7. CENTER DIVERSITY—PROGRESS AND PLANS

The NSEC based at Harvard University is committed to increasing the diversity of the science and engineering workforce, and to making science and engineering accessible to a broad audience. NSEC faculty participants are dedicated to increasing participation by members of underrepresented groups and to giving these scientists and engineers the resources and guidance needed to succeed in each stage of their careers so as to become leaders in both education and research. Our strategic plan for increasing diversity builds on connections we have made through various programs, and seeks to increase our impact by developing new partnerships, both internally and externally. The recently released reports of the Task Force on Women Faculty and the Task Force on Women in Science at Harvard present several opportunities for leveraging NSF and University support to increase participation of women and underrepresented groups in science and engineering.

We have identified five broad goals that will be accomplished through a variety of initiatives: (1) to intensify the recruiting, support and professional development of a more diverse group of graduate students and postdoctoral researchers; (2) to increase the diversity of faculty participating in the NSEC; (3) to strengthen recruiting and mentoring of members of underrepresented groups through our joint REU programs; (4) to mentor pre-college students as they consider careers in science & engineering; and (5) to develop long-term partnerships with predominantly female and minority-serving institutions.

Goal 1: Recruiting, Professional Development and Support of a Diverse Group of *Graduate Students and Postdoctoral Researchers*

Graduate students and postdoctoral researchers are at crucial stages in their careers. Their experiences in terms of professional development, mentoring, and access to facilities and other opportunities have a significant impact on their career choices. Our goal is to leverage NSF and University support to recruit graduate students and postdoctoral researchers from underrepresented groups in science and engineering, and to provide resources to the students that will empower them to become educational and research leaders.

Strategy 1: Recruiting. Many of the strategies in place in the REU program to recruit highly qualified undergraduates to the summer program have been shared in recruiting of graduate students and postdoctoral researchers, including publicizing the graduate program and postdoctoral positions at conferences and on websites that reach a large population of underrepresented minorities. The Director of Educational Programs **Kathryn Hollar** coordinates with the Director of Graduate Admissions in SEAS and the Graduate Program Administrator in Physics share resources in these efforts.

More directly, we are using the REU program as a method to recruit students to our graduate programs. Since 2004, at least 12 former REU students have been accepted into graduate programs at Harvard, including 4 minority students and 6 women. Eight of these students are currently graduate students at Harvard (2 minority and 4 women).

Strategy 2: Professional Development and Mentoring. The NSEC has developed a program of professional development for NSEC-affiliated graduate students and postdoctoral researchers through the research exchange seminar and the AP298r course. Postdoctoral researchers and graduate students also have the opportunity to participate in our educational programs, including developing mentoring and project management skills through our REU program and experience in presenting to K12 classrooms through connections with the Cambridge Public Schools and our RET programs, and engaging the public at the Museum of Science, Boston.

The NSEC will also work in concert with the School of Engineering and Applied Sciences, the Chemistry and Chemical Biology Department, and the Physics Department and the University administration to leverage support for more professional development opportunities for graduate students and postdoctoral researchers. We will use some of our funding to support these professional development activities and for travel support.

Strategy 3: Support. The NSEC supports several postdoctoral researchers from underrepresented groups each year through prestigious postdoctoral fellowships. Past and present Postdoctoral Fellows are listed in ***Section 8--Education***. In the future, we will continue this valuable form of support, and also work with the university to offer opportunities for women and minority postdoctoral researchers and graduate students to form a community in which issues unique to underrepresented groups can be addressed.

Goal 2: Increase Diversity of *Faculty* Participating in NSEC

One of the major challenges facing the science and engineering community is to increase the diversity of the faculty ranks. The collaborative and interdisciplinary nature of the research of the NSEC provides a supportive environment that effectively integrates young scientists and engineers into a vibrant scientific community at the beginning of their academic careers. The NSEC also provides access to cutting-edge instrumentation facilities, which are a valuable resource at an early career stage. Furthermore, several NSEC Faculty have leadership roles at Harvard—e.g., **Narayanamurti**, Dean of HSEAS, and **Friend**, Chair of the Chemistry Department and Associate Dean of FAS—and are committed to making progress in this key area. Taken together, the NSEC at Harvard is ideally positioned to play a leading role in diversifying the faculty in science and engineering at Harvard.

Strategy 1: Partnership with Radcliffe Institute. Barbara Grosz, Dean of Science for the Radcliffe Institute, organizes a yearly Radcliffe Symposium on a topic that is important to the public and will draw an audience from Cambridge and nearby communities. Leading scientists and engineers address the issues and answer questions from the audience that address public concerns.

In 2005, the Center worked with Dean Grosz to set up the Radcliffe Symposium titled *Designing Biology*. Experts from biology, medicine, nanotechnology and business addressed questions of how scientists aim to use biological principles to predict and

control the behavior of biological systems by design, using tools developed at the interface of biomedical and physical systems. The speakers included Joanna Aizenberg (Bell Labs), Linda Buck (Fred Hutchinson Cancer Research Center), Angela Belcher (MIT), Vicki Colvin (Rice), Drew Endy (MIT), and Ellen Williams (Univ. of Maryland) from the research community. In the afternoon, a group including Mara Hart (Harvard Business School), Lita Nelson (MIT Technology Licensing Office), Bryan Roberts (Venrock Associates), and William Sahlman (Harvard Business School) talked about how one can transfer advances in research to business through licensing or by starting a new company. The Symposium attracted a large audience, including many local people who were engaged, and asked many interesting questions. Joanna Aizenberg recently joined the faculty of Harvard's School for Engineering and Applied Sciences, and will bring her expertise in biological materials here.

In addition to Symposia, the Radcliffe Institute supports fellowships to bring accomplished researchers to Harvard during the year. Rachel Goldman, a member of the Advisory Board for our Center, was a Radcliffe Institute Fellow in 2005-06.

