TESTIMONY

David A. Ucko, Ph.D.
Deputy Division Director
Division of Research on Learning in Formal and Informal Settings
Directorate for Education and Human Resources
National Science Foundation

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Hearing on Nanotechnology Education

Chairman Baird, Ranking Member Ehlers, and distinguished members of the Subcommittee, thank you for the opportunity to describe National Science Foundation (NSF) education programs based on nanoscale science, engineering, and technology.

The NSF invests in a comprehensive set of programs in formal and informal nanoscale science and engineering education (NSEE). Overall, these programs seek to address the "Learning" goal in the NSF FY 2006-2011 Strategic Plan *(Investing in America's Future*[1]), which is to cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens. In addition, the programs seek to increase understanding through research and evaluation of effective learning and teaching about nanoscience and technology. Thus, they also address the "Discovery" goal to foster research that will advance the frontiers of knowledge. These investments contribute to the National Nanotechnology Initiative (NNI) Societal Dimensions Program Component Area subtopic: Education-related activities such as development of materials for K-12 schools, undergraduate programs, technical training, learning in informal settings, and public outreach (PCA 7[2]).

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[1] National Science Foundation Investing in America's Future: Strategic Plan FY 2006-2011. http://www.nsf.gov/strategicplan; last accessed 09/24/2007.

[2] The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry. Supplement to the President's 2007 Budget. July 2006. p. 25. http://www.nano.gov/NNI_07Budget.pdf; last accessed 09/24/2007.

Background

The NSF investment in NSEE is important for several reasons. Nanotechnology is an emerging field with enormous potential economic impact and implications for preparing our future workforce. In addition, NSEE opens new prospects for teaching and learning science and technology. It is inherently inter-disciplinary, drawing from physics, chemistry, biology, engineering, and other fields. It focuses on a size range (one to 100 nanometers) intermediate between the atomic and macroscopic scale that heretofore has been less studied and taught, yet involves new materials exhibiting unique and useful properties. As a result, nanotechnology offers a nearly limitless range of interesting applications that will likely impact our lives and society. For this reason, an informed public is essential. NSEE fits into the larger picture of improving science and engineering education and literacy by providing a vehicle for engaging learners in current research and the ongoing process of discovery.

NSEE also presents challenges. The concept of scale, particularly outside the realm of our everyday experience, is difficult to grasp. Content drawn from nanoscale science and engineering (NSE) is abstract, complex, and involves quantum effects that are also challenging to understand. Like other areas of current science and technology, the body of knowledge constantly changes as new discoveries are made daily around the world. From an instructional standpoint, NSE content is not a part of the mainstream K-12 curriculum. Because they were developed a decade ago, the National Science Education Standards make no mention of NSE. Widely used and tested NSE curricula do not yet exist, and it is difficult to add new content to existing overcrowded curricula, state standards, assessments, and textbooks. There is limited educational research and evaluation about learning and teaching in this area.

This context has guided NSF program development in NSEE. The NSF investment for NSEE awards in FY 2007 was $28 million, out of a total NSF NNI investment of $373 million. The educational investments are made by the Directorate for Education and Human Resources, of which I am part, as well as by the Directorates for Research and Related Activities. Like other NSF education programs, the NSEE programs seek to target nearly all audiences, from young learners to older adults, through a wide range of educational activities. They 1) develop and research instructional resources for students in grades 7-12 and their teachers; 2) develop and research undergraduate NSE programs; 3) promote public engagement and understanding through museum exhibits, programs, media, and web sites; 4) offer education and outreach programs in conjunction with NSE research centers; 5) incorporate NSEE within core programs, such as those that provide research experiences to teachers and students; and 6) study the impact of these educational efforts through research and evaluation. Awards are made based on proposals submitted to NSF and recommended through the merit review process.

I would like to highlight examples that demonstrate the range of audiences and activities addressed through these educational investments.

