- Pre-service programs are not preparing teachers for interdisciplinary content.

Members of the informal community emphasized that museum-based and other informal programs, not constrained to align with specific disciplines or audience ages, have greater flexibility than classroom programs. Museums can introduce nanoscale topics in the context of engineering or technology, fields that accommodate interdisciplinary approaches. Participants supported stronger links between formal and informal programs, specifically in sharing instructional resources, linking schools to museums that would provide access to costly visualization tools and technologies, and collaborating in teacher professional development that addresses both content and engagement.

Session V. NSEC, NCN, NNIN, and MRSEC projects

Framing Questions:

- What design principles guide the development of education outreach materials?
- Professional Development programs: What works? With whom? How do we measure success?
- Student programs: What works? With whom? How do we measure success?
- Fostering collaboration among the nanoscience and education communities: how can they support one another?

The discussion began with questions about what students know about nano. Although few studies are available, there was consensus that students acquire impressions from television, but much of their background is misinformation.

Workforce development is a major concern of the education outreach programs, along with meeting the needs of adult audiences. When students at NSEC-sponsored summer camp were asked what they knew about nano, most responded, "Nothing." Following a 3-day program, students report interest and excitement. The hope is that they will pursue science-oriented careers. While there was some discussion of the value of nanotechnology to teach basic science concepts, most were concerned about guidelines for building public understanding of specific topics in nanoscience and engineering. Participants wanted to know more about successes at other Centers and questioned whether the NCLT and NISE had the capacity to serve as a clearinghouse for these efforts.

The discussion of professional development focused not on teachers, but on the needs of legislators, the business community, lawyers, journalists, and other non-technical audiences. As in previous sessions, participants emphasized the need to respond to fear and misinformation generated by science fiction novels, such as Crichton's *Prey.* Interestingly, one participant talked about using the novel to generate interest and pose questions that would be answered with accurate information.

Some Centers offer workshops in nanotechnology for media people. Industries are contacting the Centers for more education programs. Some Universities are engaging nanoscience and engineering graduate students to lead tours and outreach sessions for business people and for students from other university departments. A big challenge is communicating key ideas in jargon-free, non-technical language.

The discussion of student programs brought forth concerns about reaching diverse, currently underserved audiences and providing them with information about career opportunities. Some suggested collaborating with community organizations that have programs reaching underserved youth. Specific examples of youth programs were described: Howard University has a charter middle school that focuses on science; University of California-Santa Barbara provides Chip Camps for local Spanish-speaking students; and Princeton University's Materials Academy hosts students from the Trenton Public Schools. There were also descriptions of programs targeting young women with featured presentations by female researchers and doctors. Project leaders were urged to invest in professional evaluations to study the impact of these programs and guide future efforts.

There was optimism about increased collaboration across the nanoscience and education communities now that the NNIN (National Nanotechnology Infrastructure Network) and the NISE (Nanoscale Informal Science Education) Network are in place and intend to share resources with each other and with regional partners. The museums bring expertise in how to make effective presentations to the public. The research centers provide essential content expertise. It was suggested that the NCLT serve as a clearinghouse for resources for formal education and that all NSEE resources be centrally housed and disseminated on-line.

Conclusions and Next Steps

A cross-section of NSEE professionals representing the NSECs, MRSECs, and formal and informal projects funded through ESIE attended the workshop and provided their perspectives on current needs and challenges. There was general agreement that nano scale phenomena offered many "hooks" to engage learners of all ages in science and that ultimate success would depend on finding a balance between generating engagement and promoting understanding.

Workshop participants supported the following conclusions:

- Establish a clearinghouse for sharing information and resources.
- Take advantage of informal venues to promote awareness and broaden participation.

- Foster partnerships to share expertise across scientific and education communities, both formal and informal.
- Develop a research-based sequence of learning goals to guide resource development.
- Expand professional development efforts for teachers and other professionals.
- Plan future meetings for exchange of ideas across the NSEE community.

Networking across the projects began at the start of the workshop. By the final session, resources, particularly teacher materials and presentation outlines, had been shared, and several participants agreed to make presentations for other projects. In January 2006, the Division of Elementary, Secondary, and Informal Education (ESIE) funded a conference for experts in nano science, learning sciences, and instructional materials development to collaborate with teachers in the development of a learning trajectory to guide NSEE efforts. It will be disseminated to the science and education research communities through a series of research articles and to teachers through a monograph published by the National Science Foundation.

Appendix 1: Cornell University/Center for Nanoscale Systems Profile

I. Description

Institution: Cornell University
PI: Robert Buhrman
Co-PIs: none
Title: Center for Nanoscale Systems in Information Technologies
Proposal: 0117770
Program Officer: Bruce Kramer
Education Outreach Director: Dr. Monica Plisch, mjp11@cornell.edu

II. Research Agenda

Research Focus: Information technologies

The Center for Nanoscale Systems (CNS) has assembled interdisciplinary teams to execute an aggressive and wide-ranging nanoscale science and engineering research program. The CNS research mission is to substantially increase the impact of nanotechnology by advancing the understanding and control of the electronic, photonic and magnetic properties of materials at the nanoscale, and by exploiting these material systems and associated nanoscale phenomena in the development and demonstration of high-performance devices and systems. The Center's primary research objective is the innovation and development of effective nanoscale systems that have the potential of being revolutionary solutions for the ever-more demanding requirements of future computational, sensing, information storage and communication systems. CNS also seeks to invent and develop effective NSE research tools and techniques to support and further advance these information technology efforts.

In parallel with pursuing its research agenda, CNS seeks to attract, educate, and mentor substantial numbers of a diverse population of students, at all levels, in both introductory and advanced topics in nanoscale science and engineering, including ethical and societal issues, and career development. CNS also operates a very significant education outreach program for high school physical science teachers.

III. Education Activities within the University

1. Research Experience for Undergraduates

Description of activities
Undergraduate students spend 10 weeks at Cornell doing research under the supervision of CNS faculty. In addition, a series of short courses and faculty lectures are designed to give students a broader understanding of NSE and introduce skills relevant to research.

Program staff and expertise
P.I.: Prof. George Malliaras, Materials Science and Engineering

Goals and objectives

Our goal is to provide 12 undergraduates with the opportunity to:

- ♦ Experience independent research at a leading center for NSE research
- ♦ Develop practical skills for research activities
- ♦ Gain in-depth perspective on opportunities in NSE
- ♦ Become part of the NSE community

Target audience (educational levels, number of students at each level, etc.)

This program funds up to 12 undergraduate students each summer. We give priority to qualified students from underrepresented minorities, women and students from primarily undergraduate institutions.

Current activities

See goals and objectives above

Nano S&E content focus

NSE research in a broad array of fields related to information technologies

2. Nanotechnology Curriculum

Description of activities

AEP 102 *Introduction to Nanoscience and Nanoengineering* is a lecture and lab course designed as a hands-on, engaging introduction to NSE.
AEP 661 *Nanocharacterization* is a serious introduction to the tools used to image and probe materials at the nanoscale.

Program staff and expertise

AEP 102

- ♦ Lecturer: Prof. Robert Buhrman, Applied & Engineering Physics
- ♦ Lab Instructor: Monica Plisch, Ph.D. Physics

AEP 661

- ♦ Lecturer: Prof. David Muller, Applied & Engineering Physics

Goals and objectives

AEP 102 - To increase students awareness and interest in NSE.
AEP 661 - To provide instruction in nanocharacterization techniques for grad students and advanced undergraduates.

Target audience (educational levels, number of students at each level, etc.)

AEP 102 is a course designed for freshmen engineering students and has room for up to 80 students per year. It has been nearly full for the past two years offered.
AEP 661 is a course designed for senior undergraduate and beginning graduate students.

Current activities

To date, 10 lab modules have been developed for introducing college freshmen to NSE. In addition, more than 200 students have taken the course to date and have increased awareness of NSE concepts, and many report a strong interest in pursuing further studies in this field.

Nano S&E content focus
See description of activities above

3. CAPES mentoring program

Description of activities
The Career Advancement Program for Engineers and Scientists (CAPES) is an innovative mentoring program with the goal of better motivating and preparing graduate students and postdoctoral scholars to excel in their chosen career by improving their competitiveness when they enter the workforce.

Program staff and expertise
Chair: Prof. Melissa Hines, Chemistry and Chemical Biology

Goals and objectives
To help students develop important real-world skills such as public speaking, proposal writing and scientific "salesmanship."
To give students a realistic and unbiased view of academic and non-academic career opportunities.
To help prepare female and minority students for high level careers in engineering and science.

Target audience (educational levels, number of students at each level, etc.)
The target audience is graduate students and postdoctoral scholars. Typically, more than 100 students attend each of the 4 seminars offered each semester.

Current activities
Slides and video from each seminar are available at www.cns.cornell.edu as an on-line resource. Also, see goals and objectives above.

Nano S&E content focus
See description of activities above.

IV. Education Activities Outside the University

1. CNS Institute for Physics Teachers

Description of activities
See current activities below.

Program staff and expertise
Director: Monica Plisch, Ph.D. Physics
Coordinator: Linda Clougherty, B.S. Accounting

Goals and objectives
To update high school teachers on recent advances in physics including NSE.
To provide teachers with take-home laboratory exercises designed to meet the time and budgetary constraints of a typical high school, as well as fitting state-mandated curriculum.
To develop a continuing relationship between CNS and participating high school teachers.

Target audience (grade levels, number of students at each level, school districts, etc.)
Our target audience has been high school physics teachers, primarily in New York State. Satellites allow us to reach teachers in other locations, including minority-serving school districts in Los Angeles and Cleveland. To date, more than 500 teachers have come to at least one CNS workshop.

Current activities
More than 10 teacher workshops are held each year across New York State and at satellite locations including Los Angeles and Cleveland.
A three-week summer institute at Cornell University with a lecture and lab format provides teachers with intensive training.
To date approximately 20 new lab activities have been developed for teaching high school physics.
An equipment lending library provides kits for teachers to implement CNS activities.

Nano S&E content focus
Lectures at teacher workshops frequently have a NSE theme related to information technologies, which is the expertise of the faculty in our center. Hands-on activities focus on helping teachers meet learning standards, which sometimes can be related to NSE content.

Nano S & E content consultants
CNS researchers work closely with teachers to develop new materials.

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences
Each year, we bring together teachers and researchers to develop new hands-on activities with the goal of updating physics classrooms and engaging students with stimulating learning experiences. Teacher training workshops are used to disseminate new activities. Activities are described on our website www.cns.cornell.edu.

Describe a recent successful education outreach activity See above.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan
All workshops, courses and classroom materials are evaluated by participants, including classroom teachers and/or students. Written and oral evaluations are used to solicit quantitative and qualitative information. This feedback is used to improve programming and materials. In addition, a three-page annual survey is sent to alumni of the summer institute to determine classroom impact.

Summarize outreach evaluation results
Teacher feedback from summer institute 2004

- Highly enthusiastic response; typical teacher comments included:
  "CIPT has provided a source of new and interesting labs."
  "I feel re-energized about physics."
  Liked best: "To see the current research."

- All teachers planned to use most labs at end of courses

- Many teachers want more
  - 9 teachers returned in 2004
  - 17 teachers returned in 2005

Follow-up survey (end of school year)

- 67% return rate for June 2005 annual survey
- Overall effect of participation? (1 = no effect, 5 = enormous effect)
  - 2003 participants: 3.9
  - 2004 participants: 4.6

Average lab implementation rate: 40%

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort.

1. Activities that meet learning standards are much more likely to be used by teachers than those that do not address the curriculum in any way.
2. It is essential to bring together researchers and teachers when developing new classroom materials and activities.
3. Teacher training is important for teachers to adopt new curricular materials.

Describe what you might do differently in the future
In the future, we plan to focus on the middle school curriculum to reach a wider population, especially underserved minority students and teachers. High school physics is infrequently taught in under-resourced schools.

Appendix 2: Cornell University/National Nanotechnology Infrastructure Network Profile

I. Description

Institution: Cornell University (with 12 other sites)
PI: Sandip Tiwari
Co-PIs: none
Title: National Nanotechnology Infrastructure Network
Proposal: 0335765
Program Officer: Larry Goldberg
Education Outreach Director (name and email address): Nancy Healy, nancy.healy@mirc.gatech.edu

II. Research Agenda

Research Focus: NNIN is not a research organization and is not directly funded for research

The National Nanotechnology Infrastructure Network (NNIN) is an NSF-funded partnership of 13 university user facilities openly available for research and development in nanoscience. We provide the tools and training to support the nanotechnology research needs of researchers in academic, industry, and government.

III. Education Activities within the University

NNIN has as its goals a wide variety of educational outreach that spans the spectrum of K-gray, i.e. school aged children through adult professionals. Education and outreach components of the NNIN include network-wide programs to address needs at the national scale and more specific efforts for communities that are local to network sites. This report will highlight activities occurring across the network and will serve as examples but will not encompass all activities occurring.

Our activities focus on the following general areas:

- Activities to encourage K-12 students to enter STEM
- Resources to inform the public
- Activities and/or information to undergraduates on careers in nanoscience
- Tools and resources for undergraduates and graduate students (teaching and learning focus and research focus)
- Outreach programs for under-represented groups
- Technical workforce development
- Activities and/or resources for K-12 teachers and guidance counselors

The 13 NNIN sites each have responsibility for specific components of our education agenda. Certain sites are also lead institutions for an outreach activity and will work in collaboration with other sites. For example, the University of New Mexico is the lead site for addressing under-represented groups but this work is in collaboration with Georgia Tech, UC Santa Barbara, and Howard University. However, all sites will utilize materials and resources that this group develops.

The NNIN education and outreach programs are typically designed to begin as local programs at each host institution and then expand to the other sites and eventually be posted on the NNIN web site for national dissemination. Because the NNIN is a national network of 13 universities, it is difficult to divide out activities between inside and outside the university. This report will describe activities occurring across our network and thus combines sections III and IV.

Description of activities

- NNIN education portal http://www.nnin.org/nnin_edu.html
- NNIN social and ethical issues portal http://sei.nnin.org
- Summer camps for high school students
- K-12 outreach programs (on-campus tours, activities, and on-site school programs, including a traveling NanoVan)
- Research experiences for high school students
- High school brochure on entering STEM and nano fields
- PSAa for middle and high school audiences at Howard University
- Science magazine for children http://nanooze.org
- REU program (81 participants in 2005 at 12 sites) with end-of-program convocation which is a "mini" scientific conference that is webcast (http://www.nnin.org/nnin_reu.html)
- RET program at Stanford, Georgia Tech, and Univ. of Washington (local programs which vary in design at each site)
- Teacher workshops at Penn State Univ.
- Exhibitors booth at NSTA
- Instructional materials development (UC Santa Barbara and Penn State have completed materials and Georgia Tech is beginning development); Stanford has an IMD award from NSF with McRel to develop high school materials under a project tilted "A Nano Leap into New Science"
- Guidance counselor brochure under development at Univ. of Washington
- Workforce development
    - Penn State and U. of Minnesota have two year college partnership programs in nanotechnology
    - UCSB offers six-month internship program for community colleges
    - Univ. of Texas nine-month internship in microelectronics and nanotechnology for community college students
    - Univ. of Washington's Ph.D. nanotechnology option (expansion under NNIN through support and training at facility)
    - Workshops held at sites on a variety of topics such as characterization, fabrication, research, and product development (http://www.nnin.org for upcoming and past events)

- Course development
  - Web-cast MEMs course from the Univ. of Michigan
  - Nano-ethics course at Univ. of New Mexico
  - On-line open textbook on nanotechnology (Univ. of Minnesota lead organizer) currently under development
- Nanotechnology graduate student organizations at Univ. of Washington and Georgia Tech.
- Two special symposia:
  - MRS Spring 2006 three day session on NanoEducation
  - AAAS February 2006 session on formal and informal education (NNIN with NISE-NET)
- Outreach materials at professional organizations conferences of under-represented groups
  - University of New Mexico developing recruitment brochure

Program staff and expertise
Each site's program staff varies in terms of expertise. The NNIN Education Office is housed at Georgia Institute of Technology which coordinates the NNIN education efforts across all 13 sites and with other national programs. Some sites have full-time education coordinators while others have a part-time person (time commitment varies for part-time personnel). The NNIN education coordinators meet twice each year at various sites and an additional two times by teleconference.

Goals and objectives
The NNIN has established the following goals for its network-based educational outreach and training:

- Expose young people to advanced and exciting research in nanotechnology and motivate them to educate themselves for careers in the sciences or engineering;
- Train teachers and guidance counselors about the discipline of experimental sciences, provide additional teaching tools, and enhance their enthusiasm for having students pursue careers in science;
- Create and distribute educational materials for children, college students, technical professionals, teachers and the general population, as well as improve the understanding of and involvement with science, technology, engineering and mathematics;
- Focus these efforts on population segments having disproportionately low employment and education in sciences, including women, disadvantaged minorities, and the economically disadvantaged.

Target audience (educational levels, number of students at each level, etc.)
The target audience for NNIN activities is K-gray which includes elementary school students through adults (graduate students, faculty, adult professionals, and the general public)

Current activities
NNIN has developed and anticipates continuing development of instructional materials for K-12 schools and teachers. In addition there will be course development for undergraduate and graduate students and adult professionals. We are also developing materials (print and media) to encourage high school students to consider careers in STEM and in particular nano. These efforts also have a focus on reaching under-represented populations. Our web site will also contain information on activities that can be done during school visits to nanotechnology research sites as well as demonstrations suitable for visits to schools.