Strategy 2: Leadership and focus in faculty hiring. The sciences and engineering at Harvard are experiencing a period of rapid growth, and faculty in the NSEC are in leadership roles at Harvard that can influence the recruitment and support of new faculty. The highly collaborative environment of the NSEC and the availability of world-class instrumentation also provides an ideal opportunity to develop the careers of new faculty. Junior faculty at Harvard contribute significantly to each research cluster within the NSEC. One recent example, is **Xiaowei Zhuang** who has played an important role in developing new directions in the NSEC. Close interaction with senior faculty helps new faculty to develop stronger individual research and educational programs. Senior faculty in the NSEC who are also in leadership positions at the department and university level include:

Professor **Cynthia Friend**: Chair of Chemistry and Chemical Biology
Professor **Robert Westervelt**: Member of Diversity Committee, Physics Department
Professor **Howard Stone**: Associate Dean of Academic Programs, SEAS
Professor **Venkatesh Narayanamurti**: Dean of Harvard School of Engineering and Applied Sciences

These faculty and others have a strong commitment to increasing diversity, as evidenced by participation in this dialogue at a national level. For example, **Cynthia Friend** co-chaired the recent workshop on *Building Strong Academic Chemistry Departments through Gender Equity* at NSF in Arlington, VA, January 19–21, 2006 (http://www.chem.harvard.edu/groups/friend/GenderEquityWorkshop/resources/pdf/Recommendations.pdf). This workshop, funding jointly by NSF, NIH, and DOE, produced a major report that serves as a blueprint for increasing diversity in academia.

Since 2002, we have increased the number of junior faculty supported by the NSEC from 1 to 6 in 2006; the number of women faculty supported has increased from 1 in 2002 to 3 in 2006.

Goal 3: Strengthen Recruiting and Mentoring of Underrepresented Groups through REU Program

NSF support for the REU programs of the NSEC and allied programs in Materials Research provides core funding for a growing undergraduate research program that includes substantial funding from Harvard. These joint programs, which now support over 45 students each summer, share a common infrastructure for recruiting, providing community and professional development activities during the program, intensive mentoring during the summer and post-program, and program evaluation and tracking. Connections made through our REU program's focus on diversity also serve as critical building blocks for our strategic diversity plan.

Strategy 1: Recruiting. A special initiative spearheaded by **Howard Stone** recruits and engages excellent students from Historically Black Colleges and Universities (HBCU) in our summer REU programs. This recruiting effort has expanded to include universities with predominantly Hispanic enrollments, and primarily undergraduate institutions that serve women. Faculty and staff have visited Morgan State University, **Howard**

Figure 7.1. *Left.* Professor **Bertrand Halperin** talks with visitors from the NSBP and NSHP joint annual conference. *Right.* Geoff Svacha (at right) gives students from the NSBP a tour of the **Mazur** group laboratory.

University, Morehouse College, Spelman College, Florida Agricultural and Mechanical University, the University of Puerto Rico (Rio Piedras and Mayagüez campuses), Sweetbriar College, Texas Prairie View Agricultural and Mechanical University, and North Carolina Agricultural and Technical State University. At these recruiting visits, we discuss not only the opportunities available at Harvard, but also the characteristics of a strong application for a research experience program. Former REU students at these institutions often lead discussions on the summer research experience. Additionally, faculty and staff recruit at professional and research conferences and career fairs for underrepresented groups, including the joint Annual Conference of the National Society of Black Physicists and the National Society of Hispanic Physicists; the National Society of Black Engineers, a National Conference on Hispanics in Engineering; New England Board of Higher Education Minority Career Fair at MIT. To reach a wider audience of applicants for our REU program, we partner with the Graduate Admissions Offices of

various departments, including SEAS and Physics, to distribute materials advertising our program at these conferences and career fairs. Attendance at these conferences aids us in recruiting students and in following up with past REU alumni. In 2006, we recruited at least 3 very talented students from these conferences to our REU program. In 2007, we hosted a reception and laboratory tours in conjunction with the National Society of Black Physicists and Hispanic Physicists joint annual conference in Boston, MA (Figure 7.1). We also hosted a visit by Morehouse College students who were exploring graduate programs during their spring break.

In addition to these recruiting visits, we also advertise on many websites and listservs that are resources for underrepresented groups. REU participants report that the internet is an important resource for finding summer programs; therefore, we also advertise on websites and listservs that target underrepresented groups in engineering, such as the Faculty for the Future website (www.engr.psu.edu/fff/), and the Women in Engineering Professional Advocates Network (WEPAN). These efforts resulted in an increase in applicants to the joint programs from 247 in 2004 to over 350 in 2007. As discussed in ***Section 8—Education***, targeted recruiting efforts have resulted in a diverse REU program. In 2006, 3 of the 9 NSEC-supported REU students were of Hispanic ethnicity, and 2 were African American; 4 of the 9 students were women.

Through the National Research Centers Educators Network (NRCEN), **Kathryn Hollar** has also made many connections with minority-serving institutions and organizations.

Strategy 2: Mentoring and Professional Development. The summer REU program includes many community-building and professional development activities for both REU participants and mentors, including a workshop on presentation skills, a luncheon on applying to graduate school, and weekly presentations by faculty on research and ethic. An intimate luncheon hosted by the Harvard Foundation for Intercultural Affairs gives students from underrepresented groups a unique opportunity to interact with a small group of faculty (Figure 7.2). This luncheon has resulted in many instances of mentoring that have extended beyond the summer program, and will continue to be an integral part of our plan for students from underrepresented groups.

Figure 7.2. David L. Evans, Senior Admissions Officer, shares his journey from sharecropper's son to engineer to admissions officer at Harvard during the Harvard Foundation's luncheon for REU students.

Strategy 3: Post-Program Mentoring and Tracking. The relationships developed during the program extend past the summer; mentors provide guidance and support as students apply to graduate school, and also include students in the process of writing and submitting papers that are based on their summer work. Students are encouraged to

present their work at local and national conferences, and funds are available through the REU/RET Site in Materials Research to support travel for mentors and REU participants to national conferences. These include the Materials Research Society fall conference in Boston, Massachusetts, the American Physical Society March meeting, and the National Society of Black Physicists and Hispanic Physicists.