K-12 Nanoscale Science and Engineering Education

Students in grades 7 to 12 are a key audience for introducing NSEE because many are beginning to consider future careers. NSF has funded a flagship program to bridge formal education and NSE research through the *National Center for Learning and Teaching in Nanoscale Science and Engineering* (NCLT) at Northwestern University, in partnership with Purdue University, University of Michigan, University of Illinois at Chicago, and University of Illinois at Urbana-Champaign (with collaborating partners Alabama A & M University, Argonne National Laboratory, Fisk University, Hampton University, Morehouse College, University of Texas at El Paso, and several public school systems). The mission of NCLT is to develop the next generation of leaders in NSE teaching and learning, with an emphasis on capacity building. The work is organized around five themes: Learning Research and Development—developing, testing, and disseminating learning activities; Nanoconcept Research and Development—introducing the latest concepts into science and engineering courses; Higher Education—training faculty and developing undergraduate courses and programs; Professional Development for High School Teachers—training teachers in nanoscience/engineering concepts; and Evaluation. Additional information can be found at http://www.nclt.us.

Other NSEE K-12 projects are developing materials for classroom learning and teaching. *NanoLeap* (Mid-Continent Regional Educational Laboratory) is creating and testing two month-long units in nanoscience to be used as replacement units in high school physics and chemistry courses (see http://www.mcrel.org/NanoLeap/). *NanoSense* (SRI International) is creating, testing, and disseminating a larger number of shorter curriculum units (see http://nanosense.org/). A *Workshop to Identify and Clarify Nanoscale Learning Goals* (University of Michigan) has assembled the most significant and developmentally appropriate learning goals in nanoscience for grade 7-16 learners; a report is currently in draft form.

These projects are examples of the NSF research-based approach to NSEE curriculum development, which involves interviewing students to determine initial conceptual understandings; determining appropriate nanoconcepts and associated learning goals; developing valid and reliable assessments of student understanding; developing learning activities; pilot-testing, assessing, and revising the activities; conducting teacher professional development; broader field-testing, further revising, and disseminating the activities; and assessing student understanding. To date, projects are at the pilot-testing stage. Although we are some distance from incorporating nanoscience as a major thread in the K-12 curriculum, these projects are developing and testing models that ultimately could lead to widespread adoption.

Nanotechnology Undergraduate Education

Advances in nanotechnology research also provide new opportunities in undergraduate education. With their focus on imaging and manipulating atoms, NSE offers a multitude of new interdisciplinary teaching opportunities for engaging interest and for broadening vision by undergraduate students of science, engineering, and technology. In so doing, NSE makes possible new strategies for enhancing science and engineering literacy, preparing the workforce for emerging technologies, and attracting a diverse group of talented students to the workforce of tomorrow. The most recent competition (FY 07) focused on nanoscale engineering education with relevance to devices and systems, and on the societal, ethical, economic and environmental issues relevant to nanotechnology. Nearly half the awards included funds to purchase equipment, such as scanning or atomic force microscopes, as part of the development of undergraduate courses, modules, or laboratory experiences.

Examples of Nanotechnology Undergraduate Education (NUE) awards in Engineering include: *Teaching Nanosystems Engineering to Early College Students with Active Learning Experiences* at Louisiana Tech University, which led to the nation's first Nanosystem Engineering B.S. degree program; *Integrating Nanoscale Science and Engineering into the Undergraduate Engineering Curriculum* at the University of Wisconsin-Madison, which has made possible the introduction of a new course and revision of existing ones; and *Introducing Nanotechnology into the Curriculum at a Predominantly Undergraduate Institution* at Jackson State University, which created courses and research experiences at a historically black university. The NUE program has been funding these types of awards since FY 04.