Nano S&E content focus The NNIN also focuses on social and ethical issues of nanotechnology. The SEI portal has numerous resources available http://sei.nnin.org. Each site has an SEI coordinator with lead SEI sites being Cornell, Univ. of Washington, Univ. of New Mexico, Stanford, and Georgia Tech. The SEI programs are coordinated by the Cornell University site. Below is a summary of current SEI activities:

- SEI portal developed at NNIN web site
- REU participant developed training video in SEI; all REU students participated in REU activities at their sites and at the convocation
- An analysis of public awareness and perceptions of nanotechnology, particularly as it relates to public health
- Georgia Tech is examining how nanotechnology enters commercial markets
- Development of a nano-ethics course at Univ. of New Mexico
- Survey of nano-researchers on ethical issues
- Univ. of Washington is examining how nano-researchers communicate their work and what ethical issues they face.
- Cornell Univ. is examining the laboratory life as it pertains to research and development of nanotechnology
- Co-sponsoring of workshops and symposia
    - AAAS February 2006 session on SEI issues

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences

Examples of some of NNIN efforts:

- The NNIN education portal has information on several topics suitable for K-12 students including our science magazine *Nanooze*. Additional materials for the web site are under development
- We have instructional materials developed and under development that will soon be posted on the web site. For example, Penn State has developed a NanoProducts lesson that can be used with visiting school groups, by teachers, and community organizations. They are also beta testing high school chemistry units that have a nanotechnology theme. Additional units are being developed in physics and biology.
- Lessons developed by RET teachers are under revision and will be posted on the site once edited.
- Georgia Tech has developed a tour/demonstration program for school groups and is modifying it so that other sites can use the model. This will be posted on the web site.
- The on-line Open Textbook in Nanotechnology will be available to anyone through our web site. It is due for completion within the next year.
- Promotional materials targeting high school students and undergraduates are under development and will be distributed to schools, at conferences, and be posted on the web site.

Describe a recent successful education outreach activity
The NNIN 2005 REU program hosted 81 students at 12 sites. These students performed hands-on research in nanotechnology using our state-of-the-art facilities. Our program received 500 applications from across the nation. Survey results of our participants indicate that 31% applied only to our program and another 15% to only one other REU program. Because of the diversity of our sites (in terms of research focus and equipment) we offer students a wide variety of research projects that allow them to see the breadth of nanotechnology and to gain an understanding of the interdisciplinary nature of nanotechnology. The NNIN REU program culminates with a convocation where students present their results in both oral and poster format. Students learn about research conducted by their peers at other sites and have a time to network with their peers. Our survey results indicate a high level of satisfaction with the program and that the convocation is an important professional experience for the participants. Student presentations can be viewed at http://www.nnin.org/nnin_reu.html.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan
Individual activities have their own survey instruments to determine success of a program. For example, Georgia Tech's NanoCamp surveys their participants at the end of the camp to determine satisfaction/non-satisfaction with the numerous activities during the week long program. Other sites do similar survey. In addition, through our communication network, sites share survey instruments which than can be adapted for each sites programs.

The NNIN is also developing a data management system for collecting evaluation data on our numerous programs. Our system will collect information on the outreach activities occurring at all levels and will include typical information on type of activity, number of participants, demographics of participants, and survey results.

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort.
If you are a multi-site program, it is imperative that you get to know your counterparts at the different sites. It will make communication go a lot easier.

If you are a multi-site program, it is imperative that you establish a communication system for regular communication among and between sites.

Teachers are interested in nano but don't know where it fits into the curriculum. They are also interested in all level of nano instructional materials from short little introductions/"fillers" to full scale lesson tied to the standards.

Appendix 3: Harvard University/Nanoscale Science and Engineering Center Profile

I. Description

Institution: Harvard University
PI: Robert M. Westervelt
Co-PIs: Bertrand I. Halperin
Title: Nanoscale Systems and their Device Applications
Proposal: 0117795
Program Officers: Denise Caldwell, Ulrich Strom
Education Outreach Director: Kathryn Hollar, ofhollar@deas.harvard.edu

II. Research Agenda

Research Focus: The Center has overlapping interdisciplinary research areas in

Cluster I: Tools for Integrated Nanobiology
Aims to build bridges between the physical and biological sciences. The physical sciences offer powerful new tools for manipulating and testing biological cells and tissues. In turn, biology offers an enormous range of engaging problems in functional biological systems, and the opportunity to think about "hybrid" systems that combine biological and non-biological components.

Cluster II: Nanoscale Building Blocks
Addresses the synthesis of new classes of nanostructures that exhibit size-dependent properties, with an emphasis on structures with unconventional shapes, as well as on zero-, one- and two-dimensional nanostructures based on metal chalcogenides, and the incorporation of nanostructures into novel devices.

Cluster III: Imaging Electrons
Imaging Electrons at the Nanoscale explores new ways to image the quantum behavior of electrons inside nanostructures using custom-made scanning probe microscopes (SPMs). Semiconductor heterostructures with novel properties are grown using Molecular Beam Epitaxy (MBE).

The Nanoscale Science and Engineering Center (NSEC) is a research collaboration with Harvard University, the Massachusetts Institute of Technology, the University of California-Santa Barbara, and the Museum of Science-Boston with participation by Delft University of Technology (Netherlands), the University of Basel (Switzerland), the University of Tokyo (Japan), and the Brookhaven National Laboratory, the Oak Ridge National Laboratory, and the Sandia National Laboratory.

III. Education Activities within the University

Research Experience for Undergraduates (REU)

- **Description:** NSEC-supported REU students work closely with faculty, graduate students, staff, and postdoctoral researchers on individual research projects for 10 weeks.
- **Staff/Expertise:** The REU Program is coordinated by Dr. Kathryn Hollar, Director of Educational

Programs for the Division of Engineering and Applied Sciences. She holds a PhD in Chemical Engineering, and has taught chemical and general engineering courses, as well as preparatory programs for graduate teaching assistants.

- **Goals and Objectives:**
  - ◊ To encourage a diverse group of future scientists and engineers to pursue careers in nanoscale science & engineering
  - ◊ To increase awareness of research areas available for graduate studies
  - ◊ To give graduate students and postdoctoral researchers preparation and experience in project management
- **Target Audience:**
  - ◊ In 2005, a total of 49 students were funded through our joint programs, which span various science and engineering disciplines. Of these students, 17 students were mentored by 11 NSEC-supported faculty, and additional 4 interns were funded by NNIN.
  - ◊ Students were recruited from a variety of institutions, and ranged from rising sophomores to rising seniors. 27% of the students were from underrepresented groups in science and engineering, and over 50% were female.
- **Current Activities**: The REU interns also participate in a structured program of professional development seminars and workshops, from presentation skills to faculty-led research talks as part of our larger joint REU program that funded 49 students in summer 2005.
- **Nano S&E Content Focus**: Students supported by NSEC funds participated in projects that were within NSEC cluster themes.

Applied Physics 298r: Interdisciplinary Chemistry, Physics, and Engineering

- **Description:** Graduate and advanced undergraduate students participate in AP298r, *Interdisciplinary Chemistry, Engineering and Physics*, an interdisciplinary graduate survey course of ongoing research at the Center.
- **Staff/Expertise:** The course is taught by Professor Robert M. Westervelt. Faculty from the NSEC gave 20 lectures during the spring semester.
- **Goals and Objectives:** To give graduate students and advanced undergraduates the opportunity to explore the research areas within the NSEC.
- **Target Audience:** Graduate students and advanced undergraduates Over 25 students enrolled in the course in Spring 2005.
- **Current Activities:** Students enrolled in the course prepare a presentation and paper on a selected topic, in addition to attending all seminars.
- **Nano S&E Content Focus:** Course requirements include a paper and oral presentation on one of the topics. Course handouts and faculty presentations can be downloaded at www.nsec.harvard.edu/AP298.htm.

Research Exchange Seminar

- **Description:** This postdoctoral and graduate student researcher-led seminar was held biweekly on Tuesday at lunchtime during the academic year (2004-05).
- **Goals and Objectives:** To encourage NSEC postdoctoral fellows and graduate students to learn about each other's research. The Exchange seminar blossomed into a venue where graduate students could get the advice of the postdoctoral fellows on preparation for oral presentation and then give their talk at the Exchange.
- **Target Audience:** Graduate students and postdoctoral researchers
- **Current Activities:** Speakers and topics have been suggested for next fall and many of the presentations during the past year have been presented in shortened form at professional society meetings.
- **Nano S&E Content Focus:** Presentations are based on NSEC-funded research.

Postdoctoral Fellowship Program for Members of Underrepresented Groups

- **Description:** We have established Center fellowships to encourage the participation of women and members of underrepresented groups in science and engineering.
- **Goals and Objectives:** To provide support and professional development for members of underrepresented groups in science and engineering so that they may become leaders in their fields.
- **Target Audience:** Members from underrepresented groups in science and engineering. Thus far, 5 Fellows have been funded.
- **Current Activities:** These Fellows are integrated into the research and educational community of the NSEC, and connections with faculty and institutes across the university are facilitated through this program. Access to research facilities and educational and professional development opportunities helps develop a strong pool of well-prepared researchers for faculty positions and the scientific community.
- **Nano S&E Content focus:** Fellows participate in many NSEC educational and outreach activities.

IV. Education Activities Outside the University

Activities at the Museum of Science, Boston

- **Description:** The participants and their colleagues develop innovative science communication strategies for enhancing public understanding of research in nanoscale science and engineering, engaging a broad range of audiences at the Museum of Science and elsewhere.
- Program Staff & Expertise:
  - **Carol Lynn Alpert**, NSEC Director for Public Engagement and Director of Strategic Projects at the Museum of Science
  - **Daniel Davis,** Education Associate for Nanoscale Science & Engineering
  - **Adam Weiss** and **Greg Murray**, Education Associates for Current Science & Technology, Museum of Science, Boston

- **Goals and Objectives:** To enhance public understanding of nanoscale science and engineering, and to provide communications expertise and resources to scientists and engineers in nanoscale science & engineering.
- **Target Audience:** K-gray; public audiences
- **Current Activities**
  - ◊ Monthly Live New England Cable News Cablecasts have informed an audience of over 1.6 million viewers
  - ◊ Reaching a national audience via Cable TV
  - ◊ Live presentations on the Current Science & Technology (CS&T) stage at the Museum of Science, Boston; over 160 presentations have reached more than 5400 museum visitors
  - ◊ Guest Researcher Appearances on the CS&T Stage, featuring NSEC researchers, have engaged over 400 museum visitors
  - ◊ Nanotech Consumer Products Display
  - ◊ Communicating Science workshop with REU and RET participants impacted over 45 undergraduates and teachers.
  - ◊ Multimedia Research Updates for Touchscreens and Web
  - ◊ Nanotech Symposium for Teachers and Guidance Counselors scheduled for November 2005
  - ◊ For more information, see www.mos.org/nano and http://www.nsec.harvard.edu/pages/education_mos.htm.
- **Nano S&E Content Focus:** Broadly focused, highlighted by ongoing research in the NSEC based at Harvard University

Research Experience for Teachers

- Description: The NSEC, in collaboration with an REU/RET Site in Materials Research and Engineering, hosted 7 teachers in 2004 and 5 teachers in 2005. These teachers work side-by-side with faculty, postdoctoral researchers, graduate students, and REU participants on research or science curriculum projects at Harvard University. Program Staff and Expertise: The RET program is coordinated by Dr. Kathryn Hollar, Director of Educational Programs for the Division of Engineering and Applied Sciences.
- Goals and Objectives: Teachers commit to 6–8 weeks during the summer, and are invited for a second summer to refine educational modules that are developed as a result of their research experience. Goals of the program are to develop long-term relationships with these teachers and their home school systems and infuse the high school science curriculum with tested examples of nanotech applications that can be widely disseminated to impact many students and teachers.
- Target Audience: High school teachers in the Eastern Massachusetts, New Hampshire and Rhode Island area, with a focus on recruiting from urban school districts, including the Cambridge Public Schools.
- Current Activities: This program has resulted in educational modules and several initiatives and partnerships that extend beyond the summer experience, including planning for the Nanotech Symposium for teachers at the Museum of Science, Boston.

- Nano S&E Content Focus: Teachers have developed projects in soft lithography, laboratories in current and voltage, and developing high school ConcepTests in chemistry, physics, and biology.

Small Scale Science Seminar for Teachers in the Cambridge Public Schools

- Description: Faculty and postdoctoral researchers funded by the NSEC developed lectures on ongoing research for teachers in the Cambridge Public Schools as part of the teachers' professional development requirement.
- Goals and Objectives: To provide teachers with ideas for incorporating nano-focused research and concepts into their curriculum, and to encourage teachers to participate in the RET program.
- Program Staff and Expertise: The seminar series was coordinated by Dr. Kathryn Hollar, Director of Educational Programs for the Division of Engineering & Applied Sciences, in collaboration with Dr. Melanie Barron, Science Curriculum Coordinator for Cambridge Public Schools, and Maureen Havern, teacher liaison for the NSF GK12 collaboration between Harvard and Cambridge Public Schools.
- Current Activities: Faculty and researchers in the NSEC will continue to deliver presentations for teachers in the 2005-2006 school year that are focused on the tools for integrated nanobiology. These presentations will also be available for students enrolled in the new course, *Research Internships,* at Cambridge Rindge and Latin School.
- Nano S&E Content Focus: Faculty, postdoctoral researchers, RETs, and graduate students presented topics in nano- and small-scale research, including nanowires, microfluidics, and soft lithography.
- Nano S&E Content Consultants: The program also featured presentations and discussions with Nanotech Education Associates Dr. Daniel Davis and Joel Rosenberg of the Museum of Science, Boston.

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences

- **Soft Lithography: Fabrication on the Micrometer and Nanometer Scale.** Developed by Colleen O'Shell (Chemistry, Cambridge Public Schools, MA), Christina Talbot (Physical Sciences, Memorial High School, Manchester, NH), Logan McCarty (Graduate Student advised by Prof. George Whitesides). The concept of fabricating micro- and nanostructures using soft lithography is tailored in a straightforward experiment for high school students using polymers, metal deposition, and chemical etching. This experiment applies the two most common methods of pattern transfer known as molding and printing. Students create a polymer stamp of a master pattern. Through a chemical deposition process a glass slide is coated with a silver film. The stamp is swabbed with hexadecanthiol and printed on the glass slide. The print creates a self-assembled monolayer, a molecule thick, that acts as a resist on the silver surface. The printed glass slide is then passed through an etching solution that removes the silver that has not been printed. The polymer stamp is also placed on another polymer substrate where a solvent can be applied. The solvent, through capillarity, draws the polymer into the crevices of the stamp. After evaporation of the solvent occurs the stamp is removed leaving the polymer substrate with a pattern that is the reverse of the stamp and a copy of the master. The adaptability of this process to recreating most small scale patterns allows students to envision the applications of this process beyond the laboratory into every day use. This experiment promotes comprehension of soft lithography, nanotechnology, polymerization, polymers, redox equations, covalent bonding, solubility and chemical and physical properties. This experiment was piloted at Harvard University during the summer of 2005 with high school students with varied chemistry knowledge.

- **Dissemination format:** This module will be available on the www.eduprograms.deas.harvard.edu website, and will be disseminated through the Nanotechnology Symposium for Teachers and Guidance Counselors at the Museum of Science, Boston in November 2005. Conference presentations are also planned.

Describe a recent successful education outreach activity
In July 13 and August 3, 2005, the joint REU programs and NSEC researchers hosted over 25 Junior Scholars from the Crimson Summer Academy, as part of their Career Explorations program. The Crimson Summer Academy is a Harvard-funded program that brings economically-disadvantaged students of high potential to Harvard in 3 consecutive summers in a rigorous college and career preparation program. During their visit to the Division of Engineering and Applied Sciences, Junior scholars had a lunch-time discussion with REU students from diverse institutions and backgrounds, graduate students, and postdoctoral researchers. Topics covered included selecting a college, why panel members chose science as a career, and financial aid options. Junior Scholars then participated in brief presentations and lab tours on nanobiology and femtosecond laser research. The day culminated in a lecture by an NSEC faculty member and a reception.

Benefits of this collaboration include increasing awareness of science and engineering career paths for underrepresented groups in S&E. The program also engaged visiting undergraduates (many of them from underrepresented groups), graduate students, postdoctoral researchers, and faculty in the broader educational programs of the NSEC in a format that emphasized the community present in the NSEC and in DEAS.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan
REU and RET programs involve on-line exit surveys of program participants, including undergraduates, teachers, graduate students, postdoctoral researchers, staff, and faculty. These surveys are adapted from existing models, including those developed by Dr. Fiona Goodchild (RET) and Dr. Mari Goldman (REU). Teachers who attend workshops are asked to fill out an evaluation at the end of each workshop.

Summarize outreach evaluation results
The REU and RET programs are rated highly successful by participants in the areas of the mentor relationship, professional development activities, social interaction, and diversity of participants. Mentor evaluations in 2004 indicated a need for more pre-program training, which we addressed in early 2005, and plan to strengthen in 2006.

Teachers rated workshops as high quality, but requested more hands-on modules and assistance in implementing concepts into the curriculum.

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort.

- Develop long-term relationships and collaborations with school systems and teachers, and follow up regularly.
- Listen to collaborators and respond to needs by providing the right resources and connections.

Describe what you might do differently in the future

- More front-end formal evaluation so that impacts can be assessed more accurately.
- More training of researchers in public engagement skills.

Appendix 4: Johns Hopkins University/Materials Research Science and Engineering Center Profile

I. Description

Institution: Johns Hopkins University
PI: Chia-Ling Chien
Co-PIs: Howard E. Katz, Robert L. Leheny, Nina Markovic, Daniel H. Reich, Peter C, Searson, Kathleen J. Stebe, Mark Stiles, Oleg Tchernyshyov, Gang Xiao, Jian-Gang Zhu
Title: Materials Research Science and Engineering Center
Proposal: 0520491
Program Officer: Maija Kukla
Education Outreach Director: Daniel H. Reich, reich@jhu.edu

II. Research Agenda

Research Focus: The Interdisciplinary Research Group of the JHU MRSEC focuses on the exploration of new materials and new fundamental phenomena in magnetic nanostructures with potentially novel magneto-electronic applications.