Goal 4: Introduce *Pre-college Students* to Science and Engineering Programs through Summer Camps or Year-round Programs

We continue to expand our repertoire of activities for pre-college students and teachers, focusing on collaborations that effectively impact schools and students that have high need or significant achievement gaps between student groups.

Strategy 1: Increase Collaboration with Cambridge Public Schools at the High School Level. In 2006–2007, Cambridge Rindge and Latin School for a second year offered a course, "Research Seminar in Science, Technology, and Design," for advanced students. This innovative course is part of the *Cambridge Science Initiative*, which seeks to provide extraordinary opportunities for *all* students and teachers in Cambridge Public Schools through partnerships with universities, industry, and other community partners.

This involvement builds on a relationship and infrastructure already established through short-term assistance on science fair projects, including project mentoring and judging. We continue to support this course by advising students on how to select and narrow down projects so that some results can be obtained during the semester.

Strategy 2: Strengthen Collaborations with Cambridge Middle Schools, Parents, and the Community. As discussed below in ***Section 8—Education*****,** NSEC Faculty participate in Project TEACH (The Educational Activities of Cambridge-Harvard), which brings each 7th grade class from CPSD to Harvard for a college awareness and science presentation day. The Cambridge Public School District is an urban district that is over 60% minority, with 37% of students enrolled in a free or reduced lunch program.

Strategy 3: Develop Connections with Urban Schools through RET. Our RET program recruits teachers from local urban schools to participate in the Center's research and educational activities for 6–8 weeks during the summer. We encourage many follow-up activities with teachers, including classroom visits and field trips to Harvard. As we continue to build research and educational programs in close partnership with CPSD, we will integrate our RET teachers and their students into these activities.

Strategy 4: Pursue Internal Partnerships. A new partnership with the Harvard Graduate School of Education has developed links with pre-service teachers in the sciences through the NSF Noyce Scholarship Program. In the first year of the 3-year Noyce program, several teachers took graduate science or engineering courses with NSEC faculty. Our goal is to increase enrollment in graduate level science and engineering courses by Noyce participants by addressing scheduling of in-service dates and course offerings by NSEC faculty. We will also offer professional development

seminars that include course materials developed by RET participants during the spring and summer of 2007.

These four initiatives, natural extensions of established relationships, are examples of how we will continue to develop science education partnerships that engage students, teachers, and parents.

Goal 5: Develop Long-term Research and Educational Collaborations with Predominantly Female or Minority-serving Institutions

We will build on the connections we have made with predominantly minority-serving institutes through our REU program to develop research and educational collaborations. For example, **Howard Stone** visits Morgan State University each year to recruit students for our REU program. This connection will be strengthened by extending the visit to include a series of guest lectures in core engineering classes and a research seminar for students. We continue to build on the connections we have made with predominantly minority-serving institutes through our REU program to develop research and educational collaborations. In March 2007, we also hosted a visit by students from Morehouse College as part of their annual graduate program trip during spring break.

Our goal over the course of NSF support is to formalize these research and educational partnerships with predominantly female and minority-serving institutions by facilitating the exchange of educational strategies and developing research collaborations.

8. EDUCATION AND HUMAN RESOURCES

Center participants continue to be actively involved in programs that engage the public, teachers, students, and young scientists and engineers in the excitement of scientific discovery and increase awareness of the impact of scientific research on their daily lives. Our broad goals are to increase public engagement in and awareness of advances in nanoscale science and engineering, and to promote career advancement for a diverse group of young scientists who represent the future of science and engineering. We continue to enhance and expand existing programs and collaborations that address the needs of a diverse population (www.nsec.harvard.edu/education.htm). Our educational initiatives at the pre-college, undergraduate, graduate, and postdoctoral levels include embedded diversity initiatives and strategic collaborations whenever possible to encourage individuals from underrepresented groups to pursue careers in science and engineering.

Public Presentations—Holiday Science Lecture for Children and Families

Howard Stone, RET participant Meghan Walbran, Daniel Rosenberg (Harvard Science Center demonstration staff), and Educational Programs Director **Kathryn Hollar** developed the fifth annual interactive Holiday Lecture, "Science by Candlelight," that was held December 16, 2006. This child- and family-friendly science presentation is modeled after the Christmas Lectures first presented by Michael Faraday at the Royal Institution in London. This year's lecture was attended by over 750 children and adults.

Figure 8.1. Professor **Howard Stone** asks young audience members to help with a demonstration on the phases of matter.

Community Engagement—K12 Students, Teachers and Parents

In addition to events on the Harvard campus that engage the public, faculty, postdoctoral researchers, and graduate students, NSEC faculty also participate in off-site public science events such as science fairs and community science days. For example, **Jennifer E. Hoffman** devoted a day to the Davidson Institute for Talent Development (http://www.ditd.org/) which brought a group of 150 kids, ages 4–17, to Boston for a week of intellectual enrichment. She gave several presentations for the different age groups, explaining the physics of magnetism and the relevance of superconductivity and organized demonstrations (*e.g.,* levitating magnets *via* the Meissner effect in the high-T_c superconductor YBCO) to capture their interest. **Eric Heller** has given over 12 public lectures since 2003 on the history and current work in acoustics and nanostructures, which are quite analogous, to mostly lay audiences of about 100–150 people. He has also given public talks on images, art, and science to substantial audiences (300–400) in Telluride and New York.