Nanoscale Informal Science Education

The *Nanoscale Informal Science Education Network* (NISE Net) was funded at the Museum of Science in Boston, in partnership with the Exploratorium in San Francisco and the Science Museum of Minnesota (along with initial collaborators: Oregon Museum of Science and Industry, North Carolina Museum of Life and Science, New York Hall of Science, Sciencenter in Ithaca, Fort Worth Museum of Science and History, Cornell University, University of Wisconsin-Madison, the Materials Research Society, and the Association of Science-Technology Centers). Now in its third year, NISE Net is establishing a national network linking science museums and nanoscale science and engineering research centers. It is developing exhibit units, educational programs, public forums, media, and other resources for implementation at more than 100 partner sites across the U.S. These activities will provide a wide variety of ways for the public to become engaged in and more knowledgeable about nanotechnology and provide a new model and national infrastructure for linking scientific research and informal education. Further information can be found at the NISE Net web site, http://www.nisenet.org.

NSF has invested in other Nanoscale Informal Science Education (NISE) awards aimed at increasing public understanding, such as *Earth and Sky Nanoscale Science and Engineering Radio Shows* and the traveling exhibition *Too Small to See*, which reached large family audiences at EPCOT Center in Florida and is now on tour to science museums across the nation. These awards were funded through the NSEE solicitation in FY 04 and FY 05.

Nanoscale Science and Engineering Centers Education and Outreach

Since 2001, NSF has funded the following Nanoscale Science and Engineering Centers (NSECs):
* Center for Nanotechnology in Society (Arizona State University)
* Center for Electron Transport in Molecular Nanostructures (Columbia University)
* Center for Nanoscale Systems (Cornell University)
* Science of Nanoscale Systems & their Device Applications (Harvard University)
* Center for High Rate Nanomanufacturing (Northeastern University)
* Center for Integrated Nanopatterning & Detection Technologies (Northwestern U.)
* Center for Affordable Nanoengineering of Polymeric Biomedical Devices (Ohio State)
* Center for Directed Assembly of Nanostructures (Rensselaer Polytechnic Institute)
* Center for Biological and Environmental Nanotechnology (Rice University)
* Center for Probing the Nanoscale (Stanford University)
* Center of Integrated Nanomechanical Systems (University of California at Berkeley)
* Center for Scalable & Integrated Nanomanufacturing (U. of California at Los Angeles)
* Center for Nanotechnology in Society (University of California, Santa Barbara)
* Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (University of Illinois at Urbana-Champaign)
* Center for Hierarchical Manufacturing (University of Massachusetts Amherst)
* Nano/Bio Interface Center (University of Pennsylvania)
* Center for Templated Synthesis and Assembly at the Nanoscale (University of Wisconsin – Madison)

along with Nanotechnology User Facility Networks
* National Nanotechnology Infrastructure Network (NNIN)
* Network for Computational Nanotechnology (NCN)

and Materials Research Science and Engineering Centers, several of which focus on NSE.

These centers and facilities all conduct various forms of education and outreach that complement their primary research activities. The following list indicates the many types of programs that the centers and facilities develop and conduct:

- Research experiences and internships for teachers, undergraduates and high school students
- Courses and modules for undergraduates in two- and four-year colleges
- Professional development workshops and summer institutes for middle and high school teachers
- Hands-on activities for middle and high school classrooms and community organizations
- Tours, demonstrations, and Open Houses for visiting school groups
- Summer camps for middle and high school students
- Learning modules and kits for students
- Traveling exhibitions and public presentations for science museums
- Brochures on career opportunities for high school guidance counselors
- Web sites for students and the public
- Cable television broadcasts
- Planetarium show

Both formal and informal education components are required in the new solicitation to establish a Center for the Environmental Implications of Nanotechnology (CEIN), which is intended to conduct fundamental research and education on the implications of nanotechnology for the environment and for living systems. (This Center will be funded by NSF in partnership with the Environmental Protection Agency.)