MRSEC Description
The JHU MRSEC is a single-IRG MRSEC, centered at Johns Hopkins, with additional co-PIs at Brown University, Carnegie Mellon University, and NIST.

III. Education Activities within the University

Description of activities

- ***REU***: we run a summer REU program for 6-8 students, who do research in MRSEC labs. Students are recruited from across the US.
- ***High School Student Summer Internships:*** Each summer, eight students from the greater Baltimore area spend four weeks working with MRSEC researchers. This program is designed to introduce highly motivated high school students to materials research by providing an in-depth research project in the MRSEC setting.
- ***High School Teacher Summer Internships:*** Physics and chemistry teachers from Baltimore-Washington area high schools participate in one-week internships each summer. The program provides teacher interns with the opportunity to enhance their scientific knowledge through hands-on workshops, to develop new demonstrations, experiments, and student projects, and to establish contacts for future access to the MRSEC's educational resources.
- ***RET:*** This two-summer-long program provides in-depth research experience that culminates in educational modules and demonstrations created by the teachers for their own use and for dissemination over the MRSEC website to other teachers across the country.
- ***Physics Fair:*** The MRSEC co-sponsors the JHU annual Physics Fair, whose goal is to generate excitement and fascination in the physical sciences for K-12 students. The program includes more than

100 demonstrations run by 50 undergraduate and graduate students, including many MRSEC graduate students. The program also includes physics challenge tests, a “Physics Bowl” contest, and a “Physics Show” given by a suitably charismatic physics professor.

- ***Materials Science Outreach Workshop:*** The MRSEC holds periodic outreach workshops on current themes in materials science and engineering. The events are designed to foster interest in science among middle school students and their families, and to promote careers in science. The program is a mix of lecture-style presentations, and hands-on workshops. The most recent, *Explorations in Nanoscale Science and Engineering*, attracted 299 middle school students and 292 parents from 12 states.

Program staff and expertise
All programs are conducted by MRSEC members. Logistical and recruitment support for some programs is provided by the JHU Center for Talented Youth.

Goals and objectives
(see above)

Target audience (educational levels, number of students at each level, etc.)
(see above)

Current activities
Anticipated outcomes and/or deliverables (see above)

Nano S&E content focus
Programs 1-4 above are built around the nanoscience research in MRSEC laboratories. Program 5 is not specifically nano. Program 6 had broader focus to include nano-bio research and other nanoscience programs at JHU as well as MRSEC research.

IV. Education Activities Outside the University

Description of activities
“Inventors of the Future” Mentoring Program: This new program, beginning this year, seeks to interest and motivate students in inner-city high schools to study science and mathematics by providing resources for independent study and research projects. The program, created in partnership by JHU, CMU, the National Inventors Hall of Fame, and the Washington Academy of Sciences, is funded by NSF’s Urban Systemic Program. Student participants will be drawn from inner-city high schools in Baltimore, Pittsburgh, and Washington, DC. MRSEC faculty and researchers will serve as mentors and consultants to both participating students and teachers.

Program staff and expertise

Goals and objectives

Target audience (grade levels, number of students at each level, school districts, etc.)

Current activities
Anticipated outcomes and/or deliverables (student awareness, teacher professional development, curriculum materials, classroom demonstrations, etc.)

Nano S&E content focus

Nano S & E content consultants

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences
As an example, RET participants have created web-based modules on x-ray diffraction, and molecular dynamics simulations for use in high school classrooms. These are available on the MRSEC website. Our high school teacher internship provides half-day or full-day workshops on areas including: characterization of crystal structures and nanostructures diffraction, e-beam and photolithography, scanning electron microscopy, and electrodeposition of nanomaterials. Versions of many of these activities suitable for classroom use have been developed, and instructions are made available to the participants.
Describe a recent successful education outreach activity

Our most recent Materials Science Outreach Workshop, *Explorations in Nanoscale Science and Engineering*, attracted 299 middle school students and 292 parents from 12 states. It featured two keynote lectures for all participants on "*What is nanoscience?*" and *"Nanomaterials for tissue engineering."* The students, in groups of 15, each participated in 3 50-minute hands-on workshops ranging from "Magnetic Nanowires in Liquid Crystals," to "Deposition of Nanoparticle-Based Phosphors." During the workshops, a separate lecture program was run for the parents on topics including "Magnetoelectronics" and "Micro and Nanofluidic Technology."

VI. Education Outreach Evaluation

Summarize outreach evaluation plan
We conduct exit interviews, follow-up interviews, and surveys of participants. We track the career paths of former high-school student interns.

Summarize outreach evaluation results
Feedback from participants has led to improvements in several programs, for example, the HS Teachers Internships, where we have adjusted the schedule and content to better suit their needs.

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort.
A key ingredient for success is close contact between participants and the MRSEC members. Wherever possible, try to emphasize one-on-one mentoring in a research environment.

Describe what you might do differently in the future
Arrange so that HS teachers can get Continuing Education credit for participation in MRSEC programs.

Appendix 5: Northeastern University/Center for High-rate Nanomanufacturing Profile

I. Description

Institutions: Northeastern University, University of Massachusetts Lowell, and University of New Hampshire
PI: Ahmed A. Busnaina
Co-PIs : Joey L. Mead, Carol M. F. Barry, Nicol McGruer, and Glen P. Miller
Title: Nanoscale Science and Engineering Center for High-rate Nanomanufacturing
Proposal: 0425826
Program Officer: Delcie Durham
Education Outreach Director: Carol Barry, Carol_Barry@uml.edu

II. Research Agenda

Research Focus: High-rate, high-volume, template-directed self-assembly of nanoelements, including nanotubes and polymers, along with concurrent assessment of environmental, economic, and societal impact of the developed technology.

NSEC Description: Nanomanufacturing

III. Primary Education Activities within the Universities

Description of activities

- **Undergraduate course modules.** CHN is currently adding content to existing courses, particularly in required freshman, sophomore, and junior courses, at the three institutions.
- **Courses for non-science and non-engineering majors.** Courses will be developed from an existing Nanoscale Undergraduate Education (NUE) project at UML
    - **Goal (1,2):** a) Expose undergraduates in the core institutions to nanotechnology and interest some of them in nanomanufacturing careers. b) Disseminate modules to other universities.
    - **Program staff (1,2):** No staff. With the exception of UNH teaching post-doctoral researcher, course materials are being developed by NEU, UML, and UNH faculty with small stipends to cover faculty time, supplies, etc.
    - **Target audience:** (1) Overall, 5000+ NEU, UML, and UNH science and engineering undergraduates. (2) More non-technical majors in any year of their education.
    - **Current activities:** (1) During 2005-2006, CHN will sponsor the development and implementation "nanomodules" for engineering materials, general and organic chemistry, ethics, and other courses. Funding for the 2006-2007 academic year will emphasize expansion of the portfolio of modules and dissemination of the tested modules. (2) Developed for face-to-face and on-line delivery, the current course, "Introduction to NanoEngineering," was offered for the first time in spring 2005 and will be offered again in spring 2006.

◊ nanomanufacturing and its societal implications.

♦ **Graduate courses.** CHN is developing and delivering cross-university seminar courses

◊ **Goal:** Prepare full and part-time[3] graduate students in the core institutions for nanomanufacturing careers.

◊ **Program staff:** Course materials are being developed by NEU, UML, and UNH faculty. Distance learning support from Universities, with some extra funds from CHN.

◊ **Target audience:** Currently, full and part-time graduate students plus seniors (as elective) at NEU, UML, and UNH. Eventually, distance delivery to others.

◊ **Current activities:** (1) During spring 2005, CHN delivered a, "Introduction to High-rate, Template-based Nanomanufacturing," with an attendance of 80 students. (2) A full hybrid course, "Nanomanufacturing I," will be delivered via web and video conferencing during fall 2005. (3) Additional jointly-developed graduate courses are planned for spring 2006 and beyond. (4) In addition, faculty member at participating institutions have developed courses for delivery at their home institutions. (5) The Institutional Advisory Board (engineering deans, etc.) are currently working on an articulation agreement for these single-institution courses.

◊ **Nano S&E content focus:** Nanomanufacturing processes and their societal implications.

♦ **Research experiences for undergraduates.** A 10-week long research program with a professional development component.

◊ **Goal:** Involve undergraduates in nanomanufacturing research and interest some of them in nanomanufacturing careers.

◊ **Program staff:** NEU and UNH added REUs to existing programs for some professional development. UML partially tied to NEU program.

◊ **Target audience:** Undergraduates at other institutions, particularly HBCUs.

◊ **Current activities:** (1) Sixteen undergraduates participated during summer 2005, but most were from CHN's core Universities. (2) During 2006, an additional nine undergraduates (funded from an REU supplement) will be added to the 16 students funded through CHN. (3) We also plan to expand the professional development component.

◊ **Nano S&E content focus:** CHN nanomanufacturing research plus professional development. Students participated in ethical reflection workshop for all researchers in June 2005.

♦ **Safety training for CHN researchers.** A half-day workshop on safety issues associated with nanomanufacturing.

◊ **Goal:** Make all CHN researchers aware of worker health and environmental issues associated with nanomanufacturing processes. This workshop is an addition to current safety training at each University.

◊ **Program staff:** Michael Ellenbecker, director of UML's Toxics Use Reduction Institute and CHN researcher.

◊ **Target audience:** All CHN researchers (faculty, post-docs and students).

◊ **Current activities**: Safety training began in spring 2005 and CHN will have three workshops during September, 2005.

[3] NEU and UML have large numbers of part-time graduate students.

- ◊ **Nano S&E content focus:** Good practices for safe nanomanufacturing.

- ♦ **Societal impact workshops for CHN researchers.** Workshops on the societal impact of nanomanufacturing.
  - ◊ **Goal:** Make all CHN researchers aware societal issues associated with nanomanufacturing processes and research in general.
  - ◊ **Program staff:** Various. Donna Qualters and Perrin Cohen, NEU, led the June 2005 workshop.
  - ◊ **Target audience:** All CHN researchers.
  - ◊ **Current activities**: (1) A half-day workshop on an ethical reflection model for assessing research issues was attended by 60 CHN undergraduate, graduate, and post-doctoral researchers in June 2005. (2) A workshop on regulatory issues is planned for fall 2005.
  - ◊ **Nano S&E content focus:** Societal impact of nanomanufacturing.

IV. Primary Education Activities Outside the Universities

Description of activities:

- ♦ **Research experiences for teachers.** A 6-week long research program with professional and curriculum development (NEU and UML only).
  - ◊ **Goal:** a) Allow teachers to participate in nanomanufacturing research. b) Have teachers develop modules to introduce nanotechnology to their students.
  - ◊ **Program staff:** Researchers from NEU and UML with professional development handled by CESAME program at NEU (under direction of Claire Duggan).
  - ◊ **Target audience:** High school and middle school teachers teaching math and/or science in Massachusetts schools.
  - ◊ **Current activities:** Four teachers participated during summer 2005.
  - ◊ **Nano S&E content focus:** CHN nanomanufacturing research plus professional and curriculum development.
  - ◊ **Nano S & E content consultants:** See staff.
- ♦ **Summer teacher institute.** A week long professional development plus curriculum development program (UNH only).
  - ◊ **Goal:** a) Expose teachers to nanomanufacturing research. b) Have teachers develop modules to introduce nanotechnology to their students.
  - ◊ **Program staff:** Researchers from UNH plus UNH's K-12 staff person, Susan Greenberg
  - ◊ **Target audience:** Teachers from New Hampshire schools.
  - ◊ **Current activities:** Successful initial workshop during summer 2005.
  - ◊ **Nano S&E content focus:** CHN nanomanufacturing research plus curriculum development.
  - ◊ **Nano S & E content consultants:** See staff.
- ♦ **Workshops for industry.** Workshops on technical and societal issues associated with nanomanufacturing.

- ◊ **Goal:** Provide industry practitioners with targeted information on nanomanufacturing.
- ◊ **Program staff:** Various. Michael Ellenbecker, UML, will lead October workshop.
- ◊ **Target audience:** Industry practitioners and other interested parties.
- ◊ **Current activities**: (1) Third New England International Nanomanufacturing Workshop provided two days of technical information on nanomanufacturing as well as a half-day session on the safety aspects of nanoparticles. (2) A half-day workshop on nanoparticle safety will be held in October, 2005.
- ◊ **Nano S&E content focus:** Good practices for safe nanomanufacturing.
- ◊ **Nano S & E content consultants:** None. NEU and UML have considerable experience with industry workshops.

- ♦ Nanomanufacturing at MOS. Exhibits, interactive presentations, etc. will be
  - ◊ **Goal:** (1) Expose general public to the differences between nanotechnology and nanomanufacturing. (2) Expose general public to benefits and issues associated with nanomanufacturing.
  - ◊ **Program staff:** Carol Lynn Alpert, Museum of Science (Boston) and two half time MOS staff
  - ◊ **Target audience:** General public.
  - ◊ **Current activities**: This program is just getting started[4].
  - ◊ **Nano S & E content consultants:** See staff.

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences
CHN is just starting with education outreach, and thus, curricula are under development by teachers who participated in this summer's RET and Summer Institute programs.

Describe a recent successful education outreach activity
RET and Summer Institute programs were very successful, with K-12 teachers enjoying their time at the Universities. For example, after successfully injection molding nanoscale features at UML, the three UML teacher-researchers attempted to use tooling made by two NEU teacher-researchers. Although this was initially unsuccessful, the teachers intend to try again so that parts with be available for the curriculum module developed by the NEU-based teachers.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan. (1) Eric Heller from U Mass Amherst's Donahue Institute is the lead evaluator for all but the MOS program. Evaluation of current course work and summer institute has been through questionnaires. REU students were evaluated through focus groups and a separate questionnaire. (2) Evaluation of the RET program at NEU and UML is tied to the overall CESAME RET program. (3) Carol Lynn Alpert is currently selecting an evaluator for the MOS program.

[4] MOS program was delayed because it is partially funded by the Commonwealth of Massachusetts.

Summarize outreach evaluation results. Results are currently available only for spring 2005 graduate course. This course met the goals of familiarizing CHN researchers with all aspects of the Center's research and developing in those researchers an awareness of the non-technical impacts of their decisions. The CHN researchers did not like the round robin traveling required to deliver the course alternately at NEU, UML, and UNH, but did like the interacting with colleagues from the other institutions.

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort. (1) Linking with existing programs was worthwhile because you accessed prior knowledge from the program coordinators. (2) Freshmen courses are difficult to penetrate because of the current content. (3) Coordinating courses between three Universities is a challenge.

Describe what you might do differently in the future. Need experienced K-12 coordinator at each institution. Susan Greenberg's connections in New Hampshire have been valuable, but we are currently seeking additional funds for such a coordinator at UML.

Appendix 6: Ohio State University/NSEC Profile

I. Description

Institution: Ohio State University
PI : Ly James Lee
Co-PIs: Jeffrey J. Chalmers, Albert T. Conlisk, M. Ferrari, Robert J. Lee
Title: NSEC for Affordable Nanoengineering of Polymer Biomedical Devices
Proposal: 0425626
Program Officer: Bruce Kramer
Education Outreach Director: Paula Stephenson, Ph.D., nsec.ohio-state.edu

II. Research Agenda

Research Focus: The primary goal of the center is to develop polymer based, low cost nanoengineering technology that can be used to produce nanofluidic devices and multifunctional poly-nanoparticle-biomolecule nanostructures for next generation medical diagnostics and therapeutic applications. The research plan is comprised of three thrust areas. In the *Nanomanufacturing Thrust Area*, we combine affordable and environmentally and biologically-benign 'top-down' fabrication and 'bottom-up' molecular self-assembly techniques to produce well-defined passive and active nanoparticles and nanostructures. In the *Transport Phenomena Thrust Area*, the research aim is to achieve design capabilities at the nanoscale, and multiphase transport structures. In the *Biocompatibility Thrust Area*, our current effort focuses on 3D tissue engineering designs for advanced cytotoxicity testing.

III. Education Activities for Undergraduates and Graduate Students

Long-range plans for education and human resource development for undergraduate and graduate students are integrating the latest research developments into a practical student curriculum leading to a nanobiotechnology minor for undergraduate students and a professional certificate for graduate students. The multidisciplinary program summarized in the following table will: (1) develop and offer at least 5 entirely new courses (of which 3 are core courses covering aspects of the Center's research theme); (2) modify at least 8 recently-introduced courses to better align with the center's research theme; (3) expand 3 IGERT courses to NSEC students; and (4) use existing relevant courses from the participating departments. In the current environment, courses at OSU tend to be offered by departments for their own students in relative isolation. The center's new focus provides the incentive and structure for developing an integrated curriculum across disciplines, beginning at the freshman level. At least two new NSEC courses will be phased in every year to maintain a reasonable faculty and administrative workload. Guest lecturers will be drawn from faculty of partner universities, industry, national laboratory partners, and international collaborators. In addition to technical courses that target upper division science and engineering students, we will develop the course *Size Matters: Nanotechnology in Human Life and Society* to bring the center's activities to a general undergraduate student population, as well as to the general public via videotape or CDs. A new *lab module on Design of Nanoscale Biodevices* will be developed and introduced through a design-and-build experience to nearly 1000 freshman engineering students at OSU each year.

Courses will be cross-listed in participating departments. The first two courses listed in the following table are new undergraduate courses/lab modules that target freshmen students to draw them into further studies and careers in nanobiotechnology. The next three courses emphasize fundamentals of nanofluidic device fabrication and will be required core courses in the minor and certificate. The following four courses are electives based upon particular research interests. The last three courses emphasize modeling and provide the foundation for the design and execution of advanced research. Our preliminary curriculum design calls for the minor and certificate to include the 3 core courses supplemented by 4 elective courses chosen from other new and established courses in participating units at OSU.