Public Engagement—NISE-Net

The NSEC based at Harvard has been a strong partner in the NSF Nanoscale Informal Science Education (NISE) Network, which links multiple science museums, research institutions, professional organizations, and research centers. Harvard NSEC PI **Robert Westervelt** is serving as Chairman of the Advisory Board of the NISE Network and NSEC researchers **George Whitesides** and **Eric Mazur** are participating as advisors. In 2006–2007, researchers in the NSEC based at Harvard participated in several NISE Network programs. **Eric Heller** and **Eric Mazur** visited the Exploratorium as scientists-in-residence to develop interactive museum demonstrations on waves and optics at the nanoscale in 2006 and 2007. Education Director **Kathryn Hollar**, science demonstrations expert Daniel Rosenberg, and graduate student Tom Hunt participated in the NISE Network Nanoscale Education Outreach Workshop in May 2006, and

Figure 8.2. (*Left*) Tom Hunt, Amy Swint, Marni Goldman (Stanford), and **Kathryn Hollar** collaborate on an educational module at the Nanoscale Informal Science Education Network Nanoscale Education Outreach Workshop in May 2006. (*Right*) Dr. Michael Stopa talks with participants after his talk at one of the NISE-Net Public NanoForums at the Museum of Science, Boston.

developed an interactive talk for the Museum of Science, Boston on Atomic Force Microscopy, and a laboratory investigation on colloidal silver. NSEC postdoctoral researchers and graduate students have also participated in the NISE Network Public Forums on Nanotechnology as facilitators and speakers.

Pre-College Activities—Project TEACH

Through a continuing program, NSEC faculty share their enthusiasm for science through Project TEACH (The Educational Activities of Cambridge and Harvard). This early college awareness program is a joint effort of the MRSEC, the NSEC based at Harvard, and the Harvard Office of Community Affairs. Coordinated with the Cambridge Public Schools, Project TEACH brings each 7th grade class (approximately 400 students) from the Cambridge Public School District to Harvard University throughout the school year. During the visit, students receive information about college admissions, and learn about college life from Harvard undergraduates. The class visit culminates in an interactive science presentation by a NSEC faculty on his or her research and its societal benefits.

RET Program

The NSEC, in collaboration with an REU/RET Site in Materials Research and Engineering and a new RET Site of the National Nanotechnology Infrastructure Network, hosted six teachers in 2006. These teachers work with faculty, postdoctoral researchers, graduate students, and REU participants on research or science curriculum projects. 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.

RET participants also attend weekly seminars on research topics and on research ethics. The integrated nature of RET and REU activities, particularly the faculty seminars during the summer, provide ample opportunity for teachers to explore development of small classroom modules based on seminar content.

Figure 8.3. (*Left*) RET participant Katie Kaufman, kindergarten teacher in Lowell public schools, demonstrates some of the bubble experiments she developed to help her students understand scale. (*Right*) Josh Bridger shares his summer research and educational activities with National Nanotechnology Infrastructure Network Education Coordinator Nancy Healy at the 2nd Nanotech Symposium for Teachers at the Museum of Science, Boston.

In addition to weekly afternoon research and ethics seminars that were part of the REU/RET program, RET participants met weekly over lunch to discuss informally their research projects and how to best relate their summer research project to their curricula. The summer research experience for teachers culminated in a poster session. Teachers took these posters back to their classrooms to give students an introduction to scientific research, and to emphasize that science and engineering careers are accessible, interesting, and that science and engineering profoundly affect everyday life. These posters have also served as the basis for talks at regional and national conferences for teachers and faculty (Figure 8.3). Materials developed by teachers can be accessed at our website, www.eduprograms.deas.harvard.edu/RET.htm. NSEC-supported participant and project information can be found in Table 8.1.

Table 8.1: NSEC RET Participants, 2006

RET Participant Subject/School	Project Title
Joshua Bridger* *Physics* (Dover Sherborn High School, MA)	*Reactive Ion Etching Techniques and the High School Physics Curriculum*
Aaron Osowiecki *Physics* (Boston Latin School, MA)	*Electronics in High School: Introducing Transistors*
Meghan Walbran *Physics* (Weston High School, MA)	*Science By Candlelight*

* Joshua Bridger partially supported by NNIN RET program

This program also enriches our collaboration with the Museum of Science, Boston. RET participants Christina Talbot and Joshua Bridger shared modules, developed the Nanotechnology Symposium for teachers at the Museum of Science, Boston in November 2006, which served over 80 teachers in the Boston metropolitan area. This module was further disseminated at a workshop for teachers at the 2nd Annual Nanotechnology Conference, sponsored by the NSF Center for High-Rate Manufacturing, which reached over 70 teachers from New Hampshire. RET participants will also attend the National Science Teacher Association Annual Meeting in March 2007 to share modules with other RET participants across the nation.

Undergraduate Activities—REU Program

The NSEC has increased the number of REU participants by substantial supplemental funding from the School of Engineering and Applied Sciences (SEAS), Harvard College, and the Rowland Institute at Harvard (**Frans Spaepen**, Director). An NSF-funded REU/RET Site in Materials Research (PI **Cynthia Friend**) has also allowed us to expand our professional development opportunities for participants.

Figure 8.4 shows the demographic make-up of the nine REU participants who were fully or partially funded through the NSEC. Of these students, five were from under-represented minority groups in science and engineering, and 4 were female. Five of the students had no previous research experience. Of the nine participants, two were rising sophomores, two were rising juniors, and five were rising seniors. Three of the students were from institutions without major research facil-

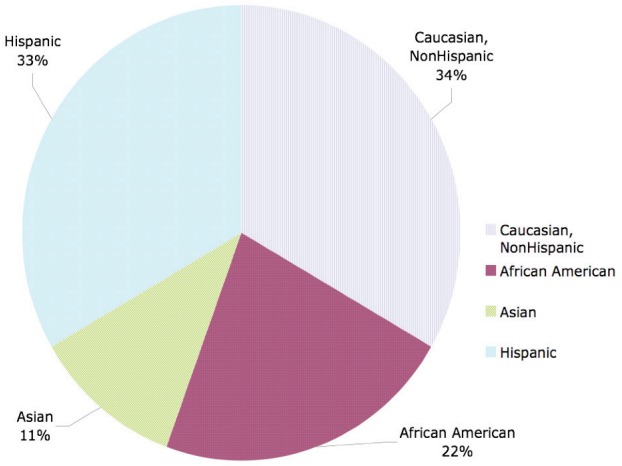

Figure 8.4. Racial and ethnic demographics of students receiving NSF support through NSEC.

ities, including one student from a community college. REU participants funded in part or in full by NSEC are shown in Table 8.2.

