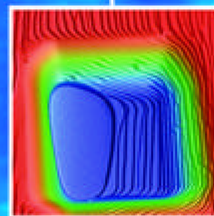
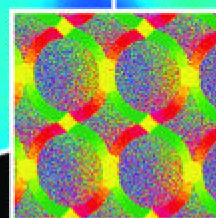
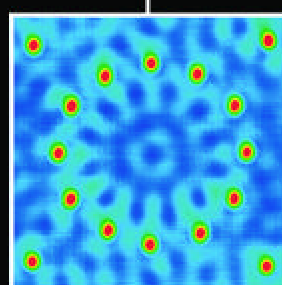
Advancing Infrastructure for Innovation

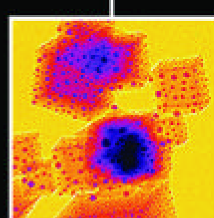
American Institute of Physics' Corporate Associates
2005 Meeting Report

Including the Academic-Industrial Workshop









November 6-8, 2005
Gaithersburg, MD

Hosted By

NIST
National Institute of Standards and Technology

2005 Industrial Physics Forum
for Corporate and Academic Leaders

MISSION STATEMENT OF THE AIP CORPORATE ASSOCIATES

To serve the industrial physics community by improving the effectiveness of people and organizations in advancing corporate goals through the use of physics.

2005
INDUSTRIAL PHYSICS FORUM REPORT

Advancing Infrastructure for Innovation

National Institute of Standards and Technology
November 7-8, 2005, Gaithersburg, Maryland

Technological advance and innovation have long been hallmarks of our nation, but never has innovation been as important to our economic security and welfare as it is today, when the rapid development of global markets makes it increasingly difficult for the U.S. to compete globally in commodity products. Within the past year, organizations ranging from the business-oriented Council on Competitiveness to the American Institute of Physics (AIP) have pointed to the need for a strong national innovation policy to maintain U.S. competitiveness.

But technological innovation in the 21st century depends critically on a strong underlying infrastructure of advanced measurement technologies. Nanotechnology—clearly an area ripe for innovation—requires the ability to observe, manipulate and control objects and events on the scale of individual atoms and close to the limits of much modern measurement technology. Biotechnology, another innovation growth area, has much the same needs plus the ability to observe and quantify webs of complex biochemical reactions that we are just now coming to understand. Quantum technology ups the ante with the added complication of the bizarre nature of quantum-level events.

Further downstream, our ability to commercialize innovations and market them globally often depends on having in place an infrastructure of generally accepted standards and protocols to ensure our entrée into foreign markets. These insights provided the thematic underpinning of the 2005 Industrial Physics Forum, hosted by the National Institute of Standards and Technology (NIST) and held in Gaithersburg, Maryland, November 7-8, 2005.

About NIST

As the nation's expert on how to measure things, NIST stands at the critical nexus between science and industry. NIST brings to bear a multidisciplinary staff of 3,000 that includes some of the world's top scientists and engineers, together with about 1600 visiting researchers. The Institute manages some of the world's most specialized measurement facilities—including the NIST Center for Neutron Research user facility, where cutting edge research is done on new and improved materials, advanced fuel cells, and biotechnology, and a new Advanced Measurement Laboratory that is the most technically advanced facility of its kind in the world.

The mission of NIST is to promote U.S. innovation and industrial competitiveness by enhancing measurement science, standards and technology in ways that enhance economic security and improve the quality of life for all Americans. David Seiler, chief of NIST's Semiconductor Electronics Division, pointed out in his opening remarks that innovation alone, however, is not sufficient without some way of using or benefiting from it. "Especially when it comes to manufacturing, we need an established infrastructure, so that innovation can take place in the appropriate context," he said. "NIST can be a unique and valuable partner in research endeavors," said Seiler. In fact, the agency relies on partnerships to innovate and to achieve its mission to move research results into practice. It has maintained strong partnerships with industry, academia and other government agencies since 1901.

THEME SESSION:
ADVANCING INFRASTRUCTURE FOR INNOVATION

NIST Director William A. Jeffrey opened the theme session by outlining the agency's role in U.S. competitiveness. In December 2004, the Council on Competitiveness released a report calling for a new era of innovation to drive future economic growth, claiming, "Innovation will be the single most important factor in determining America's success through the 21st century." According to Jeffrey, technology accounts for one-half of GDP growth in all industrialized nations (except Canada). In the U.S., the most high-tech segments of the national economy—electronics, pharmaceuticals, communication services, and software and computer-related services—account for 7-10 percent of our total GDP. For several decades, productivity in high-tech manufacturing has grown three times as fast as for all of manufacturing. Furthermore, the increase in U.S. productivity growth that began in the mid-1990s is entirely due to technology investments, and the productivity advantage of the U.S. economy over other countries accounts for three-quarters of the per capita income gap.

NIST is an incubator for tools and technologies that support U.S. industrial competitiveness. Jeffrey cited the example of the laser, which began as a laboratory instrument and eventually moved into the commercial marketplace, where it is now a critical component in numerous everyday technologies and products, from laser pointers and DVD players to telecommunications, tattoo removal, and laser eye surgery. In nanoscale electronics, NIST has developed the world's most accurate electron counter. It has also been involved in enabling components for the microfluidic lab-on-a-chip technology to detect trace chemical toxins within seconds. "We're in the business of making tools for innovation and competitiveness," said Jeffrey.

Today, the R&D enterprise is becoming increasingly globalized. India and China have emerged as new markets, bringing strong international competition. The report of the Task Force on the Future of American Innovation, released in February 2005, presented several sobering findings, concluding, "Although the U.S. still leads the world in research and discovery, our advantage is eroding rapidly as other countries commit significant resources to enhance their own innovative capabilities."

In this era of globalization and increased international competition, innovation is more important than ever in maintaining a competitive edge. The U.S. must innovate, or abdicate the world leadership position it has so long enjoyed.