Related courses are available at OSU for designing a specialized program of study in topics of polymers (processing fundamentals/membranes, polymer science and engineering, rheology, particle technology, colloids and surfaces, conducting polymer devices); nanostructures (quantum chemistry, electronic spectra, structure of molecules, high precision machining, thermodynamics, fluid dynamics/mechanics, heat/mass transfer, tribology; quantum mechanics, and atomic molecular physics); and biomedicine (micro/nanodevices biological transport, biomaterials, biochemistry, drug delivery).

Nanobiotechnology Curriculum for Undergraduate (U) and Graduate (G) Students

Blue = New NSEC courses, Green = Modified courses, Black= IGERT/other courses for NSEC students

Existing and New Courses	Level	Participating NSEC Faculty
--Freshman Courses--		
SIZE MATTERS: Nanotechnology in Human Life and Society	U	*Koelling*, Tomasko, Agarwal
Fundamentals of Engineering: ***(add lab module on Design of Nanoscale Biodevices)***	U	*Tomasko*, Rathman, Hansford
--------------------------------------Introduction to Nanobiotechnology-----------------------------------		
Nanobiotechnology Seminar (core course)	U G	LJ Lee, Conlisk,Olesik,R Lee,Chalmers
Principles of Biomedical Devices (core course)	U G	*Hansford*, Agarwal, Desai (BU)
Nanofabrication (core course)	U G	*Lu*, LJ Lee, Hansford, Yi
--Specialization Courses--		

Molecular Nanotechnology	U G	*Rathman*, Frechet (UCB), new OES in Chem E
Measurement at the Nanoscale	U G	*Menq,* Koelling
Nanotechnology in Medical Diagnosis	U G	*Chalmers*, LJ Lee, Bashir (PUR)
Nanotechnology in Advanced Therapy	U G	*Kniss*, B Lee, Lannutti, Yang
---------------------------------Fundamentals at the Nanoscale for Graduate Students-------------------		
Interfacial Phenomena and Biological Functionalization	G	*Agarwal*, Cooper, Rathman,
Micro/Nano-Fluidics: Design and Modeling	G	*Conlisk*, Hansford, LJ Lee, Fan
Molecular Modeling and Simulation of Materials	G	*Singer*, Ghosh, Peters (FAMU/FSU), OES Mech Eng
----------------------IGERT Courses Extended to NSEC Fellows and Other Students ------------------		
Introduction: Molecular Engineering of Microdevices (MEMD)	U G	Lannutti*, LJ Lee*
Seminar: Future trends in MEMD, mgt. skills, globalization	U G	LJ Lee
MEMD course on Membrane Science and Technology	U G	*Ho*, Tomasko

Additional educational elements will enhance the center's education objectives:

- *SEC Fellow Advisory Teams.* A primary advisor, one or more co-advisors, and an external mentor will jointly advise each fellow in research in one of the thrust areas.
- *Undergraduate Mentoring and Outreach*. Under faculty oversight, NSEC Fellows will mentor/supervise undergraduate students in the freshman design course's new nanobiotech module, in REU research, and in senior honors research theses. Undergraduate students will also participate in supervised K-12 outreach.
- *Undergraduate Summer Research Internships*. Five non-OSU honors undergraduate students will be selected each summer to carry out fulltime research at OSU under center supervision, for a total of 25 students over the five-year period of the center. These students will be supported by related REU awards.
- *Fellow Teaching/Outreach.* To gain teaching and leadership experience, under faculty supervision center Fellows will serve one quarter assisting NSEC courses and working with undergraduate students on research.

- *Web and CD-based Courses.* Teaching modules will be developed for NSEC undergraduate instruction and promoted for use by academicians worldwide, based on the two freshman courses. The modules will integrate class Powerpoint presentations with edited transcripts following the model successfully implemented by OSU Welding Engineering and distributed to industry. Modules will also be distributed through relevant professional associations.
- *Additional Fellow Support*. To increase the number of graduate fellows supported by the Center, doctoral students will only be supported for 4 years using a phase-in plan, with the other 1-2 years funded from other sources. Partial cost-sharing for center masters-level students will also be requested.

Project Staff: NSEC Education Committee, Paula Stevenson, Education and Outreach Director, Professor David Tomasko, Professor Susan Olesik, Professor Terry Conlisk

Goals and Objectives: To provide a various levels of understanding of nanoscience and engineering to undergraduate and graduate students in addition to professional scientists.

Target Audience: Undergraduate and Graduate Students and Professional Scientists.

Current Activities:
Curriculum Planning. In autumn quarter 2004, existing courses at OSU were inventoried and the requirements for establishing a new minor were reviewed. A draft structure for a minor in nanoscience and technology was prepared in winter quarter 2005 by the Education and Outreach Committee, incorporating new, revised, and existing courses. The Committee is currently planning an additional, new anchor course to help undergraduate students bridge the gap between traditional departmental courses and other courses in the NSEC curriculum. A syllabus is under development for the junior-level course "Fundamentals of Molecular Nanotechnology," currently envisioned to include four modules taught from the perspectives of Chemical Engineering, Chemistry, Electrical Engineering, and Physics. A proposal will be prepared and submitted this summer to curriculum committees in the College of Engineering and the College of Math and Physical Sciences. Following submission of the minor proposal, a similar proposal will be prepared to establish a Graduate Certificate or Graduate Specialization in nanobiotechnology.

Course Development. Four related new courses and one revised/expanded course have been offered to date, exceeding our proposed plans as outlined above.

The new nanobiotechnology core seminar course (LJ Lee/ChBE) was offered in Winter Quarter 2005. Topics included molecular self-assembly, nanotechnology, biotechnology, sensor technology, and bio/nanoethics. A majority of the speakers were NSEC thrust area leaders discussing the Center's long-range research goals, and faculty from the participating universities (PUR, BU, UCB, JHU, and UA). Thirty students from 8 departments (4 colleges) formally enrolled in the course, and an additional 10 or so students attended the course each week. NSEC, NIRT, and relevant IGERT students participated. Students formed research subgroups around topics of common interest and delivered presentations on the joint projects. The research subgroup meetings are expected to continue throughout the year to enhance communication and collaboration. Over 95% of the students gave the course an *overall rating* of "agree strongly" or "agree" (in summary) that the course was well-organized, intellectually stimulating, encouraged students to think for themselves, and other measures.

A second new course was developed and offered in winter quarter 05, Fundamentals of Biomedical Microscopic Imaging (Agarwal/BME). Offered to senior undergraduate students and graduate students, several NSEC students and some non-NSEC students enrolled. The course taught principles and described various microscopy techniques (light, electron and atomic force microscopy) for application to biomedical research. Students were required to carry out "virtual microscopy" sessions available via internet.

The third new course, also offered in Winter Quarter 2005, is Polymer-Based Electronic and Magnetic Materials (Epstein/Chem/Physics). Registration was open to graduate students in Physics, Chemistry, and Engineering; advanced undergraduate students could also register with the instructor's permission. Approximately 15 students from 5 departments took the course for credit. In addition, several postdocs from different departments sat in on the class. This introductory course discusses the basics of physics and chemistry of organic and polymer-based electronic and magnetic materials and devices. This includes the electronic structure of molecules, polymers and solids, and their relation to electrical conductivity and magnetism of conventional metals and materials.

The fourth new course, Molecular Simulation of Materials (Singer/CHEM), is being offered in spring quarter 2005 to advanced undergraduate students and graduate students. Over twenty students are enrolled in the course and additional students are auditing. The course provides an introduction to the use of molecular simulations to predict static and dynamic properties of interest to physical scientists and engineers. Because students are from a wide variety of backgrounds, little prior knowledge is required other than a working knowledge of multivariate calculus and what is taught in introductory undergraduate physics and chemistry classes.

The freshman engineering design-and-build course (Tomasko/ChBE) is being revised and expanded. The Center is supporting the development of special "nanotechnology" laboratory sections of Engineering 183 and H193. These courses include quarter long design-build projects based around lab-on-a-chip technology that students work on in teams. Engineering 183 is a continuation of a successful pilot from an NUE grant to Tomasko last year and the Center is providing logistical and equipment support to scale it up as a full-time complement to the regular projects in this course. In academic year 2004-05, we expect an enrollment of 210 students in the nano sections of 183. Engineering H193 is the honors version of the freshman engineering sequence and the Center is providing equipment, supplies, and logistical support to the development of an advanced lab-on-a-chip experiment to study cell adhesion on nanostructured surfaces. This course will be offered for the first time in Spring quarter 2005 with an enrollment of 30 students.

IV. Education Activities Outside the University

Description of Education and Outreach Activities
The major goals of the outreach program are to use the center's research output to train and increase the technical literacy of K-12 students and teachers, members of the industrial workforce, and the general public; and to develop international collaborations. Tomasko (faculty) and Stevenson (Education Director) will coordinate an integrated, broad collaboration among university faculty and constituency groups as part of a Nanotechnology Literacy Initiative. Long-range plans and progress to date are reported below. All center faculty, graduate Fellows, and staff will participate in aspects of the education and/or outreach programs.

Outreach for grades K-12 focuses on the development and delivery of nanotechnology content and age-appropriate materials that promote hands-on learning. Our current primary strategy is to build on existing, successful programs in the OSU Colleges of Engineering and Math and Physical Sciences. A series of new 1-3 hour hands-on training modules will be developed and offered as part of the College of Engineering's on-campus outreach and recruiting activities, starting in summer 2005. These activities include the *Women in Engineering Summer Workshop*; the *High School Co-op Program*; the *Summer Experience*; and the Minority Engineering Program's *Camp Engineer.*

A. Outreach to High School Students

Description of Activities
Engineers in Motion, Women in Engineering Summer Workshop (Offered Twice Summer 2005)

Program Staff and Expertise
These programs are managed through the Women in Engineering office in the College of Engineering at Ohio State University. NSEC faculty prepared and delivered a 3-hour module for each of these programs.

Goals and Objectives
Learn about engineering fundamentals and disciplines. Explore engineering through hands-on activities, lab tours, and industry visits.

Target audience (educational levels, number of students at each level, etc.)
Engineers in Motion – Students finishing 9^{th} or 10^{th} grade, 35 students
Women in Engineering Summer Workshop – Female students finishing 12^{th} grade and planning to enter College of Engineering, 35 students at each of 2 sessions.

Current Activities
The students participate in about 6-7 activities from different disciplines throughout the week. Activities include making LED bracelets (Electrical Eng), touring Honda of America in Marysville, DNA Extraction (Chemical & Biomolecular Eng.) among many others. NSEC faculty hosted one activity in which the students were divided into small groups (4-5 each) and accompanied to various NSEC laboratories where they worked on a hands-on activity and reported their work back to the larger group via a short presentation.

Nano S&E Content Focus
Activities included in the NSEC program were as follows:

- Femtosecond pulsed-laser fabrication (Prof. Farson, Welding Eng) – Micro and nanochannel fabrication in soft materials. Produced a CD with a channel tracing an image of an eagle.
- Liposome preparation and characterization (Prof. Lee, Pharmacy) – Prepared self-assembled liposomes in solution.
- Atomic Force Microscopy (Prof. Agarwal, Biomed. Eng) – Scanned surfaces and cells attached to those surfaces.
- Micromachining of Optic Components (Prof. Yi, Industrial Eng) – Explored high-precision machining for top-down fabrication approaches.
- Biomedical device micro- and nano-fabrication (Prof. Hansford, Biomed Eng) – Suited up and toured clean room to see photolithography and other nanofabrication methods.
- Ultrasonic micro- and nanoembossing (Prof. Benatar, Welding Eng.) – learned how to use sound waves to create and control nanofeatures in soft materials.
- Electrospinning of polymer nanofibers (Prof. Lannutti, Materials Science & Eng.) – prepared electrospun polymer fibers of a biodegradable polymer for use in tissue engineering applications.
- Thermal characterization and analysis (Prof. Ho, Chemical & Biom. Eng) – Students performed TGA analysis on biopolymers.
- Biochips (Prof. Yang, Chemical & Biom. Eng.) – Students worked with newly designed chips for high throughput ELISA.

B. Outreach and Education to Middle School Students.

Description
NSEC Faculty members visit local middle schools and later interact with the same students when they visit OSU.

Project Staff
All members of NSEC Education Committee and Other NSEC Faculty

Goals and Objectives
We expect to teach the students a basic understanding of nanoscience and technology and fabrication methods (microfabrication and nanofabrication). In addition, we want to interest minority middle-school students in science and technology through these efforts.

Current Activities
In March 2005, members of the NSEC Education and Outreach Committee met with the staff of the Columbus Public Science Office to begin planning presentations and events for academic year 2005-2006.

We have designed a nanoscience and technology unit for middle-school students that involves a visit to the school from an NSEC faculty member followed by a visit by the middle school student to OSU to do experiments and tour the NSEC labs.

In April 2005 Olesik made a presentation to the 8th grade science classes (60 students) of The Wellington School in Upper Arlington on Nanoscience and Technology. This presentation including a discussion of what the term nano means and how nature has used nanoscience for some time and now scientists and technologist are learning how to better understand and engineering nanomaterials. The students were also given a general description of what they would be doing during their visit to OSU.

In May 2005, the middle school students did laboratory experiments on micro-fabrication techniques and also visited numerous NSEC laboratories, including the operating fabrication lab.

A. Outreach to Middle-School and High School Teachers

Description of Activities
Professional Development Workshops for Middle School and High School Teachers

Program Staff and Expertise
NSEC Education Committee and Selected-NSEC Faculty

Goals and Objectives
Teach about grades 6-12 science teachers basic concepts of nanoscience and technology

Target audience (educational levels, number of students at each level, etc.)
Grades 6-12 science teachers

Current Activities
As a prelude to this, we showed Grades 3-5 teachers basic concepts on nanotechnology during the OSU Science Fellows Supporting Teachers Workshop, SFST (OSU's GK-12 program), which was held on June 21-

23, 2005. These teachers also visited the NSEC labs. We plan to offer professional development workshops Nanoscience and Technology during the winter and spring Professional Workshop Days for the Columbus Public School teachers.

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences

These were described above and will be illustrated at the conference.

Evaluation
We are in the midst of getting external evaluation of the Outreach Program configured.

Appendix 7: Pennsylvania State University/ Center for Molecular Nanofabrication and Devices Profile

I. Description

Institution: Penn State University
PI: Thomas Mallouk
Title: Center for Molecular Nanofabrication and Devices
Proposal: 0213623
Program Officer: Ulrich Strom
Education Outreach Coordinators: Ronald D. Redwing, rdr10@psu.edu and Joanna M. Skluzacek, jms1020@psu.edu

II. Research Agenda

The *Penn State MRSEC* supports collaborative, interdisciplinary research efforts in the area of nanoscale materials. The research themes of the Center are focused broadly on molecular nanofabrication, complex inorganic materials, and low-dimensional electronic nanostructures. These research themes are integrated with major efforts in educational and industrial outreach. The activities of the Center involve over fifty students and postdoctoral fellows, an approximately equal number of faculty from eight academic departments at the Penn State University Park Campus and Hershey Medical Center, and a number of external academic and industrial partners.

III. Education Activities within the University

Annually our faculty, staff and students offer educational outreach programs reaching approximately 3,500 K-12 students, 30 K-12 teachers, and 35 undergraduates. These programs provide opportunities for students, teachers and anyone with an interest in science to learn about how nanoscience touches our lives and how cutting edge research could change our world in the future. Virtually every graduate student, post doctoral fellow and faculty member of our MRSEC participates in one or more of our education and outreach programs. These programs are designed to communicate the excitement and wonder of science and technology with both general and specialized audiences.

Our summer programs for children are designed to increase interest in science and build self-esteem in students with special attention in including girls and under-represented minority children. During our annual teacher workshop, Center members work with teachers to develop ideas and resources to be used in the teachers' classrooms. Through a joint MRSEC/Physics Department Research Experience for Undergraduates (REU)/ Research Experience for Teachers (RET) site, we offer research projects that give undergraduate students the opportunity to participate in frontier materials research, as well as assisting teachers to bring cutting-edge materials research topics into their classrooms.

IV. Education Activities outside the University

Ideas about nanoscience are disseminated to large general public audiences (over 100,000 museum visitors annually) through our partnership with The Franklin Science Museum of Philadelphia, PA. This partnership has produced our *Materials Matter: It's A Nanoworld After (distributed in 2003)* and *All Nano-Bio: Zoom in on Life! (distributed in 2005)* cart-based museum shows. Each of these shows has been distributed to over twenty science and children museums nationwide. A development team consisting of Penn State faculty, graduate students, and undergraduates worked with museum staff to develop the shows. Development of a third cart based museum show began in November 2004 for distribution in 2007.

Materials Matter includes demonstrations and macro-scale models that explore the "micro" mechanisms behind the unusual and surprising "macro" behavior of materials such as aerogels, shape-memory alloys, polymers, electronic ink, and zeolites. Each demonstration is coupled with a macro-scale model to explain the mechanisms and the principles responsible for the novel behavior. In addition to funding the show development, we also provided demonstrational materials and supplies to equip a show for one to one and a half years at each museum.

Our second cart based museum show highlights processes in the body that occur at the nanoscale as the inspiration for nanotechnology research being done in our laboratories. *Zoom* consists of six hands on demonstrations that teach the principles of nanotechnology through processes occurring within our own bodies. Demonstrations topics include, scale, DNA self assembly, membranes, biological motors, viruses and antibodies, and vision as molecular switches. Included with each copy of the show is a multimedia presentation that includes photographs at the nanoscale and computer animations of each process that is demonstrated for visitors.