Table 8.2: REU Participants, 2006

REU Participant/Institution	Project Title
Nana Ayensu/Harvard University	*Electrolyte Material for Solid Oxide Fuel Cells*
Joseph Cox/Eastern Nazarene College	*Macroscopic Tunneling Phase Slips in Zn and Al Wires*
Carmem Domingues/Harvard University	*Spreading Behavior of Volatile Liquids on Immiscible Liquid Substrates*
Gunther Du Hoffman/Washington College	*Co-Localization of Integrin and Extracellular Matrix Ligands for In Vitro Investigation of Traumatic Injury to Neural Networks*
Josue Goss/Harding University	*Development of Techniques for Neuronal Outgrowth and Injury on a Patterned Surface*
Jeanette Kurian/Harvard University	*Tissue Imaging with Coherent Anti-Stokes Raman Scattering and Two-Photon Autofluorescence Microscopies*
Roanna Ruiz/Harvard University	*Magnetic Self-Assembly of 3-D Structures*
Limor Spector/Harvard University	*Manipulation of Casimir Force Magnitude Using Gold and Indium Tin Oxide*
Rafael Tilghman/North Carolina State Agricultural and Technical University	*Fabrication of Chromophore-doped PMMA Waveguides Using Femtosecond Laser Pulses*

The enhanced infrastructure provided by the REU/RET Site Program has allowed us to expand the program of professional development workshops, faculty seminars, and social and cultural activities that are designed to create community among participants and research advisors. These activities continue to include mentor training prior to the program start; weekly faculty-led research and ethics seminars; professional development workshops, including written and oral presentation skills workshops; large and small group discussions on applying to graduate school; and various athletic and social events during the summer.

One goal of our REU program is to develop essential skills in communicating effectively with scientists and the public. In collaboration with the Museum of Science, Boston, we hold a presentation skills workshop for REU students (see Figure 8.5). During this workshop, students receive guidelines from the staff of the Current Science & Technology Center at the Museum of Science, Boston, on how to present complex scientific concepts, then observe postdoctoral fellows and graduate students during a presentation and coaching session led by Museum of Science Staff. REU participants then see the final presentations at the Current Science & Technology Center at the Museum of Science, Boston. This format is very effective in increasing the confidence of these young scientists and engineers in discussing science with their peers and mentors, and demystifies the process of receiving constructive feedback. The workshop is followed by evening practice sessions in the week prior to the final symposium. An added benefit of the workshop format is that two presentations for the public were developed and given at the Museum of Science, Boston.

Figure 8.5. (*Left*) Adam Weiss, Education Associate at the Museum of Science, Boston, demonstrates some presentation techniques using physical props. (*Right*) REU students discuss their projects with their peers in a break-out session during the workshop.

In addition to the end-of-summer research symposium, mentors are encouraged to seek out opportunities for their students to participate in professional meetings. This type of early exposure to the professional life of an academic is essential in encouraging young scientists and engineers to continue in academia.

Mentoring an REU student is a valuable professional development opportunity for a graduate student or postdoctoral researcher, allowing this population to explore effective models for project management. To enhance this experience for mentors, we have implemented a series of program preparation sessions with REU mentors. New mentors participate in a series of luncheons in which faculty and other experienced mentors share strategies for mentoring undergraduate students, including planning a realistic project, modifying project goals, effectively managing time, and motivating students to work independently and as part of a team.

Graduate Activities—Course and Seminar Development

In addition to the mentoring and professional development activities embedded in our other educational programs, graduate and advanced undergraduate students participate in AP298r, *Interdisciplinary Chemistry, Engineering and Physics*, an interdisciplinary graduate survey course of ongoing research at the Center. This course has a new component, which requires students to translate each lecture into a short synopsis that is understandable at the level of a bright high school student. Lectures are also recorded and archived for future use by teachers in conjunction with presentations that are posted at the course website. These activities are further discussed in **Course and Seminar Development** below.

Postdoctoral Fellowships for Members of Underrepresented Groups

We have established Center fellowships to encourage the participation of women and minority groups in science and engineering. 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. These Postdoctoral Fellows include:

- Vidya Ramaswamy (Advisor Michael Aziz; now at General Electric)
- Amy Prieto (Advisor **Hongkun Park**, now faculty member at Colorado State University)
- Laurie Calvet (Advisor **Marc Kastner**, MIT, now in postdoctoral position in Paris, France)
- Heather Tavernier (Advisor **Moungi Bawendi**, MIT)
- Mark Bray (Advisor **Kevin Kit Parker)**
- Raquel Perez-Castillejos (Advisor **George Whitesides)**
- Maria Fyta (Advisor **Efthimios Kaxiras**)
- Xiaolin Zheng (Advisor **Charles Lieber**)

Course and Seminar Development

Applied Physics 298r: Interdisciplinary Chemistry, Engineering and Physics

Nanoscale Science and Engineering is an inherently interdisciplinary field that combines elements of Applied Physics, Biology, Chemistry, Electrical Engineering and Physics. While researchers in the field have a common knowledge of the most important topics, traditional courses don't provide the right breadth or depth. To introduce graduate and advanced undergraduate students to this new field, the Center has created *Applied Physics 298r: Interdisciplinary Chemistry, Engineering and Physics*. This course is given every other year, in the spring semester of 2003, and 2005, and currently in 2007.

Applied Physics 298r creates a introduction to Nanoscale Science Engineering in the following way: Each faculty member in the Center presents an tutorial lecture about the basic concepts that are important for their research area, and describes how these relate to other research in the Center. For example a lecture about the basics of semiconductor nanowires and nanowire devices, presents the basic ideas and describes how nanowires make possible new approaches to nanoelectronics and nanophotonics. The slides for each lecture are posted on the course website, so that they are available to the students, as well as to teachers and other people who may be interested. The students enjoy this introduction to the field very much — they learn about the range of activities in our Center and they consider possible directions for their own careers. The talks also show students supported by the Center what is happening in related areas. To make the lectures easily accessible to the community outside Harvard, we are asking AP298r students to provide a slide-by-slide text description of each lecture using everyday terms. This way, public school teachers and members of the public can learn about this new field. Please see the discussion in ***9. Outreach and Knowledge Transfer.***

NSEC Lectures

The Center brings outside experts to Harvard to present seminars about their research in Nanoscale Science and Engineering. Sometimes these NSEC Lectures are part of a regular series — for example, Lars Samuelson presented a Physics Colloquium about his research growing new types of nanowires. Other speakers are brought in to present specially scheduled NSEC Lectures about their research. This has proven to be a great way to show the students and faculty new ideas and accomplishments in this field.