Kathleen Higgins, assistant to the NIST director for homeland security, outlined NIST's current activities in the aftermath of the terrorist attacks of September 11, 2001. NIST is engaged in a wide variety of projects to assist the millions of individuals in law enforcement, the military, emergency services, information technology, airport and building security, and other areas to protect the American public. It does this by drawing on its core competency of refining the science of measurement to enable the ultra-precise engineering and manufacturing required for today's most advanced technologies, not to mention the extensive standards development and testing it does on behalf of both the private sector and government agencies. NIST has long promoted U.S. economic growth by assessing quality control. "We work on behalf of industry," said Higgins. That expertise in providing a foundation for the country's technological edge in the global marketplace is now proving vital to developing and implementing new technologies to prevent, respond to, and mitigate terrorist attacks.

For example, NIST is developing new and more accurate tools for measuring radiation, as well as low-cost gas microsensors and portable detectors for biological and chemical agents. The agency is also developing devices for far-infrared explosives detection; sensors to detect toxins in the water supply; and portable x-ray systems for bomb detection. In partnership with its collaborators, NIST is investigating new technologies for concealed weapons detection at a distance, and through-wall surveillance.

According to Higgins, bolstering national security doesn't just protect individual citizens; it also protects the economy. Both the public and private sectors are dependent on public safety, and security-related efforts can lead to improvements in technologies that can in turn spur more economic growth. In Higgins' view, performance standards will continue to play a vital and growing role in U.S. economic growth and competitiveness. Standards should be viewed as windows into what customers need, so that companies can ensure they have the technological capability required to meet those needs. "Compliance gets you into the game, but the real competitive edge comes from exceeding those standards through innovation, raising the bar for an entire industry," said Higgins.

Michael Postek, assistant to the NIST director for nanotechnology, described NIST's focus on nanometrology. Accurate nanometrology is critical both to nanotechnology and to nanomanufacturing. "Only those things that can be measured can be fully understood and if you can't measure it, you can't make it with the necessary precision," Postek said. Nanotechnology is one of the most dynamic growth areas both in the U.S. and in the global economy, soon expected to be valued at $1 trillion per year. But it requires atomic level accuracy and repeatability, and this in turn relates to the ability to precisely measure performance attributes at the nanoscale. NIST is the leading agency for such measurement, so nanotechnology is pervasive at all of its labs. NIST has more than 120 nanotech-related projects for FY2004-2005, and this work accounts for about 15 percent of the total NIST budget.

Postek gave several technical examples of the more than 100 nanotechnology-related research projects underway at NIST, much of which is done collaboratively with industry and university partners. These included controlled growth of single-crystal nanowires; a new infrared tool for measuring silicon wafer thickness, which is critical for an industry that requires its wafers to be perfectly flat and of uniform thickness; chip-scale refrigerators for nanoapplications to combat heat problems as devices get smaller and smaller; gas systems patterned with conducting polymers, which are cheap, flexible and easy to synthesize but difficult to process; a miniature magnetometer sensor to measure magnetic field changes as small as 50 pico-teslas; and a laser-based method for identifying single atoms and molecules using an "optical nose."

NIST has several unique measurement and research facilities for doing this work, most notably the Advanced Measurement Laboratory, which is designed to be the most environmentally stable laboratory in the world, featuring unprecedented temperature, humidity, air quality, and vibration control. In addition, NIST has established the Nanomanufacturing User Facility (recently renamed the Center for Nanoscale Science and Technology), which will open in 2006. The focus of the research there will be removing the barriers to U.S. innovation in nanotechnology by bridging the gap that currently exists between R&D and viable products—known as "the valley of death" in industry. "It's all about converting science into technology for manufacturing," said Postek.

Modern health care is a measurement-intensive business, according to Linda Beth Schilling, director of chemistry and life sciences for NIST's Advanced Technology Program, who talked about the agency's work in developing metrology methods and standards for biosystems and health. U.S. health care currently costs an estimated $1.9 trillion annually, and those costs are projected to increase 7.3 percent per year over the next decade. As much as 15 percent of that money is spent on measurement and diagnostics, and more than a quarter of that percentage is spent on non-diagnostic measurements, namely, repeat tests and error prevention and detection. Through research, improved test methods and data, and the establishment of clinical and health-related reference standards, NIST is helping clinical laboratories, medical manufacturers, hospitals, drug makers and biomedical researchers improve the accuracy of medical tests, saving money while also improving patient outcomes. In all, NIST produces nearly 100 health-related SRMs (Standard Reference Materials) for quality control in health care.

NIST plays an increasingly important role in bioscience research, which draws heavily on almost every other scientific discipline. For example, physics, engineering, and surface science feeds into nanotechnology research, while mathematics, physics, chemistry, electronics and information science all contribute to gene sequencing and genome research. NIST's unique cross-disciplinary perspective and cutting-edge research capabilities allow it to bring tools and expertise from all the disciplines to bear on the key challenges in bioscience. Health care and bioscience projects at the agency span a broad range of activities, from basic research on the measurement of single molecules or the behavior of cell membranes, to clinical applications such as calibrations of mammography equipment. There are also more than 150 R&D projects underway at NIST labs, and since 1990 the agency has contributed more than $500 million to cost-shared, industry-led advanced research projects in health care.

Dennis Swyt, director of NIST's U.S. Measurement System (USMS) Project, wrapped up the session. The USMS is an extensive, complex and non-hierarchical infrastructure that includes every firm and person in the country involved with making or using measurement for economic purposes, as well as every organization in the U.S. that supports making valid measurements. "We all depend every day on the effective operation of the USMS, but no one is in charge of this system," said Swyt. "It's the ultimate distributed model." NIST is responsible for setting the national standards of physical measurement, not for determining whether the USMS is adequately meeting the country's measurement needs. However, the agency has been persuaded to make an assessment of industrial measurement needs relative to technological innovation to determine the state of the USMS. The study will focus on three sectors: semiconductors, automotive, and software and information technology.

NIST is applying its expertise in standards and measurement to benefit national security, public health, and the U.S. economy.