In addition to the national distribution of the museum show, two copies of the shows reside at Penn State. These copies are used by Center faculty and graduate students to present the shows locally. We have presented the shows locally over 100 times for classroom visits, visiting school groups, summer camps and workshops.

V. Education Outreach Materials

Description of a recent successful education outreach activity:
In addition to the programs listed above, our MRSEC has teamed with the *Action Potential Science Experience*, an outreach program of the Penn State Eberly College of Science that uses theme based summer programs to teach science topics through novel hands on activities. We have developed a nanoscience and materials wizard themed summer camp for 4^{th}-8^{th} grade students. (This is the third camp in a series of camps based on J.K. Rowling's Harry Potter books.) Our faculty wrote the curriculum for the week long adventure titled *The Adventure of the Apprentice's Stone*. The innovative curriculum combines art, history, science into a weeklong adventure that transports students to the Penn State School of Wizardry. Campers learn about materials and nanoscience while trying to unlock the mysteries of the Apprentice's Stone. Each day of the five day program the activities help to reveal a magical message of the day. When combined at the end of the week, the daily messages unlock the secret of the Apprentice's Stone. Activity topics include ferrofluids, nitinol, zeolites, lithography, and spectroscopy. The camp has been licensed and, along with the other two Potter camps, was presented in the NY Finger Lakes region in the summer of 2005.

VI. Education Outreach Evaluation

Our outreach evaluation to date has been largely short term in nature, post experience surveys at the end of the program, except for our REU and RET programs, which have used pre-surveys, post-surveys and later surveys to track some limited outcomes. Improving the evaluation of our programs is currently a major focus of our education outreach efforts.

VII. Lessons Learned

Don't reinvent the wheel: we like to say that we combine our research expertise with the education expertise of existing programs.

Concept of scale is a starting point for all of our education outreach programs.

Appendix 8: Princeton University/Center for Complex Materials Profile

I. Description

Institution: Princeton University
PI: Richard Register
Co-PIs: none
Title: Princeton Center for Complex Materials
Proposal: 0213706
Program Officer: Thomas Rieker
Education Outreach Director: Daniel Steinberg

II. Education Activities within the University

Science and Engineering Expo

Description of activities
More than 1000 middle school students come to Princeton University to experience science and engineering with faculty members and students who perform cutting edge research. PCCM entirely organizes the engineering venue, which had nearly 40 tables of hands-on demonstrations and activities as well as an auditorium show representing about 50% of the entire Expo. The Science and Engineering Expo (SEE Princeton) has been a tremendous success in reaching 1000's of middle school students at an age where studies show they tend to loose interest in science. This event allows PCCM faculty members and graduate students to showcase their science research in a format in which middle school students can interact with the scientists and explore for themselves the world of engineering and materials research.

Program staff and expertise
Director – Pedagogy expert, scientist, recruiter and coach for demonstrators
Assistant – Handles administrative tasks and logistical issues

Goals and objectives
To inspire students at a critical point in their educational careers to appreciate science and possibly pursue careers in a scientific field

Target audience (educational levels, number of students at each level, etc.)
1000 NJ middle school (grades 6-8) students/year

Princeton University Materials Academy

Description of activities
Princeton University Materials Academy (P.U.M.A.) is a summer program for high school students that specifically targets students from underserved communities and young women. Students spend one to two weeks learning about materials science innovations from leading scientists in an intensive course in 2 sessions each summer. P.U.M.A. is the only program on campus that is strictly science oriented. This intensive program targets truly underprivileged, disadvantaged high school students – the especially those who have a good chance of success with the right encouragement –to give them a full immersion in science.

Program staff and expertise
Director – Pedagogy expert, scientist, experience in Education Outreach
Assistant – Experience in Education Outreach
Lead teacher – High school teacher experienced in managing classroom

Goals and objectives
Supplement high school science courses; expose students to current scientific research and university professors' expertise; inspire students to pursue science in their college careers and beyond

Target audience (educational levels, number of students at each level, etc.)
High school students, especially underrepresented minorities from Trenton, Princeton, and Lawrenceville, NJ, 45 students/year

Current activities
Anticipated outcomes and/or deliverables (student awareness, curriculum materials, classroom demonstrations, etc.)

Nano S&E content focus

Materials Mini-Camp for Teachers

Description of activities
PCCM also has several Teacher Training/Education Programs in which k-12 teachers work directly with Princeton researchers to enhance the science content of their school-year courses. The *Materials Mini-Camp for Teachers* is a new initiative in our teacher training programs. In partnership with ASM International and Rutgers University, PCCM conducts a one-week course in materials science to help integrate the field with existing science and math curricula of New Jersey schools. With these programs, PCCM is teaching cutting edge science and directly involving faculty and teachers so that teachers understand what research and science at Princeton University is about. With this experience, they can relay knowledge and enthusiasm to their students.

Program staff and expertise
Director – Pedagogy expert, scientist, experience in Education Outreach
Assistant – Handles administrative tasks and logistical issues
Lead teachers – ASM trained in Materials Mini-Camp curriculum

Goals and objectives
To provide specific tools and activities for teachers to introduce and integrate materials science into their curricula as well as enthuse teachers about science

Target audience (grade levels, number of students at each level, school districts, etc.)
30 NJ, PA, and NY high school teachers/year

Research Experience for Undergraduates

Description of activities
More than 30 undergraduate students are given the opportunity to perform actual research in materials science and engineering that compliments the ongoing research projects of Princeton Center for Complex Materials scientists. With the experience in the labs, short courses and lectures, the students are able to explore topics in materials science and engineering in a hands-on way that better prepares them for careers in science and technology.

Program staff and expertise
Director – Pedagogy expert, scientist, experience in Education Outreach
Assistant – Handles administrative tasks and logistical issues

Goals and objectives
To provide college students from smaller schools or those without research facilities with the opportunity to perform research in sophisticated labs alongside acclaimed scientists

Target audience (grade levels, number of students at each level, school districts, etc.)
30 undergraduate students/year from all over the country

Research Experience for Teachers

Description of activities
Like the REU program, the Research Experience for Teachers program provides research experience in Princeton labs with Princeton scientists, but it has a more specific objective. The RET program is designed to allow three middle school and high school teachers to enrich their science curriculums at the schools where they teach. This experience does not only benefit the teachers. Their new enthusiasm and knowledge is passed to their students and fellow teachers. These teachers can use what they've learned to engage their students and provide insight on teaching and teamwork for other struggling teachers in all subject areas.

Program staff and expertise
Director – Pedagogy expert, scientist, experience in Education Outreach
Assistant – Handles administrative tasks and logistical issues

Goals and objectives
To provide high school teachers with the opportunity to perform research in sophisticated labs alongside acclaimed scientists. To provide real world science experience to teachers that can be applied in their curriculum.

Target audience (grade levels, number of students at each level, school districts, etc.)
2-3 NJ and PA high school/middle school teachers/year

IV. Education Activities Outside the University

Science Center Collaborations; Liberty Science Center

Description of activities

PCCM has worked with the Liberty Science Center in a collaboration to supplement the Strange Matter Exhibit. The Strange Matter Exhibit is a traveling exhibit to introduce the topic of Materials Science to children and families. Liberty Science Center was the exhibit's first stop in the United States, providing Princeton University with a rare opportunity to participate in an award-winning program that makes Materials Science fun and educational for children. The Liberty Science Center asked the help of PCCM faculty to give a good solid science base for the exhibit. Faculty and students of PCCM volunteered their time at the Liberty Science Center performing pre-arranged demonstrations related to materials science. This has resulted in a strong partnership between the Liberty Science Center and PCCM. More collaborations on materials science related activities are to come.

Program staff and expertise

Director – Pedagogy expert, scientist, experience in Education Outreach
Assistant – Handles administrative tasks and logistical issues

Goals and objectives

To engage students and their families in materials science, a field new to many of the general public.

Target audience (grade levels, number of students at each level, school districts, etc.)

Tens of thousands of people/year from the Tri-State area as well as tourists

Current activities

Anticipated outcomes and/or deliverables (student awareness, teacher professional development, curriculum materials, classroom demonstrations, etc.)

Nano S&E content focus

Nano S & E content consultants

Toll Gate Science Night and other school visits

Description of activities

Toll Gate Science Night is the largest of many school visit programs, which more than 100 parents and children attended. 3rd grade teacher Connie Cloonan, very active in elementary science education programs, collaborated with Princeton Center for Complex Materials (PCCM) Educational Outreach Director Dr. Daniel Steinberg to organize the program. The event is designed to introduce children to new concepts in science, engineering and materials science. Dr. Steinberg and Ms. Cloonan train teachers and parents to teach kids principles of science and to perform demonstrations of those principles. Toll Gate students of all grades learned about density, light refraction, acoustics, photosensitivity, and many other topics in science. Often professors such as Paul Chaikin or graduate students will visit schools to conduct hands-on demonstrations for students.

Program staff and expertise

Director – Pedagogy expert, scientist, experience in Education Outreach
Assistant – Handles administrative tasks and logistical issues

Goals and objectives
To engage students and their families in science and provide students with the opportunity to ask real scientists their questions.

Target audience (grade levels, number of students at each level, school districts, etc.)
Hundreds of students and parents/year in NJ

Current activities
Anticipated outcomes and/or deliverables (student awareness, teacher professional development, curriculum materials, classroom demonstrations, etc.)

Nano S&E content focus

Nano S & E content consultants

Appendix 9: Purdue University/Network for Computational Nanotechnology Profile

I. Description

Institutions: Purdue University, Northwestern University, Morgan State University, Stanford University, University of Florida, University of Illinois, and the University of Texas at El Paso
PI: Mark Lundstrom
Title: NetWork for Computational Nanotechnology
Proposal: 0228390
Program Officer: Lynn Preston
Education Outreach Co-Directors: Michael Melloch, melloch@ecn.purdue.edu and Umberto Ravaioli, ravaioli@uiuc.edu

II. Research Agenda

Research Focus: The NCN is comprised of research themes on nanoelectronics, NEMS/nanofluidics, and nanobioelectronics – and a cross-cutting computational theme. These research themes cover a broad subset of nanoscience while providing the focus and synergy that are essential to success. The key intellectual challenge for the NCN is to develop both the engineering science and software tools necessary to understand and design nanoscale devices at the atomistic level and to relate atomistic structure to macro-scale system performance. The nanobioelectronics theme serves as an intellectual testbed in which the new knowledge and software tools developed in the nanoelectronics and NEMS/nanofluidics themes are used to explore specific devices for applications in medicine and biology. The NCN requires that each research project produce outstanding science, and also i) develop public-domain software, ii) create unique educational resources, and iii) play a visible leadership role in its field. Through this process, a growing set of software tools, design approaches, and educational resources are being made available to the nanotechnology community. To deliver these resources and services to the broader community, the NCN is developing and deploying a unique cyberinfrastructure, the nanoHUB. The NCN intends to serve as a model for other communities and actively seeks partnerships to expand the scope of its activities beyond its three science themes.

NCN Description: The Network for Computational Nanotechnology (NCN) is a multi-university initiative that was launched in September 2002 to create a unique, web-based infrastructure to serve researchers, educators, and students. NCN research, education, and outreach programs drive the development of its infrastructure. The NCN web site, www.nanohub.org, is a "science gateway" that hosts collaborative tools and delivers unique educational resources such as online courses, learning modules, lectures, and seminars. Its signature service is online simulation, visualization, and high-performance computing. We intend for the NCN to be an example of the role that theory and simulation can play in emerging fields of research, of how effective simulation can be in education, and of how innovative cyberinfrastructure can serve a community of researchers, educators, and students. In the process of this work, we will create a new generation of software tools and a web-based infrastructure of services that will become an essential component of the research and education enterprise.

III. Education Activities within the University

Description of activities
NCN is collaborating with the National Center for Learning and Teaching in Nanoscale Science and Engineering to support the development of teaching modules for grades 7-16. In particular, NCN is providing expertise, development and resources for interactive and simulation based material that can be integrated in the NCLT modules.

Program staff and expertise
Umberto Ravaioli (NCN investigator at Illinois) is member of the NCLT leadership team and heads the educational software development group, including Prof. Richard Braatz (Chemical and Environmental Engineering, Illinois) with several graduate students, undergraduate students, and researchers. U. Ravaioli has co-directed the educational effort of NCN, including the organization of two Summer Schools on nanotechnology themes in 2004 and 2005.

Goals and objectives
The NCLT has a varied set of objectives in the establishment of a methodology to introduce and evaluate educational material in nanotechnology in grades 7-16, to promote teachers' professional development and to develop educational curricula for future educators in nanotechnology. The goal of NCN is to interact with the NCLT to provide content and interactive software to pursue all of these educational tasks.

Target audience (educational levels, number of students at each level, etc.)
The primary audience for current development is now at the high school level, but activities will be broadened at a second stage to cover middle school as well as college level students. Teachers professional development is also a priority for NCLT which can be facilitate by NCN contributions.

Current activities
Development of advanced Java Applets, FLASH animations, graphical user interfaces for simulations, educational videogame framework.

Nano S&E content focus
Present focus is on the basic issues of scale and geometry which are fundamental in the understanding of any nanoscale phenomena. Simulations developed at NCN will be very valuable to provide compelling and practical application to illustrate important science and engineering concepts at all levels. The development of the Rappture framework at NCN has in particular the potential to make advanced research simulation tools accessible to a wide audience, by making available efficient interactive graphical interfaces.

IV. Education Activities Outside the University

Description of Activities
The Network for Computational Nanotechnology (NCN) has adopted a new pedagogically sound content-aggregation strategy for the nanoHUB that uses learning modules as the delivery mechanism. Learning modules offer an ideal methodology to bundle voiced lectures, PowerPoint presentations, scientific papers, and most importantly online simulation tools into a single coherent standard-compliant package. The learning modules developed by NCN adopt the Shareable Content Object Reference Model Version 1.2. This ensures that nanoHUB content can interoperate with other compliant course management systems such as Sakai and WebCT Vista. The learning module development process leverages the discovery work on-going within the NCN in an effective manner. Each learning module contains presentations, exercises,

and examples, designed by NCN scientists working on that particular area. For example, the Introduction Molecular Conduction learning module begins with a talk by Dr. Supriyo Datta – a well-known expert in this area. The most important characteristic of a learning module is the ability to provide students access to serious simulation tools within the context of their learning. The Introduction to Molecular Conduction learning module requires students to actively use the MolCToy simulation tool to complete exercises and assignments. One other area of learning that the learning module addresses is assessment. By definition, a learning module should provide students with *measurable* learning objectives. The learning modules include a quiz that includes appropriate feedback. The next challenge that NCN is tackling is to provide reliable score tracking and reporting services. Also, we want to facilitate the measurement of learning impact as part of each learning module. To this end, we are now experimenting with the integration of course management systems (in our case we are focusing on an open-source system called Sakai) with the nanoHUB. To provide better dissemination of the nanoHUB content, we are in the final phases of announcing a partnership with MERLOT (http://www.merlot.org) - an online repository for educational content.

Program Staff and Expertise
Drs. Krishna Madhavan and Mike McLennan lead the development of learning modules on the nanoHUB under the supervision of the NCN Technical Director Dr. Gerhard Klimeck and Director Dr. Mark Lundstrom. The development of all content aspects requires input from NCN PIs engaged in research. To this end, the nanoHUB maintains continuous communication with content area experts.

Goals and Objectives
The primary goal of the learning module development effort is to act as the direct conduit of research content to educators and learners. Furthermore, we want learners to interact with NCN research content at their own pace. Learning modules are ideal for self-paced learning. The allow students to focus on the use of simulation tools within the broader context of the topical area they are trying to learn.

Target Audience
Primarily undergraduate, graduate, and expert users. But, learning modules can also be designed to target K-12 levels.

V. Education Outreach Materials

Description of Activities
We have developed a museum exhibit entitled, *Nanotechnology: The Science of Making Things smaller*. The exhibit was designed and built by a team of undergraduate students and faculty. The exhibit has several components. There are posters at the start of the exhibit to emphasize how nanostructures are built from the ground up, and the idea is illustrated by the use of the popular LEGO bricks. Maintaining this LEGO theme, there is a scanning probe microscope (SPM) made out of LEGOs that is used to scan LEGO landscapes. This LEGO SPM duplicates in many ways the operation of a real scanning probe microscope. There are hands on workbenches with activities that illustrate some of the basic principles underlying nanotechnology. There are two kiosks that run cartoon animations on various aspects of nanotechnology. These animations can be viewed at www.nanohub.org. There is a kiosk that displays rotating renditions of nanostructures such as carbon nanotubes, bucky balls, and DNA. There is a wall of nano-art that consists of 18 framed scanning probe micrographs of actual carbon nanotubes, quantum corrals, atomic surfaces, etc. There are models of nanostructures such as carbon nanotubes, bucky balls, and DNA that hang above the exhibit. Finally there are take home brochures and bookmarks that provide more information to guide the students' study of Nanotechnology on the web.

The exhibit premiered at the Children's Museum of Oak Ridge, TN, where it was on view from April 2, 2005 through May 31, 2005. The next stop for the exhibit is the National Inventors' Hall of Fame in Akron, Ohio, where it will be displayed from November 1, 2005 through August 31, 2006.

Goals and Objectives
The primary goal of the museum exhibit is to introduce middle school children to the fascinating and rapidly changing field of Nanotechnology.

Target Audience
Primarily middle-school children, but all ages should find the exhibit entertaining and educational.