9. OUTREACH AND KNOWLEDGE TRANSFER

The NSEC has strong partnerships with researchers from national laboratories, industry, and international institutions. During the past year, we worked closely with members of the Nanoelectronics Research Initiative (NRI) under a supplemental proposal to the NSEC aimed at ultrasmall electronics. We also sponsored a workshop in San Francisco on the Frontiers of Nanoscale Science and Technology (FNST) that brought together leading researchers from industry as well as many of our national and international collaborators. We strengthened our international collaborations with new connections to Lund University (Sweden), NEST (Pisa, Italy), and the Polish Academy of Sciences (Warsaw). We continued the visitor programs that allowed our postdoctoral fellows and graduate students to travel to our collaborators and provided valuable educational and professional experiences. We hosted several international delegations visiting the Center, sponsored the local NanoTechnology Business Forum with Pham (Greenberg Traurig, LLP), and promoted community building within the Center through the postdoctoral fellow and graduate student coordinated research exchange seminars and courses. These activities are described in more detail below.

NSF-SIA Supplement in Nanoelectronics

The NSEC has maintained close ties with members of the Nanoelectronics Research Initiative (NRI). George Bourianoff (Fig. 9.1), for example, has been a member of our External Advisory Committee. We had a number of meetings with members of the NRI during the past several years to identify areas of overlap between the NRI forward-looking 'research vectors' and ongoing research in the NSEC. When a supplement was

Figure 9.1. George Bourianoff (*left*) highlights the new NSEC effort in nanoelectronics; **Shriram Ramanathan** (*right*) discusses the research effort at the Frontiers of Nanoscale Science and Technology workshop, January 2006.

announced by the NSF-SIA for graduate student and postdoctoral fellow to NSF Centers in nanoelectronics, we submitted a successful supplemental proposal to the NSEC to synthesize and characterize oxide nanostructures that was funded in December 2005. A new Assistant Professor **Shriram Ramanathan** (Fig. 9.1), who comes to Harvard from Intel, is one of the senior investigators involved in the research.

International Technology Roadmap for Semiconductors (ITRS) - Emerging Research Devices (ERD)

The International Technology Roadmap for Semiconductors (ITRS) is the fifteen-year assessment of the semiconductor industry's future technology requirements. These future needs drive present-day strategies for worldwide research and development among manufacturers' research facilities, universities, and national labs.

The Emerging Research Devices (ERD) Section of the ITRS evaluates new approaches from academic and industrial labs that could lead to devices that go beyond the ultimate scaling of CMOS technology. **Robert Westervelt** was invited to participate in the Emerging Research Logic Devices meeting held on Sept. 21, 2006 in Montreux, Switzerland. The technologies considered range from one-dimensional structures such as nanotube and nanowire FETs, to single-electron transistors, to spin transistors—all part of the research of our NSEC. A lively discussion between academic and industrial researchers during the meeting about the merits and limitations of different types of devices provides an important connection between our Center's research and future nanoelectronics for the semiconductor industry.

Industrial Interaction and Technology Transfer

We invited a number of leading experts from industry to the Frontiers in Nanoscale Science and Technology (FNST) workshop in San Francisco in January 2006. During the first day of the workshop, Robert Doering from Texas Instruments discussed the current strategic industry plan, George Bourianoff gave the industry view beyond CMOS devices, Phaedon Avouris from IBM spoke on carbon nanotube electronics and optoelectronics, and Pushkar Apte from the Semiconductor Industry Association presented the nanoelectronics challenge (Fig. 9.2). There was a lively question period and opportunities for students and researchers to interact with these experts from industry throughout the workshop.

Figure 9.2. Robert Doering (*left*), Pushkar Apte (*center*), and George Bourianoff (*right*) speaking at the Frontiers of Nanoscale Science and Technology workshop, January 2006.

NSEC researchers also continue to work closely with industry and several patent applications have been filed in the fields of micro-manipulator arrays and near-field laser

antennas. The best technology transfer continues to be in the form of our students and postdoctoral fellows trained in this interdisciplinary fashion for positions in industry.

Visitor Exchange Programs

The NSEC has a visitor exchange program between Center universities and the national laboratories to share facilities and carry out collaborative research. The Visitors Program is managed by our administrative staff member to encourage collaborative research by supporting student travel. Leo Kouwenhoven oversees the student exchange with Delft, which has excellent facilities to make and test nanoscale structures as well as an outstanding graduate program. It is also possible for students to spend a few weeks or months visiting, to learn new skills and conduct research. Hiroyuki Sakaki and Seigo Tarucha look after similar visits with the University of Tokyo.

There were a number of visits by Center faculty, postdoctoral fellows and graduate students to use facilities and collaborate on research with scientists at other Centers and National Laboratories. Xiaofeng Li, a graduate student working with **Donhee Ham** and **Robert Westervelt**, visited the University of Tokyo to collaborate with Seigo Tarucha and his group on terahertz applications of semiconductor nanostructures. Michinao Hashimoto, a member of **George Whitesides**'s group, visited Professor Piotr Garstecki's group at the Polish Academy of Sciences. Michinao's work at Harvard has focused on the application of the system of emulsions (bubbles and droplets) to chemistry and biology. The interest of Professor Garstecki lies in physical aspects of the same system and developing a quantitatively understanding mechanism of the formation of emulsions and complexity of dynamic, interacting systems of emulsions. As stated by Minchinao, "This experience allowed me to understand the system from a different viewpoint, and made me aware of a broader range of research in the field of microfluidics," (Fig. 9.3).