Laboratory Tours

Following the theme session lectures, conference participants toured NIST laboratories to see first-hand the various research activities and facilities provided at NIST. The tours covered six different categories. The biology and chemistry tour featured a look at NIST's recent work on single molecule manipulation and measurement, aimed at probing the molecular structure and expression of DNA and proteins. Those who opted for the materials and magnetics tour were treated to a glimpse of the agency's latest research on magnetic materials for sensors and high-speed data storage, as well as visiting NIST's Magnetic Engineering Research Facility and the Combinatorial Methods Center. The NIST Center for Neutron Research was the focus of a third tour; it is the most widely used neutron facility in the U.S., visited by more than 2000 researchers each year. Group members also toured the new Advanced Measurement Laboratory, which houses the fledgling Nanomanufacturing User Facility.

Physics and optics provided the focus for a fourth tour, providing conference participants with an overview of NIST's latest research in optical tweezers and nanocomponent manipulation; quantum information processing; and nanomagnetics. A fifth tour showcased NIST's Immersive Visualization Computer Laboratory, focusing on modeling "smart gels" and tissue engineering, as well as its work on providing measurements and standards for satellite remote sensing, and a new molecular measuring machine. The sixth and final tour focused on molecular electronics, the metrology of advanced electronics material, and a new atomic-scale linewidth measurement standard for the chip-manufacturing industry. All the tour groups received a glimpse of NIST's work on marine forensics and preserving historic shipwrecks, as well as an overview of its technical investigation into the collapse of the World Trade Center.

RECEPTION AND BANQUET

The day closed with a reception and banquet, also held at NIST. After the banquet, the 2005-2006 AIP Prize for Industrial Applications of Physics was presented to William A. Edelstein, formerly with General Electric's Corporate Research and Development Center, "for his pioneering developments leading to commercialization of high-resolution magnetic resonance imaging (MRI) for medical applications."

The highlight of the evening was a special lecture by NIST Nobel Laureate, William Phillips, on "Time, Einstein and the Coolest Stuff in the Universe." Phillips punctuated his points with such crowd-pleasing demonstrations as a frisbee made of liquid nitrogen. Albert Einstein redefined the concept of time with his theory of special relativity in 1905: instead of there being an absolute time, he asserted that time is simply whatever a given clock measures. So, scientists seek to build the most accurate clocks possible, basing their measurements on physical phenomena like the rotation of the earth (sundials), swinging pendulums and vibrating quartz crystals. But these mechanical clocks aren't perfect; their measurement of time can be affected by ambient conditions. Atomic clocks are the most accurate yet invented because they rely on the energy states of atoms. Atoms also "tick" or vibrate, and the rate at which they do so is identical for every kind of atom of the same element. For instance, every cesium-133 atom in the universe has an identical tick rate, whereas every quartz watch is just a little different than every other one.

Today, atomic clocks can be found on the 24 satellites of the Global Positioning System; they also enable many other military, scientific and commercial applications, such as encryption and high-speed communication. But motion can affect the accuracy even of atomic clocks. Special relativity says that the faster clocks move, the more slowly they tick. This effect is known as time dilation. In order to build more accurate atomic clocks, scientists must reduce the atoms' velocity. They can do this by lowering the temperature, since the colder the atoms are, the more slowly they vibrate—and therefore, the more accurate their time-keeping. Lasers can be used to chill atoms down to unprecedented temperatures; this is called laser cooling. As the atoms slow down, they cool to about 10 millionths of a degree above absolute zero. NIST has built atomic fountain clocks from ultra-cold atoms, which are the most accurate timepieces ever made: as of 2005, they are more accurate than one second in 60 million years.

The low temperatures that scientists have been able to achieve with laser cooling also verified one of Einstein's other predictions. In the 1920s, Einstein and the Indian physicist Satyendra Bose predicted the existence of a new form of matter called a Bose-Einstein condensate (BEC). If the temperature gets low enough (billionths of a degree above absolute zero) and the atoms are densely packed enough, the atoms will be able to coordinate themselves as if they were one big "superatom." In 1995, scientists at MIT and the University of Colorado/JILA used a combination of laser and magnetic cooling equipment to produce the first BEC, earning them the 2001 Nobel Prize in Physics. Scientists have since attained temperatures lower than one nanokelvin. These and other developments promise to produce clocks of astounding accuracy, which could improve the synchronization of GPS clocks, provide a worldwide standard of time-keeping, and improve ongoing tests of Einstein's theories of relativity.

POLICY SESSION:
GOVERNMENT'S ROLE IN STIMULATING NANOTECHNOLOGY FOR INDUSTRY

Tuesday morning's slated keynote speaker was Arden Bement, director of the National Science Foundation. Bement was regrettably called away to the White House, but Dave Seiler presented the text and slides of the talk in Bement's absence. There is some misunderstanding about what constitutes nanotechnology, according to Bement, who insisted that "working at the atomic level is not necessarily nano." There are three basic characteristics: nanotechnologies must deal with physical phenomena in the 1 to 100 nm range; they must feature new properties and functions that appear on this size scale; and stem from the ability to see and manipulate matter at the atomic scale. This is the official definition of the National Nanotechnology Initiative (NNI), a long-term federal effort to speed the pace of progress in nanoscale science, engineering and technology.

The NSF heads up the NNI, and provides the largest contribution to this interagency effort, with primary responsibility for investments in the fundamental research, education and research infrastructure. Government investment in NNI remains significant, with an FY2006 budget request of $1.05 billion. State and regional funds for nanotechnology research total $864 million. The field is becoming big business. Private corporations are pouring R&D funds into nanotechnology-related research, and it's expected that within a decade, global sales of nanotechnology projects could exceed $2.5 trillion. The reason for all the excitement is simple: the NSF and other government agencies recognizes nano as a "transformative technology" with potentially revolutionary impact on all facets of science and engineering, not to mention society as a whole. "The systematic control of matter at this scale will yield dramatically new technologies for electronics, medicine, aeronautics, the environment, manufacturing and national security, for starters," said Bement.