Appendix 10: Rensselaer Polytechnic Institute/Center for Directed Assembly of Nanostructures Profile

I. Description

Institution: Rensselaer Polytechnic Institute
PI: Professor Richard W. Siegel
Co-PIs: none
Title: Nanoscale Science and Engineering Center (NSEC) for Directed Assembly of Nanostructures
Proposal: 0117792
Program Officer: David L. Nelson
Education Outreach Director: Dr. Linda S. Schadler, schadl@rpi.edu

II. Research Agenda

Research Focus: Our NSEC is addressing the fundamental scientific issues underlying the design and synthesis of nanostructured materials, surfaces, assemblies and devices with dramatically improved capabilities for many industrial and biomedical applications. Directed assembly is the fundamental gateway to the eventual success of nanotechnology. Therefore, our NSEC is focused on discovering and developing the means to assemble nanoscale building blocks with unique properties into functional structures under well-controlled, intentionally directed conditions.

NSEC Description: Our NSEC integrates research, education, and technology dissemination to serve as a leading national and international resource for fundamental knowledge and applications in nanoscale science and technology. Serving society, including educational outreach, is a major thrust (Thrust 3) of our NSEC**.**

III. Education Activities within the University

Description of activities
The Center's internal educational activities are focused on undergraduate and graduate education in the classroom and through research. We teach several courses on the Rensselaer campus and at our partner institution, the University of Illinois at Urbana-Champaign (UIUC). More than 75 undergraduates have worked in our laboratories. We also teach an on-site short course at Rensselaer through the Chautauqua program and host a variety of visiting scholars.

Program staff and expertise
The education and outreach program in the NSEC is supported by a half-time outreach staff member as well as part time support from a business manager and an administrative assistant. In addition, over 2/3 of the faculty in the Center are involved in either the internal or external educational activities of the Center. Numerous students and post docs have participated.

Goals and objectives
Each program has audience specific goals, however the overall aim is to increase interest in nanoscience and prepare students and professionals for successful research and development in this emerging field.

Target audience (educational levels, number of students at each level, etc.)
During the past four years our NSEC has engaged more than 23 undergraduate students, 75 graduate students, 18 postdoctoral researchers, 50 working professionals, and several visiting scholars.

Current activities
Undergraduate Research: This is an ongoing project with 23 students from RPI and UIUC having worked in our laboratories. The research has resulted in 13 publications and presentations.

Graduate Leadership Course: With NSEC support, The Archer Leadership Center at Rensselaer developed a graduate professional leadership series (PLS) open to all graduate students at Rensselaer. This non-credit course has been taken by about 60 students in the last 2 years. The course is now open to all Rensselaer graduate students and we are getting students from both science and engineering. The course meets once a week for 2 hours and includes Meyers-Briggs evaluation, a ropes course, ethics, leadership, team building, and several other related topics. Guest speakers from industry as well as Rensselaer administrators (e.g. the Dean of Engineering) visit the class and foster discussion.

Chautauqua Course: Between 15 and 20 college professors and industry researchers from around the United States have joined us each year for a 2-day NSF Chautauqua short course. The topics include nanocomposites, nano-bio interfaces, molecular modeling, and electrical and optical applications of nanoscale materials.

Graduate and Undergraduate Courses: We have developed two undergraduate level courses with significant nanotechnology content, and several graduate courses including an "Introduction to Nanotechnology," "Science of Carbon," and "Biomimetic Materials." These are well attended and well received. In addition, we teach a graduate course in the business school called "Business Implications of Emerging Technologies" that has included nanotechnology projects and involvement of Center faculty.

Nano S&E content focus
The content of the undergraduate research and technical courses has focused on the development of materials using nanoscale building blocks as well as the physics, chemistry, and biology involved in the synthesis of those building blocks. This requires background information on high surface area materials and often includes applications in areas such as sustainable energy and biomaterials.

IV. Education Activities Outside the University

Description of activities
Our NSEC conducts a multitude of educational programs that take place outside of Rensselaer and UIUC. Several of these programs have been highly successful. "Molecularium™: Riding Snowflakes," a magical, musical (digital dome video) adventure into the world of atoms and molecules was created to spark the interest of K-5 students in the nanoscale world. The Bouchet Outreach and Achievement in Science and Technology (BOAST) program at UIUC stimulates academically at-risk children's interest in science and serves as a national resource for hands-on science and Internet lessons. Nanoscope is a computer simulation of a real scanning electron microscope (SEM) that allows students to learn the SEM control interface and provides access to libraries of many samples at various levels of magnification. Our PUI program provides the means for a diversity of talented undergraduate students to engage in collaborative research at Rensselaer as well as their home institutions.

Program staff and expertise
Educational outreach programs are lead, run, and maintained by several research faculty including professors Akpalu (RPI), Braun (UIUC), Dordick (RPI), Garde (RPI), Keblinski (RPI), Lewis (UIUC), Nayak (RPI), Peters (RPI), Ryu (RPI), Schadler (RPI), Schubert (RPI), Schweizer (UIUC), Siegel (RPI), Shima (RPI), Vojack (UIUC), and Wong (UIUC). (A description of these professors is beyond the brief, 3-page scope of this document, but can be found at www.nano.rpi.edu) NSEC staff further supports these programs.

Goals and objectives
Our educational outreach programs aim to increase public science literacy, enrich primary and secondary school curricula with cutting-edge science, and enable diverse and talented college students to become successful scientists and nanotechnologists.

Target audience (grade levels, number of students at each level, school districts, etc.)
We are improving science literacy though the development of educational programs for people of all ages, which provide fundamental information about the emerging field of nanotechnology. We have reached hundreds of people so far and are on our way to reaching ever-wider segments of society. During the last four years our programs have engaged several hundred families, more than 400 K-12 students, and over 75 undergraduate students.

Current activities (Examples)
Our Signature Project – the Molecularium™ (www.molecularium.com): We have taken up the grand challenge of improving science literacy by creating the Molecularium™ The Molecularium™ is a digital dome theater (like a planetarium) presentation but instead of taking the audience on a ride into the stars, the Molecularium ship takes the audience on a ride into the world of atoms and molecules. This fantastical ship can shrink to molecular sizes and move as fast as the speed of light. The concept is similar to that of the movie *Fantastic Voyage* (1966) or the *Magic School Bus*, but we have merged advanced scientific computation with state-of-the-art digital animation technology providing scientifically correct molecular motion. The first Molecularium show, Riding Snowflakes premiered at the Children's Museum of Science and Technology (CMST) in Troy, NY on February 4th. In this musical adventure aimed at K-5, Oxy, Hydra, and Hydro manage to navigate the ship (with the help of a computer) through the clouds, where they travel in a snowflake, watch it melt, and feel and observe the wind blowing past them. Musical segments emphasize the main message that *everything is made of atoms and molecules*. Children also learn about the three states of matter ("solids slow, liquids flow, gas is fast") and take a ride along a polymer molecule. Carbón (a carbon atom), who meets our trio on their brief journey through space, takes them to his favorite place, the Earth (a place teeming with life) where he retires to join a polypeptide chain and be part of life itself! These concepts are in agreement with typical state science based outcomes for K-5 students, but are taught such that all ages will learn.

Virtual Nanoscope: The virtual nanoscope is at its core a library of scanning electron microscope (SEM) images at various magnifications and focus. These images are stored, and accessed on a computer to give the impression of using an actual SEM. We have developed a library of 5 samples that can be viewed at several magnifications, several levels of contrast and both in focus and out of focus. This has the potential to be an extremely powerful teaching tool that we will build on over the next 6 years.

Primarily Undergraduate Institution (PUI) Partnerships: We have been collaborating for the past 4 years with faculty from Morehouse, Mount Holyoke, Spelman, Smith, and Williams colleges to provide a significant research opportunity for undergraduates and to provide collaboration between Center faculty and partner faculty. Each of these colleges has outstanding undergraduate programs; the group includes two of the premier HBCUs and three of the premier women's colleges in the U.S. Through this collaborative effort, we have learned a great deal about how to partner with PUIs, completed some good research, and had about 20 students (16 of them from underrepresented groups in engineering) spend time at the Center.

Nano S&E content focus: This is similar to our internal emphasis, but adjusted to be age appropriate as required.

Nano S&E content consultants: In order to capture the interest of diverse audiences, our NSEC has consulted several educational professionals from various areas, such as primary and secondary educators, museum curators, and field experts. Projects such as the Molecularium™ have involved an even broader group including animators, composers, musicians, programmers, faculty, staff, students, etc.

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences

The Molecularium™ is a great example of an educational outreach program in which several materials were produced. An animated, musical, digital dome presentation was produced to spark the interest of K-5 students. Many state mandated science standards and lessons were addressed. For example, the New York State curriculum including the three states of matter, and the understanding that "everything is made of atoms and molecules" were clearly reinforced through this show. An educational resource booklet was developed for teachers to prepare their students for the show and then reinforce lessons after the show. This booklet includes worksheets, hands-on activities, and lesson plans. A website, www.molecularium.com, was developed to educate children and is currently being expanded to include games and online activities for children. Furthermore, assessment tools were developed to measure the educational success of the Molecularium™.

Describe a recent successful education outreach activity
Our PUI summer students delivered their final research presentations in early August 2005. At the same time, these undergraduates completed academic papers on their topic, one of which was submitted for publication. The quality of their research and enthusiasm for participation was better than ever and we look forward to next summer.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan
Our programs are assessed via surveys, open discussion, and professional assessment tools. We have used these extensively and seriously and have adjusted many of our programs based on the survey results.

Summarize outreach evaluation results
In general we are finding that the students are learning a great deal from our outreach projects and more importantly they gain a new enthusiasm for science. The Molecularium shows very specific learning and we are continuing to assess the latest version of the show.

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort.

- Hire professionals where appropriate and do not try to be an artist, graphic designer, DVD developer, web designer, when there are professionals who can do it better.
- When interacting with secondary school educators, don't tell them what they need to do, ask them what they want and can use. It has to be collaborative.

Describe what you might do differently in the future

In the future, I would like to work toward a model in which the centers on campus doing education and outreach have a central staff with specific expertise in education and outreach (as several universities have done). This staff develops programs and makes the best use of faculty expertise and also supports the faculty's ideas and enthusiasm and directs that enthusiasm to the most effective projects and interactions. A lot of faculty time is lost in relearning lessons (such as the best way to interact with HS teachers and students).

Appendix 11: Stanford University/Center for Probing the Nanoscale Profile

I. Description

Institution: Stanford University
PI: Kathryn Moler
Co-PIs: David Goldhaber-Gordon
Title: Center for Probing the Nanoscale (CPN)
Proposal: 0425897
Program Officer: Denise Caldwell
Education Outreach Director: Kyle Cole, kylecole@stanford.edu

II. Research Agenda

Research Focus: The Center for Probing the Nanoscale is developing novel probes that can dramatically improve our capability to observe, manipulate, and control nanoscale objects and phenomena. Our nanoprobe development encompasses three themes: nanomagnetics; nanoelectronics; and nanomechanics.

NSEC Description
Stanford and IBM founded the Center for Probing the Nanoscale (CPN) to achieve five principal goals:

- To develop novel probes that dramatically improve our capability to observe, manipulate, and control nanoscale objects and phenomena.
- To apply these novel probes to answer fundamental questions in science and to shed light on materials issues which have economic importance for industry.
- To educate the next generation of scientists and engineers regarding the theory and practice of these probes.
- To transfer our technology to industry so that other R&D efforts can benefit from our nano-metrology groundwork.
- To inspire middle school students by training their teachers at a Summer Institute for Middle School Teachers.

III. Education Activities within the University

In this section we describe only Year 1 Activities that have already been carried out.
Description of activities
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Postdoctoral, graduate, and undergraduate education through research.
Education and research permeate every activity at Stanford University. The development of nanoprobes to address fundamental physical questions is exciting, challenging, and multidisciplinary. Nanoprobe development attracts postdoctoral, graduate, and undergraduate researchers whose home departments are physics, applied physics, chemistry, mechanical engineering, computational sciences, electrical engineering, and materials science and engineering. These student researchers gain expertise in modern nanofabrication, materials characterization, sensitive measurement techniques, state-of-the-art experimental design, and multi-scale modeling, as well as the design, operation, and data interpretation of nanoprobes.

"Advanced Topics in Nanoprobes"
The CPN faculty, led by Mac Beasley, teach a 3-unit course to familiarize graduate students with the advanced nanoprobe technology under development. Every week, a different participating investigator teaches two lecture classes and a discussion class. They describe the interesting science that motivates them to develop their tools, the tools they are developing, the technical issues involved, and the factors limiting progress. This course familiarizes all of the Center Fellows with a variety of techniques and motivations. Enrolled students additionally present on ideas for advanced nanoprobes: in the first year of the course, these presentations frankly outclassed the faculty presentations for creativity and far-sightedness.

Visitors
The Center for Probing the Nanoscale hosted 1 professor from the National Hispanic University and 2 teachers from its associated high school, the Latino College Preparatory Academy, to do research and develop lesson plans for 8-10 weeks during the summer.

Program staff and expertise

- 3 IBM Research Staff Members and 17 Stanford faculty, including seed grant recipients, are CPN members and participate actively in CPN programs
- Associate Director Kyle Cole, Ph.D. Yale Biology, has 5 years of industry experience as a Research Manager at Affymetrix. His education background includes teaching at Lake Tahoe Community College and the Continuing Studies Program at Stanford, as well as being a College Director of the Freshman-Sophomore College.
- Program Manager Laraine Lietz-Lucas has twenty years of experience in administering educational and industrial programs at major research universities.

Goals and objectives
Our year 1 goal was to build a strong base among the CPN faculty and students. Our goal for the next few years is to build on this base to broaden our nanoprobe outreach efforts, including a webcast class offered through the Stanford Center for Professional Development and including service/outreach in learning for CPN-affiliated students.

Target audience (educational levels, number of students at each level, etc.)
The target audience for year 1 consisted of 2 postdocs, 26 graduate students, 2 undergraduate students, 1 high school student, 2 teachers, and 1 professor from the National Hispanic University.

Current activities: Anticipated outcomes and/or deliverables (student awareness, curriculum materials, classroom demonstrations, etc.)
Student awareness: Our students will complete their work here with an impressive combination of technical engineering skills, basic scientific understanding, and communication skills. They will be poised to contribute to nanoscience and nanotechnology. They will also understand the interaction between science and society and will have experience in communicating and engaging both their fellow scientists and the public.

Curriculum materials: We post all class materials on a web site. In 04-05, access to this website was restricted to CPN members (broadly defined), but in future years we plan to post the materials publicly and we anticipate that the website will eventually develop into a seminal resource.

Nano S&E content focus
Nanoprobes to observe, manipulate, and control nanoscale objects and phenomena.

IV. Education Activities Outside the University

Description of activities

Workshop

The CPN hosted the first annual workshop on Probing the Nanoscale. It had 8 speakers, mostly from industry: 21 students presented posters, and the workshop was attended by over 100 people from a broad range of backgrounds.

Summer Institute for Middle School Teachers

CPN plans to offer a Summer Institute for Middle School Teachers twice each summer to twenty teachers from California (forty teachers total per summer) for 3 units of Continuing Studies Credit. The Institute will cover nanoscience, nanotechnology, and their societal implications, as well as delving into details of advanced nanoprobes. The Institute will provide ample opportunity for teacher-teacher interaction and curriculum development. In designing this institute, we were inspired by the successful institutes for *high school* science teachers run by the NSECs at Cornell and Rice. The ability of the teachers to connect the California State Science Standards to exciting CPN research on the imaging of single atoms and nanostructures will inspire middle-school students, who are at a critical age for developing interest in science. Although we worked with four diverse nearby middle schools to identify teachers to partner in the development of the curriculum for the Summer Institute, we were unable to offer the Summer Institute this year due to lack of personnel.

Program staff and expertise

Workshop

The program for the 2005 workshop was designed by Kathryn Moler and David Goldhaber-Gordon. The logistics and advertising for the workshop were beautifully executed by Laraine Lietz-Lucas.

Summer Institute for Middle School Teachers

The leader of the Summer Institute in Year 2 will be Dr. Kyle Cole, our new Associate Director. CPN faculty and graduate fellows are excited about participating in the workshop with Kyle's guidance. In addition, several local middle school teachers and our expert partners (discussed in the evaluation section) will play key roles in the development of the curriculum.

Goals and objectives

Workshop

Our first annual workshop was a celebration of the Center for Probing the Nanoscale as well as a chance for industry and members of the public to mix with each other and university researchers.

Summer Institute for Middle School Teachers

The Summer Institute is designed to give teachers the tools that they need to teach effectively and to inspire and inform their students.

Target audience (grade levels, number of students at each level, school districts, etc.)

Workshop

Companies represented at the workshop included NanoSig, Applied Materials, KLA-Tencor, Intel, Agilent, IBM, SRI International, VLSI Standards Inc, UMech Technologies, and Cascade Microtech Inc. Schools and museums included National Hispanic University, Foothill College, Tech Museum of Innovation, UC Berkeley, Delta College, Santa Clara University, and UC Santa Cruz.

Summer Institute for Middle School Teachers
Our Summer Institute targets middle school teachers, primarily in California, from a broad range of middle schools. By reaching 40 teachers per year, we can ultimately reach tens of thousands of students in grades 6-8.

Current activities
The teachers will return to their schools with curriculum; practical, explicit lesson plans; and low-cost kits to illustrate the action of nanoprobes at a humanly-accessible length-scale. The teachers will also receive Stanford Continuing Studies Credit: we will work with each teacher's district to ensure that the institute meets their requirements for the teachers' professional development.

Nano S&E content focus
Visualizing and manipulating the nanoscale.

Nano S & E content consultants
CPN researchers, both faculty and students; Dr. Marni Goldman, the Education Director for CPIMA (a MRSEC); Prof. Maureen Scharberg, Professor of Chemistry and Director of Science Education at San Jose State University.

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences
We do not yet have K-12/informal outreach materials that are ready for publication.