Nanoscience and Engineering Education in Core Programs

In addition to those programs for which NSEE has been the primary emphasis, many other awards throughout NSF support education in NSE. For example, in addition to funding the previously-mentioned NISE awards, the *Informal Science Education* (ISE) program has funded projects, such as *Nanotechnology: The Convergence of Science and Society*. Through this award, Oregon Public Broadcasting is producing three one-hour nationally broadcast programs on the societal implications of nanotechnology using the Fred Friendly Seminar format. Other ISE awards include nanoscale science and engineering among other content areas, such as *Research Video News* by ScienCentral, which produces 90-second segments for national broadcast on commercial television news programs.

The *Advanced Technological Education* (ATE) program focuses on the education of technicians for the high-technology fields that drive our nation's economy. The program involves partnerships between academic institutions and employers to promote improvement in the education of science and engineering technicians at the undergraduate and secondary school levels. The ATE program supports curriculum development; professional development of college faculty and secondary school teachers; career pathways to two-year colleges from secondary schools and from two-year colleges to four-year institutions; and matriculation between two-year and four-year programs for K-12 prospective teachers. One example is the *Penn State Center for Nanotechnology Education and Utilization* (CNEU); its resources focus on incorporation of nano-technology into K-12 education, post-secondary education, and industry applications. The work of CNEU has resulted in associate degree programs in nanofabrication at 20 institutions across the state, including every Pennsylvania community college.

The *Research Experiences for Teachers* (RET) program provides supplements to new or renewal NSF proposals by which Principal Investigators (PIs) can offer K-12 teachers and community-college faculty research experiences at the emerging frontiers of science, which include NSE. The goal of these supplements is to transfer new knowledge into the science classrooms. The *Research Experiences for Undergraduates* (REU) program provides similar types of supplements for research awards and also funds REU Sites for multiple students.

The *Centers of Research Excellence in Science and Technology* (CREST) program makes resources available to enhance the research capacities of minority-serving institutions by establishing centers that integrate education and research. CREST seeks to broaden participation of students historically underrepresented in science and engineering, to promote the development of knowledge, and to increase faculty research productivity. Examples of the growing number of centers whose focus is NSE include: Tuskegee University's Center for Advanced Materials, the Center for Nanomaterials Characterization Science and Processing Technology at Howard University, and the Center for Nanobiotechnology Research at Alabama State University. A related program, *Louis Stokes Alliances for Minority Participation* (LSAMP), also supports NSE activities for both students and faculty.

Other efforts to broaden participation in NSE are funded through the *Experimental Program to Stimulate Competitive Research* (EPSCoR), which seeks to promote scientific progress nationwide. Examples are the New Mexico Nanotechnology Teacher Professional Development Workshops and the Center for BioModular Multi-Scale Systems (CBM^2) Education and Outreach program at Louisiana State University.

The NSF *Graduate Teaching Fellows in K-12 Education* (GK-12) program provides funding to graduate students who work collaboratively with teachers and students in K-12 schools. These interactions are designed both to introduce students and teachers to frontier research, often based in NSE, and to enhance learning and instruction in schools. The *Integrative Graduate Education and Research Traineeship Program* (IGERT) funds interdisciplinary research-based, graduate education and training activities in emerging areas of science and engineering, such as NSE. Those awards include novel approaches to training, mentoring, career development, and other aspects of NSE graduate education to prepare students to enter the workforce and pursue research careers; they often also involve outreach to schools, science museums, and community organizations. Also, awards made in the *Faculty Early Career Development* (CAREER) *Program*, which emphasizes the integration of research and education activities, frequently focus on NSE research.

In addition, many NNI-related research awards include education and outreach activities as a means to meet the Broader Impacts review criterion required of all NSF proposals.