However, Bement cautioned that along with its great potential, advances in nanotechnology come with great responsibility, and therefore innovation in this area must be accomplished in conjunction with studies of the potential environmental and health impacts of the field. Today, there is growing public concern about safety issues relating to nanotechnology, which the scientific community ignores at its peril. "We must scrutinize the risks with the same aggressiveness that we embrace the rewards," Bement said. "Industry, academia, the general public and the science and technology research community have a major responsibility for the safety and ethical development of new nanotechnologies."

According to Mihail Roco, NSF's senior advisor for nanotechnology, the FY2006 federal budget request allots $1,054 million for the NNI, for fundamental research, establishing the nanotechnology infrastructure, and training and education. Currently, the U.S. accounts for about 70 percent of the nanotech-related startups worldwide and around 60 percent of patents; there were 1,645 U.S. nanotech companies as of March 2005. In 2000, the focus was on passive nanostructures: nanostructured metals, nanoparticles, coatings, and polymer ceramics. By 2005, much of that focus had shifted to active nanostructures: amplifiers, actuators, and targeted drug delivery. The next phase is third-generation nanotechnology: a systems approach that Roco hopes will result in the achievement of guided nanoscale assembly and robotics by 2010. The fourth and final generation is molecular nanosystems, in which scientists will be able to assemble molecular and atomic devices by design—hopefully by 2015 or 2020. By 2015, there will be as many as 800,000 workers in nanotechnology.

NNI is important for the NSF because it encourages the convergence of new technologies: most research projects are collaborations featuring multidisciplinary teams, whether that research involves more sensitive nanobio-bar-code assays, nanoscale metal particles, light-driven molecular motors; or combinatorial engineering of nanomachines. Some of those efforts target near-term commercial applications, such as the manufacture of nanoactive materials: nanocrystalline materials with enhanced surface area and chemical reactivity, able to trap and destroy a wide range of toxic chemicals, as well as to the capacity to neutralize chemical warfare agents. Other breakthroughs include advances in drug delivery and cancer detection, super-hard metals, more efficient solar and energy cells, and progress in superconductivity and computing.

As Bement maintained, the NSF is also addressing long-term societal aspects, not just the immediate and continuing issues. Each manufacturing or R&D program, project or center is aligned to societal needs from the outset, and there are several efforts related to education, outreach and social implications of nanoscale research. For example, the Nanotech Center for Learning and Teaching targets high school and undergraduate students, while the Nanotechnology Informal Science Education Network works with select museum sites, such as the San Francisco Exploratorium and the Boston and Minnesota Museums of Science. The latter is a $20 million, five-year project that will ultimately include collaborations with many other science museums and research institutions. The goal is to couple interactive programs and exhibits with open public discussions designed to debate all aspects of this emerging field.

John Zolper, director of the Microsystems Technology Office at the Defense Advanced Research Projects Agency (DARPA), described nanotechnology research at DARPA, which invests in nanotechnology to produce new biophysics materials and microsystems to develop cutting-edge technological capabilities for the Department of Defense. The agency focuses primarily on areas like nanobiology and materials, nanoelectronics, nanophotonics, and NEMS (nano-electro-mechanical systems). While the armed services have a near-term science and technology research component, DARPA's approach is more long-term, with an emphasis on fundamental research, discovery systems, and concept invention. Zolper describes it as "mining the far side," with federal funding aimed at driving cutting-edge science to the point of technological feasibility. DARPA serves as a medium between the far and near-term R&D.

Carbon nanotubes are one primary area of focus. One of the challenges is how to grow and control the properties of individual nanotubes to weave long fibers, and to achieve higher manufacturing throughput for producing them. Other research focuses on exploiting the spins in semiconductor materials to achieve "spintronics." Silicon technology is now well into the nanodomain, and manipulating and controlling these structures is a major challenge. So developing new nanofabrication techniques for high-performance silicon-germanium transistors, for example, is key in order to scale new structures and improve device performance and manufacturing process flexibility.

Altaf Carim, program manager for the Department of Energy's (DOE) Scientific User Facilities Division, gave an overview of nanoscience and nanotechnology at the DOE. The DOE's Office of Basic Energy Sciences is charged with fostering and supporting fundamental research to provide the basis for new, improved environmentally conscientious energy technologies. Nanotechnology has been identified as a key cross-cutting theme in the area of energy and environment, both strong areas of focus for the DOE. For instance, development of the hydrogen economy and solar energy are among the major components of the NNI, since both those areas require new research in the area of nanotechnology and materials as key enablers. Major impact areas include solid state lighting and fuel cells in the area of energy, and sensors and remediation technology for the environment.

The DOE's "flagship" NNI activity is the establishment of Nanoscale Science Research Centers (NSRCs). Two new NSRCs have been completed and are now being equipped for operation. The NSRCs are envisioned as research facilities for synthesis, processing and fabrication of nanoscale materials, and many will be co-located at existing DOE national laboratories. It's about seeing atoms, providing user facilities to probe materials—a critical tool for enabling future breakthroughs in nanoscience. Access to neutron scattering tools is a key driver in this area, since neutrons provide unique complementary information regarding materials and phenomena at the nanoscale. Brookhaven and Argonne National Labs are both building neutron beam lines to study the growth of individual nanostructures, in combination with the synchrotron capabilities at those facilities.

Closing the session, Piotr Grodzinski, director of the NCI Alliance for Nanotechnology in Cancer (ANC), presented a talk co-authored with Gregory Downing, director of Office of Technology & Industrial Relations at the National Cancer Institute (NCI). Grodzinksi and Downing stressed the importance of leveraging federal investments in biomedical-related nanotechnology research. Cancer is now the top killer in the U.S.; some 570,300 Americans will die of cancer this year, at a time when death rates for heart disease and pneumonia are dropping. There is a need for a disruptive paradigm that will shift the approach to combating cancer, and the key might lie in nano-based biotechnology. This year, NCI launched the ANC, a $144.3 million initiative dedicated to early detection and therapy for cancer patients. The ANC is a five-year program designed to "ignite" nanoproduct development and commercialization, including molecular imaging and detection, in vivo imaging, and multifunctional therapeutics. The initiative requires academic and commercial partnerships for each project.