Describe a recent successful education outreach activity
Ms. Dixie Sinkovitz, a physics and math teacher at the Latino College Preparatory Academy, completed a 10-week internship at the Stanford University Center for Probing the Nanoscale. On returning to LCPA, she delivered an 8-day lesson on the nanoscale to about 60 LCPA high school students.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan
We plan to construct our outreach evaluation plan in partnership with three experts. Dr. Marni Goldman is the Education Director for CPIMA (a MRSEC). Prof. Maureen Scharberg is a Professor of Chemistry and Director of Science Education at San Jose State University. Dr. Nora Sabelli is the co-Director of the Center for Teaching and Learning at SRI International. These three education experts have been extremely helpful in advising our Center since its conception.

Summarize outreach evaluation results
Course and workshop evaluations were quite favorable, but the real impact of our outreach will be determined after the efforts have ramped up in the 05-06 year.

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort.

- Graduate students are an awesome resource.
- It's not good to be located in Silicon Valley during one of the world's most severe housing bubbles when recruiting an education director candidate.
- Describe what you might do differently in the future
- Focus early on the infrastructure needed to create a successful program.

Appendix 12: University of California Los Angles/Center for Scalable & Integrated Nanomanufacturing Profile

I. Description

Institution: University of California, Los Angeles (UCLA)
PI: Xiang Zhang
Co-PIs: Eli Yablonovitch
Title: Center for Scalable & Integrated Nanomanufacturing (SINAM)
Proposal: 0327077
Program Officer: Cheng Sun
Education Outreach Director: Adrienne Lavine, Director, lavine@seas.ucla.edu and David Martinez, martined@seas.ucla.edu

II. Research Agenda

Research Focus:
IRG 1 will focus on top-down nano-lithography, including the Plasmonic Imaging Lithography and Ultramolding Imprint Lithography, aiming toward critical resolution of 1~10nm.
IRG 2 will explore novel hybrid approaches, in combining the top-down and bottom-up technologies to achieve massively parallel integration of heterogeneous nanoscale components into higher-order structures and devices.
IRG 3 will develop system engineering strategies to scale up the technologies developed in IRG 1 and 2, and in product design and development.

NSEC Description: While exciting nano scientific discoveries stream continually from research laboratories, due to the lack of new manufacturing paradigms, scaling to industrial level production still faces critical challenges. We envision two main challenges critical to expedite the nano-technology revolution: (1) the ability to do lithography below 20 nm, and (2) the ability to fabricate 3D complex nanostructures.

III. Education Activities within the University

Description of activities
Nano-Manufacturing Summer Academy (NMSA): The NMSA program is held for an 8-week period in the summer. Participants are college and high school students, who engage in full-time research on a topic related to nano-manufacturing.

New Nano-Courses within UCLA Engineering: Five courses were added or augmented amongst SINAM institutions for 2004. A new undergraduate course, entitled "Bio-NEMS Lab", was designed and taught by Professors Yong Chen and Jeong-Yeol Yoon of UCLA.

Program staff and expertise
Adrienne Lavine, Ph.D., Mechanical Engineering Professor, third year as Director of Education & Outreach for SINAM. David Martinez, M.S. Operations Research Engineering, first year as Assistant Director of Education & Outreach.

Goals and objectives

- **Diversity.** Collaboration with programs on our campuses whose objectives are to attract and prepare underrepresented students for the next steps in their education.
- **Educating SINAM students** at our campuses within a supportive, collaborative environment that fosters their continuing education and research success within the interdisciplinary context of nanomanufacturing.

Target audience (educational levels, number of students at each level, etc.)
High School Level (100), Community College Students(50), Undergraduates(60), Graduate Students(40). All engineering majors.

Current activities
Graduate Young Investigator Award: The GYI is an established program which is successful in supporting student-initiated research. We will monitor how many projects either generate useful results within one year or are incorporated into on-going SINAM research.

Courses: The number of courses is probably sufficient. We need to make courses available between campuses, using either videoconferencing or recorded course lectures.

Nanomanufacturing Summer Academy: The NMSA is an established program which has increased participant diversity in the second year. The desired outcomes are: 1) students express satisfaction with the research project, mentoring, and academic preparation workshops. 2) Undergraduates go to graduate school, high school students go to college in engineering or science.

CEED Engineer-in-Training Workshop (highschool students) and NSF/CEED STEP-UP Convocation (community college and CSU students): These events are coordinated through CEED, the Center for Excellence in Engineering and Diversity, and are based on the MESA model, which has been extensively and positively assessed for its effectiveness in preparing students for four-year institutions.

Nano S&E content focus
Nanomanufacturing, nanolithography, nanoimprinting, nano-Legos, AFM usage, Nanomanipulator

IV. Education Activities Outside the University

Description of activities
Inquiry-Based Module Development & Implementation: Collaborations with faculty from NC State, UNC-Charlotte, the California NanoSystems Institute (CNSI), and the National Center for Learning & Teaching in Nano-scale Science & Engineering (NCLT) have begun in an effort to design inquiry-based learning modules revolving around nano-science principles.

Nano-Manipulator and Haptic Device: SINAM has placed an order for a Nano-Manipulator (nM) and haptic device system to be incorporated into inquiry modules, school science assemblies, 1-2 day classroom workshops, and the LATTC community college nano-technology course. The nM has the capability to take data from an AFM scan of a nano-scale device and create images for students to see. The nM can also be connected to a haptic device that will allow students to virtually “feel” the nano-particle as it is displayed in the nM image.

Joint Collaboration with Los Angeles Trade Technical College: A program is being developed that involves a partnership between Los Angeles Trade Tech community college (LATTC) and UCLA SINAM. The program involves two stages; with the first stage representing a pilot program to serve as the model to expand implementation into the second stage.

New Nano-Courses: A new full-year graduate course series at UCSD incorporates the courses of "Advanced BioPhotonics", "BioElectronics", and "BioNanotechnology". Altogether, the courses had an enrollment of sixty students for the entire year. The series, taught by Professor Mike Heller of UCSD, represents an interdisciplinary approach where the convergence of science and technology spurs the creation of new nanotechnology.

Graduate Young Investigator (GYI) Program:
This is a proposal competition amongst graduate students within SINAM. Three proposals were awarded $30,000 each for a one-year period starting July 1, 2004 and ending June 30, 2005.

Program staff and expertise
Adrienne Lavine, Ph.D., Mechanical Engineering Professor, third year as Director of Education & Outreach for SINAM. David Martinez, M.S. Operations Research Engineering, first year as Assistant Director of Education & Outreach.

Goals and objectives

- **CC Outreach.** Reaching out to the community college district and the Los Angeles Unified School District, which serve diverse populations. These are opportunities to expose under-served populations to nanotechnology concepts and the innovative SINAM research.
- **Outreach to grades 7-12.** Our goals here are to: 1) Raise awareness of and enthusiasm for nanoscale concepts among grade school children. 2) Effectively engage students in nanoscience and nanotechnology modules that awaken an interest and encourage persistence in science or engineering.

Target audience (educational levels, number of students at each level, etc.)
High School Level (300), Community College Students(100)

Current activities
LATTC Phase I: Phase I is the offering of a Nanotechnology course at LA TradeTech College in the Fall. The course will be taught by Dr. Miguel Moreno with two kinds of input from UCLA faculty – advisory input on the curriculum and bringing students into our faculty labs for approximately two lectures.

Nanomanipulator and Haptic Device/Module Development: We will use the Nanomanipulator in three ways. It will be incorporated into the Los Angeles Trade Technical College Nano-technology course (on-deck for Fall). It will be used in grades 7-12 classroom visits in "basic" modules; these are modules that address basic concepts of nanometer scale, nanoscale science concepts, geometry, and trigonometry. These can be developed quickly (for Fall).

Nano S&E content focus
Nanomanufacturing, nanolithography, nanoimprinting, nano-Legos, AFM usage, Nanomanipulator.

Nano S & E content consultants
UCLA Graduate School of Education, UCLA MESA, USC MESA, high school teachers, Lawrence Hall of Science.

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences

MESA Engineers-in-Training Workshops: Mathematics, Engineering, Science Achievement (MESA) operates out of the CEED office at UCLA. The program focuses its efforts on organizing pre-college programs to garner interest for engineering and science amongst K-12 students. This particular event was broken up into three hour-long repeat workshops with students from local high schools (Dorsey, Hamilton, and Morningside) in attendance.

CEED Step-Up Convocation: UCLA SINAM volunteered to attend this event to discuss current nano-manufacturing research and nano-technology principles with students from Cal State Los Angeles and various California community colleges. The event targeted minority serving institutions to promote successful transfer to UCLA and stimulate research interest at UCLA in technical disciplines.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan

Graduate Young Investigator Award: The GYI is an established program which is successful in supporting student-initiated research. We will monitor how many projects either generate useful results within one year or are incorporated into on-going SINAM research.

Nanomanufacturing Summer Academy: The desired outcomes are: 1) students express satisfaction with the research project, mentoring, and academic preparation workshops. 2) Undergraduates go to graduate school, high school students go to college in engineering or science. For #1, we will give a survey. For #2, we will track student progress annually.

LATTC Phase I: An evaluation is written into the project proposal to be done collaboratively by SINAM and LATTC. This will address the number and diversity of students taking the course, the competence of the students in the course material, and their expressed future interest in nanotechnology.

Summarize outreach evaluation results

In Progress

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort:

- Collaboration is key, especially with limited staff. Hosting joint events or attending outreach events that other programs (especially diversity programs) host goes far to promote education and diversity agendas.
- There exists an unlimited amount of programs, centers, and offices that have connections to your target students…all one needs to do is to find them.
- Have a plan, module, or outline before collaboration is sought. This helps to minimize wasted time and promotes further collaboration and funding

Describe what you might do differently in the future

- Maximize the assistance of graduate students as they can relay their research to students in imaginative and interesting ways.

Appendix 13: University of Illinois/Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems Profile

I. Description

Institution: University of Illinois, Department of Mechanical and Industrial Engineering
PI: Dr. Placid M. Ferreira
Co-Pis: Dr. Ilesanmi Adesida, Dr. John Rogers, Dr. Paul Kenis
Title: NSEC: Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS)
Proposal: 032816
Program Officer: Dr. Kevin Lyons
Education Outreach Director: Lizanne Destefano, destefan@uiuc.edu and Ms. Martha R. Atwater, atwater@uiuc.edu

II. Research Agenda

Research Focus: The Center's goal is to develop a reliable, robust and cost-effective nanomanufacturing system to make nanostructures from multiple materials.

NSEC Description: Scholars from mechanical, industrial, chemical, biomolecular, electrical, computer and materials science engineering collaborate with colleagues in applied physics, chemistry, and molecular and cell biology to create a viable manufacturing technology and science base for nanomanufacturing. The Center's research goals are addressed through a coordinated set of 28 research projects organized into four research thrust areas: Micro-Nano Toolbit, Nanoscale Sensing, Manufacturing Systems and Applications, with Computational Modeling as a cross-cutting activity. The research, commenced in January 2004, spans four campuses: University of Illinois at Urbana-Champaign (UIUC), North Carolina Agriculture and Technical State University (NCAT), the California Institute of Technology (Caltech) and Stanford University.

III. Education Activities within the University

Description of activities
The Nano-CEMMS education team concentrates in the following areas:

- **Courses** in nanoscience, nanotechnology, and nanomanufacturing for undergraduate and first year graduate school courses
- **Research Ethics Training** for all participants of the Center
- **Graduate Student Group** that serves to enrich the student experience and to promote collaboration
- **REU Program** where undergraduates from various institutions gain laboratory experience under the direction of faculty sponsors and graduate student mentors
- **Teacher Workshops** that are designed to introduce middle and high school science, math, and industrial arts teachers to nanomanufacturing research and to facilitate knowledge transfer to their students.

- **Designated Diversity Recruitment Programs** that deliver nanotechnology-related content to underrepresented middle and high school students and recruit undergraduate students for graduate school
- **Summer Camp Programs** that target audiences of middle and high school students who are interested in engineering, math and science.
- **Evaluation** is conducted by College of Education evaluators who submit constant feedback to Center programs.

Program staff and expertise
Faculty and students involved with Nano-CEMMS spend 15% of their time participating in the Center's educational outreach activities. The Nano-CEMMS Executive Committee sets priorities for the HRD team. To maximize efficiency and output, the team is augmented by professors, teachers (high school and middle school), students (graduate, undergraduate, high school) and part-time professionals just as needed to provide particular expertise or to execute particular tasks.

Martha Atwater	Education Coordinator	50%
Prof. Devdas Pai and Prof. Cindy Waters (NCA&T)	Education Facilitators	
Joseph Muskin (UIUC)	Education Facilitator	25% during the school year, 100% during summer
Kaamilyah Abdullah-Span (UIUC)	Diversity Programs Coordinator	50%
Patrick Grenda (UIUC) Deborah Bartz (NCA&T)	Education Evaluators	50%

Goals and objectives
Nano-CEMMS targets its internal HRD activities to:

- Contribute to the diversity of the Center participants and the scientific community
- Promote the professional advancement of B.S., M.S., and Ph.D. students
- Educate and transfer knowledge specific to Nano-CEMMS research to visiting secondary and community college students and to the Center's undergraduate and graduate students.

Target audience
Nano-CEMMS provides a wide range of activities specifically targeting undergraduate students, graduate students, middle and high school students, and teachers who come to university programs. The following chart shows the numbers of people reached from 9/1/2004 until 9/1/2005.

Graduate students	61
Undergraduate students	16
Middle and high school teachers	54
Middle and high school students	1096

Current activities
Throughout the year, the Center provides programs for schools and community organizations. We are also working in the following areas:

- **Learning Modules –** The summer teacher workshops yielded kernels for several new learning modules that use common materials to transfer laboratory research concepts into lessons for school students. The education team is currently finalizing and piloting the learning modules.
- **Learning Kits** – With a grant from Motorola, Inc., the education team is building learning kits for the various Nano-CEMMS learning modules. The kits will include all the materials necessary to teach a module to 30 students as well as assessment and evaluation instruments and return postage. Nano-CEMMS will advertise the kits through various mailing lists and professional organizations, and teachers will order kits through the Center website.

Nano S&E content focus
Nanomanufacturing

IV. Education Activities Outside the University

Description of activities

- **School and Community Presentations** inform students and the general public about upcoming changes in manufacturing and the societal implications of this change
- The **Central Illinois Community College Initiative** includes faculty and students within the university, community colleges, high schools plus state and local government agencies and industries. This consortium is planning a training program to prepare a nanomanufacturing workforce for Central Illinois.
- The **Museum Initiative** trains and supports educators at the Children's Discovery Museum in Normal, Illinois, who deliver the Nano-CEMMS education modules in their Learning Labs program for school students.

Program staff and expertise
Same as above

Goals and objectives
Educate and transfer knowledge specific to Nano-CEMMS research to external secondary and community college students, teachers, and community members.

Target audience
Nano-CEMMS conducts external recruitment activities for undergraduate students, training for teachers who will deliver Nano-CEMMS education modules, and programs for schools and community groups. The following chart shows the numbers of people reached in external programs from 9/1/2004 through 9/1/2005.

Undergraduate students (external recruitment)	89
Middle and high school teachers	19
Middle and high school students	482

Current activities

- Preparing for external programs
- Developing materials specifically targeted for recruitment within the diversity program
- Seeking new partnerships with outreach efforts at partner institutions

Nano S&E content focus
Nanomanufacturing

Nano S & E content consultants
Nano-CEMMS faculty and graduate students provide content expertise.

V. Education Outreach Materials

Materials developed for outreach activities for the K-12 and/or informal audiences
The Center's ability to present effective educational experiences to a variety of audiences with minimal staff is directly related to the development of learning modules with clearly identified learning objectives, targeted audience types, and timeframes. The modules can be "snapped together" in various configurations depending on the particular interests and age ranges of the audience, as well as the time allotted for the presentation.

The Nano-CEMMS learning modules include a wide variety of cognitive, affective, and psychomotor learning experiences, and all have clearly stated learning objectives that are geared to Illinois and national learning standards. Module development is ongoing by education staff and by teachers and secondary students who are engaged in workshops and special projects. The modules are used extensively in camp and school programs and are modified based on piloting and evaluation. Each learning module contains a teacher's activity guide, a PowerPoint presentation, student handouts, evaluation instruments and lab materials.

Recent successful education outreach activity

Two teacher workshops held in July illustrate how the Center teams of faculty, graduate students, undergraduates, secondary teachers and high school students collaborate to create curriculum.

- A high school science teacher who had attended a 2004 workshop spent the month of June visiting various Nano-CEMMS labs to determine developing technologies that would make effective learning modules for high school science classes and working with faculty and students to prepare for the teacher workshops.
- During teacher workshops in July, middle and high school teachers spent one week learning about the Nano-CEMMS technologies from the principle investigators and from graduate students and undergrads who conducted research demos and hands-on labs.
- The teachers and a high school student spent the second week replicating the experiences using inexpensive materials and developing safe procedures that are practical for a middle or high school classroom. As a result, the teachers created:
- a 3D printing technique using a data projector and PowerPoint slides
- a device using PDMS and Puffy Paint that shows laminar flow of dyed alcohol in small channels
- a lab to make colloidal gold and silver and to demonstrate that the two colloids can be separated using commercially available filters

The Center's education team will work during the fall semester to finalize these labs for classroom use.

VI. Education Outreach Evaluation

Outreach evaluation plan
The evaluation effort is a collaboration between Nano-CEMMS and the College of Education faculty and staff at UIUC and NCA&T. Evaluation is imbedded in all of the Center's human resource and education activities and is keyed to the goals set for each program component. The approach is designed to provide both formative and summative feedback regarding program improvement and progress toward goals. Quantitative and qualitative data are gathered using direct observation, interviews and surveys.

Summarize outreach evaluation results
Goals for each program were reached.