Fabio Beltram from the National Enterprise for NanoScience and NanoTechnology (NEST) Pisa, Italy also visited the NSEC to form collaborations with researchers in the Nanoscale Building Blocks and Imaging at the Nanoscale Clusters. Lars Samuelson has also become an active collaborator with members of the NSEC. Samuelson is well known for his synthetic work in semiconductor nanostructures from Lund University in Sweden.

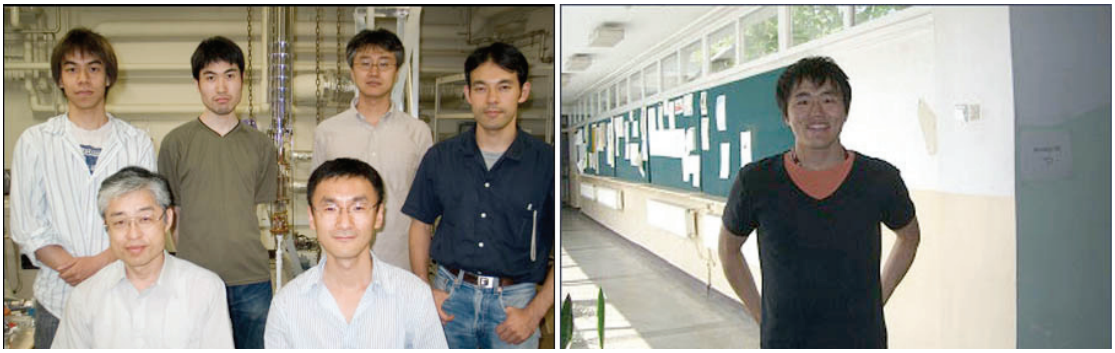

Figure 9.3. (*Left*) Seigo Tarucha (seated left) and Xiafeng Li (seated right) visiting Tarucha's group at the University of Tokyo; (*right*) Michinao Hashimoto visiting the Polish Academy of Sciences.

Ania Bleszynski, an NSEC graduate student, traveled to both Delft and Lund Universities were she worked with researchers to fabricate nanowire quantum dots of InAs and InAs/InP. Linus Froberg, from Lars Samuelson's group traveled to Harvard, in turn, to learn and perform transport measurements of these nanostructures using the custom-built scanning probe microscope developed in the Center.

The NSEC has fostered a remarkable group of international collaborators who are not only outstanding scientists but also leaders of pre-eminent research institutes for nanoscale science worldwide (Table 9.1). This is an important outreach activity supported by the NSEC, since much of the best research is done in Japan or Europe. We have seen directly that our researchers learn from our collaborators how to make new structures and devices, how to conduct new experiments, and how to understand theoretically how a device or systems works.

Table 9.1 International Collaborators

Fabio Beltram	National Enterprise for NanoScience and nanoTechnology (NEST) Pisa, Italy
Piotr Garstecki	Institute of Physical Chemistry Polish Academy of Sciences, Warsaw, Poland
Leo Kouwenhoven	Kavli Institute of Nanoscience Institute Delft University of Technology, The Netherlands
Eugenia Kumacheva	University of Toronto, Canada
Daniel Loss	National Center of Competence in Research Nanoscale Science, University of Basel Switzerland
Maria-Anita Ramp	University of Ferrara, Italy
Hiroyuki Sakaki	Institute of Industrial Science, Japan
Lars Samuelson	Nanometer Structure Consortium Lund University, Denmark
Seigo Tarucha	University of Tokyo, Japan

International Workshops

In January 2006, we organized the Frontiers in Nanoscale Science and Technology (FNST) workshop held in San Francisco. This location was selected to draw both a national audience as well as allow participants and collaborators from Japan and Europe to attend. Over ninety researchers from industry, national laboratories, and academic institutions attended. Our NSEC provided student scholarships to graduate student researchers both from other NSECs (Wisconsin and Stanford), but also from U.S. universities who applied and presented their work during poster sessions. The first day of the workshop was devoted to challenges in nanoelectronics presented by members of industry (Fig. 9.2) described above. The second and third days focused on topics in nanophotonics, imaging, and information processing (Fig. 9.4). Additional support for the workshop was provided by ICORP-JST, SORST-JST, IT-MEXT [from Japan]; Greenberg Traurig, LLP; and the Center for Nanoscale Systems (CNS) [Harvard

University]. The FNST workshop was the fourth international workshop since the beginning of the NSEC in 2001. Again this year, the workshop served to bring together the many postdoctoral fellows and graduate students who began collaborations through the visitor exchange program. The workshop is an opportunity to learn what progress has been made since those visits and explore new areas of exploration. The fifth international workshop is scheduled for March 29–31, 2007 in Tokyo, Japan. The Center also hosted several international groups during the past year including delegations from England, France, Germany, Italy, Sweden, and Switzerland. In March, we hosted a delegation of Japanese students sponsored through the NSF/MEXT young scientist exchange program. Several graduate students and postdoctoral fellows from our Center, together with young scientists from Japan gave research talks. We had smaller group discussions and tours of the shared experimental facilities during the afternoon. We plan to host another delegation from the NSF/MEXT exchange program in March 2007.

Figure 9.4 Frontiers of Nanoscale Science and Technology (FNST) Workshop in San Francisco, January 2006.

Industrial Partnership Workshop

In May 2006, NSEC members participated in the annual meeting of the Industrial Partnership Workshops (IPW) sponsored by Harvard's School of Engineering and Applied Sciences (HSEAS). The IPP is directed by Executive Dean Fawwaz Habbal and is aimed at strengthening external collaborations by facilitating mutually beneficial relationships between outside groups and HSEAS interdisciplinary research groups. The

Figure 9.5. (*Left*) **George Whitesides** speaking and (*right*) interactions during student poster session at the Industrial Partnership Workshop, May 2006.

workshop was on Bioengineering, Materials Science and Nanosystems: A Confluence of Innovation (www.deas.harvard.edu/partnerships/biomatsci06/agenda2.html) and was heavily subscribed (Fig. 9.5). With nearly 200 registrants, a video and sound feed to a second room was set up. **George Whitesides** spoke about the *Intersection of Biology and Materials Science*, **Kevin Parker** talked on the *Use of Self-assembly in Cardiac Morphogenesis,* and **Robert Westervelt** discussed advances in *Tools for Integrated Nanobiology*. Following presentations on Initiatives for Harvard-Industry Collaboration and a Networking Session, there was a poster session with NSEC postdoctoral fellows and graduate students to allow for more detailed interaction between the NSEC researchers and attendees.