Clinical applications of nanotechnology include nanoparticles such as quantum dots, nanoshells, nanotubes and virus engineered particles. These enable non-invasive treatment. For instance, researchers can deposit gold nanoparticles into a tumor, and this can be used to burn the tumor away, because the gold is more sensitive to the heat from light. Another benefit is better sensing and imaging capability. Cancer often metastasizes before it can be detected, and the spread of tumors is difficult to control once this happens. Microfluidic nano-based sensors can help with early detection because they can monitor many different genetic and protein based biomarkers at the same time. As for drug delivery, standard chemotherapy treatment is non-specific. It doesn't reach just the tumor but kills healthy cells as well, and thus the therapy has toxic side effects. The solution is to deliver smaller payloads of the drugs delivered directly to the tumor site. Nanotechnology enables such targeted therapies, resulting in localized killing of cells, lower doses of chemotherapy and other drugs, and fewer side effects. The ultimate goal is drug delivery systems that combine targeting agents with efficacy reporters. The development of such multifunctional nano-platforms will enable researchers to be more effective in detecting and treating cancerous tumors.

Systemic control of matter on the nanoscale will lead to a revolution in technology and industry that will affect almost every sector of society. Nanotechnology not only makes transforming tools more powerful, but also carries a greater risk of unintended consequences than for other technologies, so long-term societal aspects must be addressed in conjunction with the R&D efforts. Federal agencies can and should play a vital role in supporting these efforts.

Frontiers in Physics Session

Ralph Lorenz, a professor at the University of Arizona, gave an update of the Cassini-Huygens probe sent to explore Titan, the giant moon of Saturn, by far the largest satellite around the planet known as the "Mars of the outer solar system." Among the "magnificent seven" satellites of the solar system, Titan is unique because it has an atmosphere, comprised primarily of nitrogen and methane, which causes a strong greenhouse effect. At 5000 km in diameter, Titan falls somewhere between our own moon and Mars in size, making it more like a planet. Cassini is the Saturn orbiter, while Huygens is the Titan probe. It was launched in October 1997 and arrived in 2004, seven years later. The Huygens probe went to the surface in January 2005; the descent took 2-1/2 hours. The probe transmits data to Cassini in real time so scientists have been able to see something resembling a shoreline. The fluvial channels in the landscale resemble desert washes—the types of features that result from flash floods. This is consistent with what is known about Titan's atmospheric makeup: there are very little oxygen bearing compounds and lots of water-bearing ones. Cassini continues to orbit Saturn, so more data will be gathered and analyzed over the next three to five years.

Ronald Wadsworth, a senior lecturer at the Harvard-Smithsonian Center for Astrophysics, reviewed the achievement of stopped light by Harvard researchers. In February 1999, the researchers found they could slow down light—which normally travels at 669,600,000 MPH—to just 38 MPH by shining a laser beam through a BEC. Two years later they briefly brought light to a complete stop. Stopping light raises the possibility of encoding information in atoms and transmitting it over light waves, in much the same way that we encode electrical signals onto radio waves. This is known as quantum communication, and it might one day allow ultra-secure data transmissions—but only if we could stop a light wave long enough to change its state and send it on its way again. The first time stored light was achieved, it was stored less than 1 millisecond, but researchers demonstrated they could preserve information about the light's phase coherence. In 2003 they showed they could preserve quantum correlations. By 2004-2005 storage time had been increased to 10 milliseconds; researchers were able to controllably generate single photons. The potential applications include all-optical delays and switches for telecommunications networks, as well as key technologies for quantum information processing, especially ultra-secure communication and ultrafast computing.

David Awschalom, a professor at the University of California, Santa Barbara, gave an overview of the history and recent progress of the field of spintronics. The goal is to create a new class of electronics using the spins of electrons to control the flow of information, and the technology offers an alternative or complementary direction for ongoing efforts to develop of quantum-scale computing. The spin-up/spin-down states of electrons correspond to the 0s and 1s of conventional semiconductor electronics. Controlling these effects at small size scales is a major challenge, but over the last 18 months, researchers have demonstrated the ability to create, transport, manipulate, store and detect electron spins—even imaging single spins in diamond at room temperatures. The potential payoff is huge. Ultimately, spintronics could link two highly lucrative technologies: the $250 billion global semiconductor market, and the magnetic recording industry, estimated at $150 billion worldwide.

Michael Deem, the John W. Cox Professor at Rice University, closed the session and the conference with a discussion of his work on evolvability, defined as the capacity or propensity of a biological system to evolve—including the mutation of disease-causing viruses like HIV, or certain drug-resistant strains of bacteria. Deem has studied how protein molecules adapt and evolve, and concluded that evolvability is a selectable trait. His computer simulations revealed that evolvability is enhanced by large amounts of genetic "swapping" triggered by harsher and more frequent changes in the environment, and that the more diverse a population, the greater the potential for evolution. The mechanisms that define genetic change are encoded in the genes and are therefore selectable, and mutational processes fundamentally determine evolvability. "There is selective pressure to evolve in a changing environment," said Deem. An organism must strike "a balance between staying in a favorable niche and adapting to a newly created niche." Deem's findings could have important implications for drug discovery, among other applications.

From the far reaches of Saturn near the edge of our solar system, to the tiny realm of photons, electron spins, and protein molecules, the Frontiers in

Physics session aptly demonstrated that cutting-edge physics research at all size scales has the potential to revolutionize both fundamental science and practical applications.

The 2006 Industrial Physics Forum will be held in conjunction with the AVS International Symposium in San Francisco, CA, on November 12-14, 2006. The meeting will take on a new format, and focus on “Nanotechnology in Society and Manufacturing.”

2005 ACADEMIC-INDUSTRIAL WORKSHOP

A Compelling Public Case for Science: The Scientist as Citizen

A Pre-Conference Workshop of the Industrial Physics Forum

November 6, 2005, Gaithersburg, Maryland

Approximately 35 participants representing research careers in academia, industry, and federal facilities gathered on November 6, 2005, in Gaithersburg, Maryland, for the 2005 Academic-Industrial Workshop, held in conjunction with the annual Industrial Physics Forum of the American Institute of Physics (AIP). Gary White, Director of the Society of Physics Students (SPS) and Sigma Pi Sigma (ΣΠΣ), welcomed meeting participants and put the meeting in context. The workshop was intended to stimulate dialog between industrial and academic leaders on subjects of mutual importance to them, and to the physics community as a whole.