- **Graduate Students** - Participants took ownership of the Graduate Student Group, identified needs and interests they shared, and took steps to meet them. Participants identified connections across research areas and gained an understanding of their individual roles within the Center's research plan.
- **Undergraduate students** - All participants gained hands-on experience in nanoscience/technology, and progress was made in reaching underrepresented groups.
- **Teachers** - Participants expanded their knowledge of nanoscience, created modules that were incorporated in their classrooms, and continued their involvement with the center during the year by participating in curriculum development and piloting.
- **Middle and High School Students** - Participants were exposed to a range of information regarding nanotechnology. Participants were exposed to positive modeling regarding diversity in science.

VII. Lessons Learned

Three lessons learned

- **Use existing infrastructures –** Nano-CEMMS has formed collaborative relationships with many well-established camp programs at UIUC and NCA&T. All have the infrastructures to handle the housing and entertainment facets of camp life, allowing Nano-CEMMS to utilize resources efficiently to create learning modules for the various camps.
- **Modularize learning materials –** The Center's modular approach to curriculum development allows the team to respond quickly to requests for presentations.
- **Hire staff just as needed –** Nano-CEMMS has a small part-time staff of secondary teachers and undergraduates who work as needed to fulfill its education goals. The staff is augmented when necessary by faculty and graduate students who also provide content expertise. This staffing plan maximizes efficiency and controls costs.

What the Center is doing differently in the future

- **Workshops** - Recruiting teachers who serve a higher percentage of underrepresented students
- **Curriculum** - Focusing future development efforts on materials directly related to nanomanufacturing
- **Internships** - Working with industry to provide more internships for students
- **Collaboration** - Identifying opportunities to work with outreach efforts at the Center's other partner institutions

Appendix 14: University of Massachusetts Amherst/ Center for Hierarchical Manufacturing Profile

I. Description

Institution: University of Massachusetts Amherst
PI: Jim Watkins
Co-Pis: Mark Tuominen
Title: NSEC: Center for Hierarchical Manufacturing (CHM)
Proposal: 0531171
Program Officer: Kevin Lyons
Education Outreach Director: Mark Tuominen tuominen@physics.umass.edu and Mort Sternheim, mort@k12.umass.edu

II. Research Agenda

Research Focus: Basic research is divided into three technical thrusts: nanoscale materials and processes, nanoelectronics, and bio-nanotechnology. Testbed projects, carried out with industrial partners, are the vehicle used to establish proof-of-concept prototypes in nanomanufacturing. A National Nanomanufacturing Network (NNN) is nucleated within the project, in partnership with other NSECs, as a vehicle for university-industry collaboration and nanomanufacturing clearing house activities. Societal impact studies complement the other activities.

NSEC Description: The CHM is a NSEC with a focus on nanomanufacturing R&D. The center has a strong emphasis on catalyzing interactions and activities that lead to integrating nanotechnology into safe commercial products.

III. Education Activities within the University

Description of activities (Note this new NSEC starts in October 2005)

- K-12 T*eachable Nanoscience* summer workshops for science teachers
- Undergraduate course Introduction to Nanoscience for science and engineering majors
- Summer REU experiences
- Video-based learning modules for technical community college (in collaboration with Springfield Technical Community College)
- Public outreach: Web based nanotechnology "vignettes" that highlight nanoscale science and engineering
- (Affiliated) NSF IGERT graduate program on nanotechnology: "Lab to Fab"

Program staff and expertise
Search in progress for our NSEC education and outreach coordinator; Mort Sternheim K-12 education coordinator; Gordon Snyder community college education coordinator; others to be named.

Goals and objectives
Creation of sustainable and updatable curriculum materials for nanoscience education; training experiences for students from community college to graduate level.

Target audience (educational levels, number of students at each level, etc.)
Pending

Current activities
Project has not yet started

Nano S&E content focus
Teachable Nanoscience (K-12)

IV. Education Activities Outside the University

Description of activities
Web-based educational materials development with STCC (see above)

Program staff and expertise

Goals and objectives

Target audience (grade levels, number of students at each level, school districts, etc.)

Current activities
Project has not yet started.

Nano S&E content focus

Nano S & E content consultants

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences
One-minute nanotechnology video vignettes for public outreach; delivered via web.

Describe a recent successful education outreach activity
Project has not yet started.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan
Periodic external evaluation by Peterfreund and Associates (or equivalent).

Summarize outreach evaluation results

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort
Project has not yet started.

Describe what you might do differently in the future

Appendix 15: University of Pennsylvania/NSEC Profile

I. Description

Institution: University of Pennsylvania
PI: Dawn Bonnell
Co-PI's: Yale Goldman
Title: Molecular Function at the Nano/Bio Interface
Proposal: 0425780
Program Officer: Ulrich Strom
Education Outreach Director: James McGonigle, jmcgon@seas.upenn.edu

II. Research Agenda

Research Focus: Two multi disciplinary research teams are focused on aspects of the fundamental issues. Two cross cutting initiatives develop ideas integral to each and make explicit links between them. The two fundamental themes are: (1) optoelectronic function in synthetic biomolecules and (2) mechanical motion of molecules from physiological systems. In each area physical interfaces probe, control, or influence the outcome. Each theme has a strong fundamental component and obvious technological impact that ranges from nanoelectronics to medical diagnostic devices. Intersecting each theme is an initiative on development of new probes of molecular/nanostructural behavior. In addition, an overarching activity concerns the ethical implications of nanotechnology specific to the research themes and in a broader sense.

NSEC Description: The center's research is aimed at the interface of nanotechnology and biology at the molecular level. Potential practical outcomes are in the areas of nanoscale device manufacturing, drug delivery and integrated chemical sensors as well as understanding basic complex biological and physiological processes. The center will impact public education, social discourse, workforce development, and diversity, both locally and nationally, and will examine ethical issues in nanoscience and technology.
III. Education Activities within the University

One of the important outcomes the NSEC in terms of human resources will be a population of undergraduate and graduate students as well as post docs with high quality training in nanotechnology as is relates to the important issues at the nano/bio interface. In order to properly prepare students to take leadership roles in these areas, new curricula are required for which academic disciplines do not exist. The students supported in this NSEC will have access to two new curriculum initiatives in nanotechnology that are administered by the center.

The goal of the education activities within the University is to increase the involvement of students in the field of nanoscale science. The NBIC supports a number of programs aimed at under gradate and graduate students. Undergrads are supported in summer research positions in various labs along with the ability to apply a minor in nanotechnology to their degree. Graduate students can add a certificate in nanotechnology to their transcripts
Workshops and Seminars. The NBIC will support various workshops and seminars. This year, the Center supported the Chemical Biophysics Mini-Symposium on Single Molecule Approaches held on 21 April 2005.

IV. Education Activities outside the University

The goal of education programs designed to extend beyond the University is to reach as wide an audience as possible with programs and activities that introduce nanoscale science and its growing impact across society. Programs are aimed at high school science and math teachers, pre-college students, and the general public.

Program staff: James McGonigle is the Programs Coordinator for the NBIC for programs within and outside the University. He has a MS in Biology and a BS Ed. in Biology and General Sciences. Since 1987, he has worked as an education director in various museums and research laboratories where programs were focused on teacher professional development. Prior to that, he taught high school biology and environmental science.

NanoDay @ Penn is an open-house type event featuring exhibits, demonstrations, a poster session, and various talks and seminars. Most of the attendance is made up of University students. This year NanoDay is inviting local high schools to tour its labs and participate in the day's events. Scheduled for 26 October 2005.

RET-NANO is a 5-week Research Experience for Teachers run in collaboration with the Drexel University Nanotechnology Institute. This summer, 18 teachers from the Philadelphia School District and surrounding region participated. The 2005 program ran from 11 July - 12 August.

Professional Development Workshops are develop and presented to individual school faculties or other specialized groups. This year, the NBIC provided workshops for science and math faculty at the Marianna Bracetti Charter School in North Philadelphia along with a workshop for high school principals from the Bronx, New York in collaboration with Penn's Graduate School of Education.

High school students from across the country participated in a 3-week nanotechnology summer academy on the Penn campus. Two graduate students from the NBIC acted as the primary program staff and instructors. Participants toured the microfabrication lab and nanotechnology characterization facility and conducted numerous laboratory activities.

V. Education Outreach Materials

The NanoDay @ Penn program scheduled for 26 October will be our first opportunity to develop a variety of exhibits or demonstration to explain and interpret nanoscale science in outreach programs.

VI. Education Outreach Evaluation

We have adopted the pre and post survey tool developed for RET programs across the country. We will use these evaluation data locally to further develop the program and plan to submit data to the researchers at Notre Dame University for the national study of RET programs.

VII. Lessons Learned

It is important to communicate with teachers early and well in advance of their participation in programs like an RET. Next year, we will prepare a more specific "nanotech primer" that teachers will be required to complete prior to arrival to the program. This way, everyone will have an opportunity to develop a basic understanding to nanoscale science and perhaps be better prepared to integrate into the research group with whom they will work over the ensuing 5-week period.

Appendix 16: University of Wisconsin Madison/NSEC Profile

I. Description

Institution: University of Wisconsin-Madison
PI: Paul Nealey
Co-PIs: Robert Hamers, Franz Himpsel, Mark Eriksson, Padma Gopalan, Nicholas Abbott, Sam Gellman, Shannon Stahl, Sean Palacek, Arun Yethiraj, Juan de Pablo, David Schwartz, Michael Graham, Susan Coppersmith, Wendy Crone, Franco Cerrina, Clark Miller, Daniel Kleinman, Eric Schatzberg, Karin Ellison, Linda Hogle, Mark Suchman, Sarah Pfatteicher, John Moore, Joseph Bisognano, Luke Mawst, Thomas Kuech
Title: Templated Synthesis and Assembly at the Nanoscale
Proposal: 0425880
Program Officer: Thomas P. Rieker
Education Outreach Director: John Moore, jwmoore@chem.wisc.edu

II. Research Agenda

Research Focus: The UW-Madison NSEC has four interdisciplinary research thrusts that explore complementary concepts around a central theme of self-assembly at the nanoscale. The thrusts are **Thrust 1:** *Directed Self-Assembly and Registration of Nanoscale Chemical Architectures*; **Thrust 2:** *Templated Chemical Synthesis of Sequence Specific Heteropolymeric Nanostructure*; **Thrust 3:** *Driven Nano-Fluidic Self Assembly of Colloids and Macromolecules*; and **Thrust 4:** *Research in the Societal Implications of Template Synthesis and Assembly at the Nanoscale*. Multiple cross-Thrust activities and interactions further capitalize on our multidisciplinary environment, which is essential for successful completion of our research mission. As of April 2005 the entire project has involved 27 faculty from science, engineering, and public policy departments, 8 postdocs, 35 graduate students, and 3 undergraduates.

III. Education Activities within the University

Description of activities

- **Institute for Chemical Education Chemistry Camp**: A week long half day camp for 5th-8th grade students. Camp included a nanoscience day with activities developed by NSEC graduate students and presentation by NSEC postdoctoral associate.
- **Online Nanotechnology Teacher Education Course:** The UW-NSEC is developing an online continuing education nanotechnology class. The course will be a broad overview of current nanotechnology topics with a focus on implementing nanoscience into K-12 classrooms.
- **Educational Fellowships**: The UW-NSEC funds two teachers per summer to join the education and outreach staff to aid in the development of nano related educational materials. Teachers serve as educational consultants through out the school year to help keep developed materials at grade appropriate levels.
- Program staff and expertise
- **Diane Nutbrown**: Director of Chemistry Camp. NSEC graduate student and Institute of Chemical

Education Outreach Specialist

- **Janice Hall**: Online Nanoscience Course Developer. NSEC graduate student.
- **Andrew Greenberg:** Educational Fellows Supervisor. NSEC Postdoctoral Associate
- Goals and objectives
- **Chemistry Camp**: The goals of the chemistry camps are to provide hands on inquiry based science experiences for 5^{th}-8^{th} grades students. The camps are developed to excite and teach campers about current science topics.
- 2 **Online Nanotechnology Teacher Education Course**: The course aims to provide resources for teachers to use in their classroom and clearly show how the topic can relate to current curricula.
- **Educational Fellowships**: The fellowship program strives to provide an exciting and rewarding nanoscience professional development experience for K-12 science teachers.
- Target audience (educational levels, number of students at each level, etc.)
- **Chemistry Camp**: Students entering 5^{th}-8^{th} grade. Summer 2005 120 campers.
- **Online Nanotechnology Teacher Education Course**: High School Science Teachers
- **Educational Fellowships:** High School Science Teachers. Summer 2005 two teachers.
- Current activities (Deliverables)
- **Chemistry Camp:** Camp curriculum manual to be sold via the Institute for Chemical Education.
- **Online Nanotechnology Teacher Education Course:** Course webpage containing nanoscience classroom content and laboratory exercises.
- **Educational Fellowships**: Three nanoscience based educational kits available for purchase through the Institute for Chemical Education, each kit will contain a demonstration and/or lesson based on research being conducted in NSEC Thrusts.
- Nano S&E content focus
- **Chemistry Camp**: Products of nanotech, Gold nanoparticles, and Nickel nanowires
- **Online Nanotechnology Teacher Education Course:** Broad overview of current nanotopics
- **Educational Fellowships:** Societal impacts, Molecular architecture, Self assembly, and DNA elongation.

IV. Education Activities Outside the University

Description of activities

- **SPICE (Students Participating In Chemical Education)**: NSEC graduate students present nanoscience and chemistry demonstrations shows for K-12 classrooms and local community events.
- **Sciencounters:** A collaboration between the Madison area Boys and Girls Clubs and the UW-NSEC to provide hands on science activities for underrepresented groups in science and engineering.
- **Independent Laboratory Access for Blind and Visually Impaired Students (ILAB)**: A collaboration between Penn State, Truman State, The Indiana School of the Blind, and the UW-NSEC to develop, test, assess, and market instruments and course materials for blind and visually impaired students to work independently in science laboratories. The UW-NSEC is responsible for the assessment and adaptation of current nanoscience experiments for use in K-12 classrooms with blind and visually

impaired students.

- **Today's Science for Tomorrow's Scientists (TSTS)**: A website containing innovative tutorials designed to teach current research being conducted within the Department of Chemistry at UW to the K-12 community. Included are tutorials on NSEC research being conducted in the Department of Chemistry.
- Program staff and expertise
- **Diane Nutbrown:** Director SPICE and Sciencounters
- **Andrew Greenberg:** ILAB evaluation and nanoscience adaptations
- **Caroline Pharr:** TSTS developer. NSEC graduate student
- Goals and objectives
- **SPICE:** SPICE aims to excite the general public and K-12 community about science and engineering.
- **Sciencouters:** Sciencounters provides opportunities for underrepresented groups to explore science in a fun relaxed atmosphere in the hopes of exciting students to pursue careers in science and engineering.
- **ILAB:** ILAB seeks to raise the expectations of blind and visually impaired high school and college students, as well as educators of these students, with the goal of encouraging them to consider careers in science, technology, engineering, and mathematics professions.
- **TSTS:** The goals of TSTS are to make young people more aware of cutting edge research in chemistry and related sciences. Illustrate why researchers receive funding and how their findings impact people. Show that research is done by real people working together in a group environment. Provide an interactive way to learn modern chemistry while meeting national science education standards.

Target audience (grade levels, number of students at each level, school districts, etc.)

- **SPICE:** K-12**,** 2. **Sciencouters:** Teenagers**,** 3. **ILAB:** 9-16**,** 4. **TSTS:** Grades 5-12
- Current activities (Deliverables)
- **SPICE:** Demonstrations shows.
- **Sciencouters:** None
- **ILAB:** Instrumentation and adapted laboratory exercises.
- **TSTS:** Web based tutorials.

Nano S&E content focus

- **SPICE:** Memory metal and Amorphous metals
- **Sciencouters:** Memory metal and Amorphous metals
- **ILAB;** To be determined
- **TSTS:** Self assembly

Nano S & E content consultants
High School Teachers, Vin Crespi (Penn State Center for Nanoscale Science), NSEC faculty.

V. Education Outreach Materials

Describe and provide examples of materials, outlines, demonstrations, etc. developed for outreach activities for the K-12 and/or informal audiences

- Chemistry Camp Manual: Camp manual to be published and sold through the Institute of Chemical Education
- Demonstration Kits: Nanoscience demonstration kits on DNA elongation and Molecular architecture to be sold through the Institute for Chemical Education.
- Online Nanotechnology Teacher Education Course: Materials including laboratory activities available via course webpages.
- TSTS: Web based tutorials and games available for classroom and personal use,
- ILAB Lab modifications available for download from project webpage and instrumentation to be sold through science educational catalogues.

Describe a recent successful education outreach activity
Chemistry Camp: The summer 2005 chemistry camp which had 120 participants from Madison area highlighted inventions from chemistry and nanoscience. Campers spent two hours a day running inquiry based laboratory activities including making gold nanoparticles and nickel nanowires.

VI. Education Outreach Evaluation

Summarize outreach evaluation plan
Evaluation of ILAB began in August with data collection of the control group for a study to determine if developed instruments help to increase blind and visually impaired students' attitudes toward science. The evaluation plan includes case studies of students using the instruments as compared to a control group doing the experiments in the traditional format with sighted helpers.

UW-NSEC has hired an evaluation consultant to help develop appropriate evaluation plans for other NSEC programs. Evaluation will start in the upcoming months on Chemistry Camp and TSTS.
Summarize outreach evaluation results

No results have been collected to this point all the NSEC programs are in their first year of existence.

VII. Lessons Learned

List 2-3 lessons learned to share with others embarking on a nano education outreach effort.

1. When developing nano education products it is important for the lessons to be at the appropriate educational grade level of your target audience.
2. Working with programs that have fluid participation, The Boys and Girls Clubs, causes difficulty to maintaining continuity of a program.

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