Coordination and Evaluation

Within NSF, the diverse NSE and NSEE programs are coordinated, and priorities are determined, through the National Nanotechnology Initiative (NNI) Working Group chaired by Mihail Roco. This group meets regularly to discuss issues related to program planning and implementation, as well as budgets. NSF staff also participate on interagency committees, such as the Nanoscale Science, Engineering and Technology Subcommittee (NSET) of the National Science and Technology Council (NSTC) and its working groups. For example, I serve on the Nanotechnology Public Engagement and Communications (NPEC) Working Group. It provides a forum for sharing NSEE issues with representatives from other federal agencies. In this capacity, I assisted in organizing the Public Participation in Nanotechnology Workshop in May 2006, which brought together NSE representatives from government, industry, non-governmental organizations, media, and academia, including formal and informal educators. That workshop represented a first step towards engaging diverse stakeholders in educational and societal issues related to nanotechnology.

NSEE workshops were held in October 2005 and January 2007 to encourage creation of a community of practice among NSE educators from NSF-funded projects. The participants included representatives from formal education, informal education, and those conducting outreach at NSE research centers. In addition to fostering networking and collaboration, these workshops provided forums for exchanging ideas, sharing progress, and gaining complementary knowledge. In addition, NSEE project PIs participate in panels on education and outreach at the annual NSF NSE Grantees Conferences. Similarly, NSE research PIs and graduate students participate in the annual meetings of the NISE Network.

A third NSEE workshop is being planned for November 2008. It will include an international component to share perspectives and approaches to NSEE from other nations. Since many of the early NSEE projects will be close to completion by this time, the workshop will provide an opportunity to disseminate findings so that others can begin to build on the initial body of work. In addition, the workshop discussions will help inform NSF as it considers new opportunities for further investments in NSEE.

Planning at NSF will be further guided by a program evaluation planned by the Division of Research on Learning in Formal and Informal Settings (DRL) of awards made through the NSEE solicitations. Analyzing and synthesizing project reports, preparing case studies, and studying the impact of collaborations between NSE researchers and educators will add to our preliminary knowledge of NSE learning and teaching.

Nanotechnology in the Schools Act

The intent of the Nanotechnology in the Schools Act (H.R. 2436) to strengthen the capacity of high schools and universities to teach students about nanotechnology is commendable. However, the Administration has concerns that the program in the legislation is inappropriately structured to effectively meet this objective. For example, it is unclear that special equipment is a priority need to teach students nanotechnology effectively. Moreover, because nanotechnology is broadly defined as multi-disciplinary science and engineering at the molecular scale, “equipment” under the legislation could encapsulate a wide variety of routine tools and supplies that should remain the responsibility of recipient institutions or local education agencies, not the Federal government.

To this end, the Administration recommends addressing the goals of the legislation through a variety of ongoing approaches by NSF. For example, several existing programs embed NSF funding of nanotechnology equipment purchases within comprehensive sets of integrated activities that are more likely to achieve intended educational outcomes. These grants enable PIs to develop innovative approaches to NSEE, and generally require formative and summative evaluation to ensure that the materials and approaches taken as a whole—not just tools and instruments— are effective with the target audience and that others can learn from and build on the knowledge gained.

In addition, cyber-enabled learning is beginning to suggest promising new directions for engaging students through growing resources for NSE images, simulations, and remote access to instrumentation. Students can even take part in virtual field trips. For example in one of the approaches tested in the *NanoLeap* project, high school students "visited" the Stanford Nanofabrication Facility online, where they interacted with researchers in real time.

The Subcommittee should perhaps consider revisiting this issue after further knowledge has been gathered from current NSEE projects about the potential educational impact of the various approaches being developed for students in K-12 classrooms, two- and four-year colleges, and the public. Given the current limited state of knowledge about NSEE, the first priority is to determine which educational strategies are most effective for these different audiences based on research and evaluation. Such a direction also would be consistent with the increasing emphasis on research, development, and evaluation in NSF educational programs as preparatory steps towards implementation and scale-up.

Mr. Chairman, thank you again for allowing me the opportunity to testify on this important matter. I hope that these comments provide a helpful context for you as you continue to discuss best practices in addressing our national needs in science and engineering education.

I would be glad to answer any questions.