This year’s workshop focused on the role of the scientist as citizen, particularly in building a compelling public case for science. Now more than ever, public support for science and technology is imperative to science funding. Public recognition of scientists as trusted sources of unbiased information is critical to maintain respect for science in the American culture. Scientists must play leadership roles in describing science and its consequences to citizens, decision makers, and taxpayers. This is why most federal programs that support science ask for, or require, scientists to propose to engage in topics labeled “broader impacts (NSF)” or “education and public outreach (NASA).”

Examples of activities that meet these requirements include giving interactive presentations at science centers, reviewing curricular materials for scientific accuracy, providing resources and input for the development of exhibits at local science museums, or even working with teachers in professional development programs. However, the current state of graduate and undergraduate education programs that prepares scientists does not place much emphasis on communication and leadership skills. This year's workshop provided a forum for describing current effective practice and offering recommendations for improved future practice.

SESSION I:
PARTNERSHIPS (LARGE SCALE NETWORKS)

The first session focused on the importance of investing in partnerships between working scientists and educators. Building these kinds of large-scale integrated networks is critical to the long-term health of scientific education, according to Cheryl Peach, co-director of the Scripps Center for Educational Outreach Connections. Peach opened the session with an overview of a large national network called the Centers for Ocean Science Educational Excellence (COSEE). COSEE is intended to spark and nurture collaborations between scientists and educators by making it easier for researchers to participate in science education and outreach. The network features multiple layers of partnerships: those between centers, between both research and educational institutions, and partnerships between individuals. Unfortunately, there is a wide communication gap between the two communities, which needs some form of facilitation in order to come together. That is the purpose of COSEE.

"Many within the research community view the broader impact criterion (of the NSF) as a burden," said Peach. "We are striving to make researchers see it as an opportunity to help solve a national problem—and scientists' participation has never been more important." Peach's job is to help scientists find good educator partners, and education and outreach opportunities, which match their research interests, available time, and budgetary constraints. The approach is successful because the partnerships are tailored to the individuals. According to Peach, most scientists are not trained adequately to be pre-college educators and shouldn't try to create their own educational products or programs without partnering with science educators. Fortunately, there are many high-quality, effective programs and projects that already exist. Through efforts like COSEE, scientists gain access to professionals with expertise in translating research topics into educational products—a skill that most researchers lack. And they are able to reach a more diverse audience of students, teachers and the general public.

The basic approach of COSEE has been demonstrated successfully on a local level, and the program now looks to scale up the model to a national level. Some strategies for accomplishing this objective include the establishment of a compendium of opportunities for scientists, as well as developing a guide to engage scientists and educators to work together in education and outreach. There is also a need for better collaboration with large initiatives and programs at the NSF, NOAA, and other federal and state funding agencies to coordinate all the efforts. Small contributions from many in the community often result in enormous impact. According to Peach, "without the advocacy and participation of researchers, science education in the U.S. will fall far short of what is necessary for the nation to continue to lead the world in science and technological innovation." Ultimately, the educational partners in the program will be able to take over the details so that partnerships can flourish on their own. COSEE's long-term vision is nothing short of broad cultural change in both the ocean research and science education communities, through the creation of a vast network of researchers and educators working together.

Susan Cook is education director for the Consortium for Oceanographic Research and Education (CORE), which serves as the public "face" of COSEE in Washington, DC. Cook offered a broader view of the COSEE network, describing her own perspective on building transformative partnerships. One essential component is striking the right balance between building large national networks, for the broadest possible impact, while still maintaining the creativity and flexibility of smaller regional efforts. The COSEE model focuses on a diverse grassroots approach, creating centers around the country—seven so far, with three more slated for completion by December 2005—all coordinated by a large national network. The emphasis is on so-called "catalytic linkages" to create successful partnerships.

Cook shared many valuable lessons learned through COSEE. For instance, trust and a shared vision can't be dictated by a mere program announcement; they take time to develop. Cook has found that the competitive culture of independent principal investigators is a major challenge. Many PIs question why they should be devoting precious financial resources on network activities that are well beyond their particular project's scope. "We must make the case that there is an added value beyond the sum of the individual parts," she said.

As COSEE moves into its fourth year in 2006, the program's goal has shifted to coordinated expansion and better integration. The agency is actively looking for more partners in government, academia and industry. In closing, Cook reiterated the need to involve the research community in the education and outreach partnership process in order to effect long-term change and jump-start vital connections between researchers and pre-college science education.

When scientists collaborate with individuals who work professionally in education and public outreach, both groups benefit.

SESSION II: THE DIGITAL AGE OF OUTREACH

The World Wide Web offers a powerful tool for making a compelling public case for science because of the numerous opportunities for reaching so many people, according to Cathryn Manduca, director of Carleton College's Science Education Resource Center. When it comes to science, the Internet can provide a source of unbiased information that is important to taxpaying citizens and policy makers. Effectively exploiting Web technology and online resources can help researchers make the case that science is important and relevant to our lives in the real world. It can also help disseminate the scientific worldview, namely, that unbiased science is a process—a methodology of thinking—not individual opinion or belief. Moreover, reported scientific results that are important to a specific issue should be brought to bear on that issue, both on an individual and public policy level. "We want our science to be used correctly," said Manduca.

The Web can be used in three ways for this purpose: (1) as a dissemination mechanism to present information or arguments; (2) to support inquiry and application; and (3) to mobilize action, such as with COSEE, which uses the Web as a support tool and a facilitator. But there are some surprising challenges to developing an effective Web site, according to Manduca. First and foremost, one needs to have a clear idea of the purpose and hoped-for objectives of the site: how can we help the user learn? Also key is finding ways to draw one's audience: we must encourage them to visit our Web sites for a significant length of time if we hope to make a lasting impact. Determining that impact is equally problematic, since there is currently no way to measure how much site visitors have learned from their browsing, or how they may have applied their new knowledge. None of these problems relate to the technology aspect of creating an effective Web site; instead, they relate to human behavior and ways of learning, which can vary widely.

Understanding how people use Google and other search engines should also inform Web site design. For instance, Manduca has found that most faculty in the geosciences are not thinking of their problems in terms of pedagogy. They get their information on pedagogy from their colleagues, not from books, the library, or the Web. They think about teaching in the context of the topics they teach, so they search for those terms. Furthermore, they are more interested in concrete examples, not abstract pedagogical methods. They search regularly for images and other useful information for the classroom, but they do not search for pedagogical information. So it's important to link the pedagogy to specific examples with images.

Manduca maintains that scientists can be proactive in making the public case for science, but building a virtual community takes just as much time and effort as building "real" communities. Scientists should be more involved and know what to say, when and how to say it, and they must understand the opportunities at local, national, and even international levels; for broader impacts for their research; for teaching beyond the walls of the classroom; and for being engaged as a citizen, not just a scientist. They need to know how to use the full spectrum of the communication tools available to them, and Web sites are one such potentially powerful tool.

David Mogk, a professor at Montana State University, augmented Manduca's presentation by providing some context for the rationale behind the "broader impact" criterion. Ultimately, the NSF seeks to integrate research and education, ideally to convey the joy of discovery and an awareness of its various connections, as well as an appreciation for the scientific method—directed inquiry, careful observation, and analytic thinking—to students at all levels.

According to Mogk, the 21st century workforce needs to know some science but may lack the necessary training to be able to navigate existing scientific resources, electronic or otherwise. For instance, the geosciences has a huge information database and existing infrastructure for specialists in the field, but it is impenetrable to non-expert users. "We need to create user-friendly interfaces to encourage access to this knowledge," said Mogk. He suggested minimizing the technology, which can be a barrier to learning, and linking information with pedagogy to encourage students to develop what he terms "scientific habits of the mind." For Mogk, "It's about making science alive and real for both students and other members of the public." Users should be encouraged to ask and explore topical questions to foster thought in a process of self-discovery. "We don't give the answer, but present the evidence and lay out the case for them with embedded resources," said Mogk, pointing to the use of integrated learning modules such as the history of the science. Making connections among disciplines is very important. It is equally important to integrate the science with discourse on public policy when appropriate. For example, one page on Mogk's Web site discusses impacts of uranium mining on Navajo nations, such as cases of lung cancer and other related health effects.

Mogk concluded with a 1954 quote from nuclear physicist J. Robert Oppenheimer, who mourned the increased specialization of science as "an inevitable accompaniment of progress; yet it is cruelly wasteful, since so much that is beautiful and enlightening is cut off from most of the world." Oppenheimer felt that it was "the proper role of the scientist" not merely to communicate research results to colleagues but also to teach, in an attempt to bring "the most honest and most intelligible account of knowledge to all who will try to learn." Oppenheimer's vision is just as apt in the early 21st century. The World Wide Web and similar technological resources can help foster communication between specialists and the public, thereby empowering students and citizens to use science to solve problems in their own lives.

The World Wide Web engages a much larger audience and provides a wide set of opportunities for education and public outreach.

Session III: Broadening Scientists' Perspectives: More Inclusive Science

Diandra Leslie-Pelecky, an associate professor at the University of Nebraska, Lincoln, clarified the NSF definition of "broader impact," which is often misunderstood by researchers. The term applies to grant-related activities whose results will not only be disseminated broadly to enhance scientific and technological understanding, but can also be shown to benefit society as a whole. The stated objectives are threefold: (1) advancing discovery and understanding while promoting teaching, training and learning; (2) building the requisite infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships; and (3) broadening the participation of under-represented groups, particularly women and minorities. These objectives are particularly important in light of recent trends regarding future technological workforce needs. By 2050, 24 percent of the total U.S. population will be comprised of Hispanics, with African-Americans accounting for 13 percent, yet these groups (along with women) are not proportionately represented among physicists and in related fields. The talent pool from which STEM fields can draw their future workforce will shrink even further if this under-representation is not addressed.

The NSF's definition is deliberately broad to allow researchers as much flexibility as possible in designing their grant projects, yet the requirement is often interpreted very narrowly. Leslie-Pelecky outlined some common misconceptions. For instance, NSF's list of examples has led some researchers to believe they must be involved in activities targeting K-12 and the general public. Leslie-Pelecky pointed out that the lists are examples, not requirements; researchers should become involved in activities that make sense within the parameters of their own research project. Second, some think that broader impact activities must be restricted to education and outreach, when in fact the definition also includes such areas as technology transfer and science policy. Third, some think they must develop something new and innovative, which can be time-consuming and require a lot of additional effort that many researchers can't really afford. But the NSF actually encourages researchers to adapt and build from existing materials and knowledge.

Leslie-Pelecky offered several hints for developing more inventive broader impact activities, based in part on suggestions made by participants in a May 2005 workshop, "The Broader Impacts Toolbox"—including scientists, education and outreach professionals, and representatives from professional societies. First, she insisted, "Don't re-invent the wheel." Make a point of reviewing the literature to see what's been tried and what's proven to be effective. Second, don't propose an activity that isn't tailored to the skills and resources one has on hand. Collaborating with those who have expertise in related areas is another option for enriching the scope of broader impact activities. Third, explicitly state the goals and expected results of one's broader impact activity, and make sure there is a mechanism in place for evaluating its effectiveness. Finally, be sure to disseminate those results to the broader community so others can learn what you did, how it was done, and whether or not it was effective. "It is in our community's best interest to engage as many people as we possibly can, but there are as many ways of doing this as there are individual scientists," she concluded.

While Leslie-Pelecky touched upon the issue of recruiting more under-represented groups in the physical sciences as part of a broader discussion of building an infrastructure, Roman Czujko, director of the Statistical Research Center of the American Institute of Physics, provided some specific numbers on the latest trends from a recent AIP survey. He began by citing two comments from scientists responding to the survey, both of whom opined that the notion of "under-represented minorities" in physics is either an exaggeration—with no corresponding need for efforts to address the imbalances—or an outright fallacy. To Czujko, such comments are particularly disturbing in light of his latest statistical findings.

With regard to the representation of women, the latest survey found that 57 percent of all BS degrees awarded in the U.S. in 2001 were earned by women, yet only 22 percent of those were awarded in physics. This is a marked improvement from 1966, when only 5 percent of BS degrees in physics were awarded to women. However, it compares unfavorably with many other countries: in Turkey, 39 percent were awarded to women, and in Poland, 36 percent. As for minorities, blacks and Hispanics combined accounted for only 4 percent of all BS degrees in physics awarded in 2001, compared to 10 percent and 5 percent, respectively in computer science.

To provide a broader context, Czujko pointed out that over the last five years, 6 million BS degrees were awarded. For every 100,000 students who earned BS degrees, 339 earned them in physics, 17 in oceanography and 14 in astronomy. But out of every 100,000 black students who earned BS degrees, only 161 earned them in physics. Historically black colleges and universities (HBCUs) graduated about 60 percent of all African Americans with BS degrees in physics. Czujko emphasized that three of the top five schools in this category were in New Orleans and are now gone, thanks to Hurricane Katrina, which could have a devastating effect on the numbers of under-represented minorities in physics in the future. The representation of minorities in physics remains staggeringly small, and location and geography appear to play a role in this.

To take advantage of the talent pool of the future, science must become more inclusive in many ways.

Roundtable Discussions

Workshop participants engaged in lively roundtable discussions following each session, and came up with a number of useful insights. First and foremost, they identified a critical need to overcome the prejudice that physics education is "not real physics." Education and outreach isn't really valued in academia; in fact, it's often viewed negatively because it takes time and resources away from actual research. The universities need to place greater emphasis on education and outreach in their tenure considerations to combat this attitude.

There aren't very many programs designed specifically for science teachers; this tends to be done within the science departments themselves. It's not an attractive career option for many physics majors because of the low pay and poor resources. Science teachers are rarely treated like professionals. The "No Child Left Behind" legislation has only added to the burdens and restrictions on teachers. One idea is to have the research universities interact more with the teaching universities, which can be very provincial and insular. And since faculty are often thirsty for research interaction, scientists can give talks at special seminars about how a research career works. Most research universities have such seminar series, and a similar model could prove effective in teaching universities. This would help the two communities learn to communicate on the same wavelength, since scientists and educators often use the same words differently.

There were several suggestions for new education and outreach activities. For instance, elementary and high school textbooks are "abysmally inaccurate." Scientists can provide the equivalent of peer review for such textbooks, either suggesting corrections as needed, or promoting Web-based tools and other supplementary teaching materials. Researchers in industry can be particularly valuable partners because one good way to communicate the importance of science is through applications of physics in our everyday lives. One problem is how one should evaluate education and outreach activities, since there is no good metric yet for determining whether something is effective. Merely citing the attendance at a given event isn't sufficient. As one participant pointed out, it's not just about the numbers: "If 50 people show up for a public lecture, how many are asleep?" Participants felt that the NSF should revise its reporting system to explicitly ask researchers how they satisfied the broader impact criteria for their grants.

Some questioned whether the NSF's "broader impacts" requirement is the best way to accomplish its stated objectives, and suggested that perhaps education and outreach activities should be considered separately from research grants. Providing supplemental funds for such activities that are still tied in some way to the PI's research would help avoid creating two tiers of people: those who do research and those lesser beings (in the eyes of many scientists), who choose to focus on education and outreach. Finally, not everyone has the skill or talent for education and outreach, and can sometimes do more harm than good. Perhaps not every scientist should be involved in those kinds of activities. Still, forming useful partnerships with those who do have a gift for education and outreach might ultimately produce more well-rounded scientists who can better communicate outside their fields.

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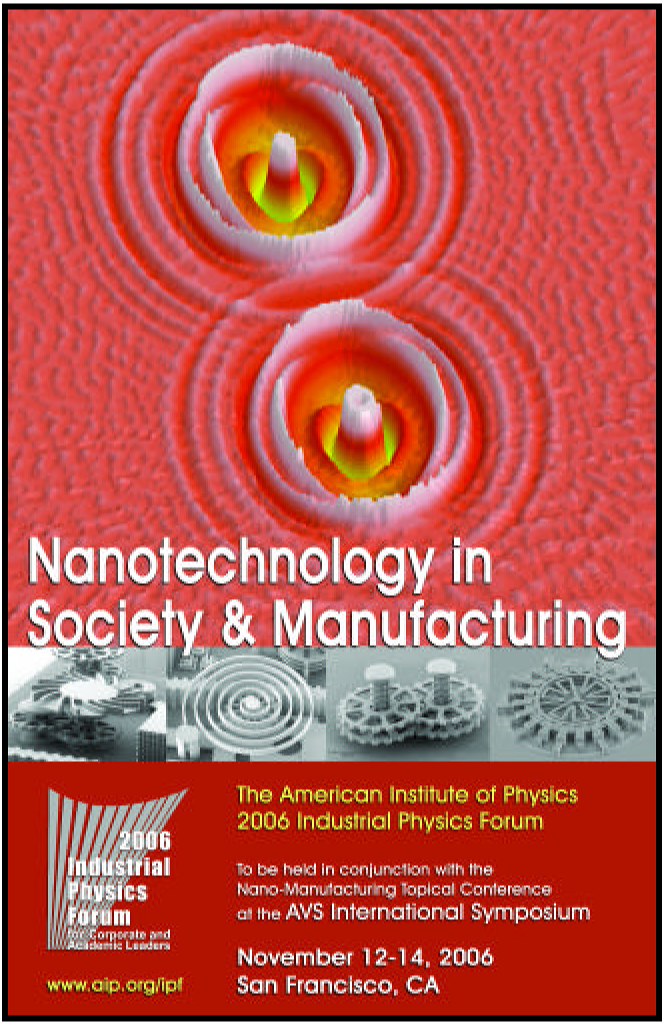

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