Figure 9.6. Chinh Pham (*left)*, **Federico Capasso** (second from left) and **Robert Westervelt** (*right*) during a panel discussion at NSTI Nanotech, May 2006.

Nanotech Business Forum

Westervelt worked with Chinh Pham (Greenberg Traurig, LLP) to initiate the NanoTechnology Business Forum in the Fall of 2004. The NanoTechnology business forum brings together leaders from local business, industry, government and academia for monthly networking meetings. The monthly meetings have rotated to different venues in the Boston area including Harvard and M.I.T. (Fig. 9.6). **Robert Westervelt** spoke about activities ongoing at Harvard in nanoscale science in November 2006. The Nanotechnology Business Forum was a key factor in bringing together Rick Rogers (Harvard School of Public Health), Giannoula Klement (Children's Hospital), and Dale Larson (Harvard Biophysics Program), who have become collaborators on the research in Cluster I on the hybrid CMOS/microfluidic systems with **Ham** and **Westervelt**. The participants in the Nanotechnology Business Forum have also been regular attendees at the annual Industrial Partnership Workshop (IPW), to learn about key developments inside the NSEC and more broadly at Harvard. Greenberg Traurig together with our NSEC supported a session at the NSTI Nanotech Conference in Boston in May 2006 on Novel Tools & Devices for Nanoapplications. **Westervelt** spoke about ongoing work at the interface on nanotech and biology and **Capasso** discussed Center research in nano-photonics. The session and panel discussion (Fig. 9.6) attracted at large audience attending this prominent annual meeting.

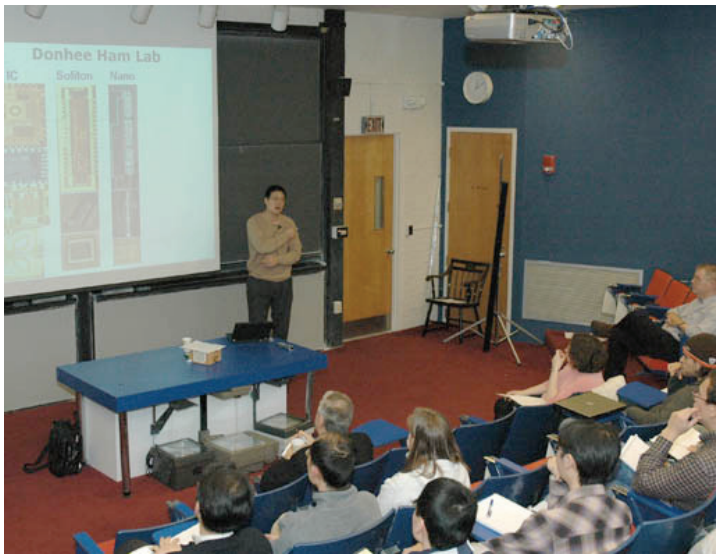

Figure 9.7. Donhee Ham gives his AP298r lecture.

Community Building

During the past two years, the Center hosted a Research Exchange seminar run by NSEC postdoctoral fellows. The seminar is held biweekly on Tuesday at lunchtime during the academic year to encourage NSEC postdoctoral fellows and graduate students to learn about each other's research. The Exchange seminar has blossomed into a venue where graduate students can get the advice of the postdoctoral fellows on preparation for oral presentation and then give their talk at the Exchange. On occasion, outside speakers are invited and the seminar is held at Harvard and MIT, emphasizing both locations of our NSEC activities in Cambridge.

With the realigned research activities, a major theme of new tool development has emerged. We also initiated a bi-monthly series of meetings for graduate students, postdoctoral fellows and faculty members involved in imaging tool development. These meetings help promote the exchange of best practices and technical expertise among members of the NSEC.

In the Spring of 2007, the NSEC is sponsoring the academic course *AP298r: Interdisciplinary Biology, Chemistry, Engineering, and Physics*, which covers fundamental concepts in nanoscale research as well as possible applications in a series of lectures by twenty-one NSEC faculty members (Fig. 9.7). Topics for the course are drawn from Tools for Integrated Nanobiology, NanoBuilding Blocks and Imaging Electrons at the Nanoscale. The course in-cludes tutorial lectures on modeling at the nanoscale and the use of electron microscopy for image analysis. A paper and oral presentation on one of the topics is required and the lectures are being transcribed by the students at a level appropriate for secondary teachers as a further extension of our outreach efforts. Twenty-five students took the course for credit and another fifteen researchers and staff members regularly attended the class as auditors. The lectures are available on the course website.

Research from the NSEC also has been woven into undergraduate courses. The engineering course *ES 122: Cellular Engineering*, taught by **Parker** this past fall, was a laboratory course designed to give students a cutting-edge research experience; one selection was taken from NSEC-related work. The undergraduate class was broken down into research teams with a graduate student as the team leader. In the laboratory, the students learned cell tissue culture, cell motility assays, light, fluorescent, and video microscopy, immunohistochemistry, and microcontact printing. They met milestones with written and oral reports and were held to high standards in that they kept a detailed and graded lab notebook. The final project presentation incorporated all they have learned, plus other techniques that they taught each other. It was the intent of the class to present the final projects as posters at the Biomedical Engineering Society meeting (BMES). *ES 174 Photonic and Electronic Device Laboratory*, taught by **Crozier** this spring term, introduces undergraduates to semiconductor lasers, photodetectors and optical fibers. An important element of the course is the use of shared facilities to fabricate MOSFETs and other devices based on training in lithography, deposition, etching, oxidation, implantation, diffusion and electrical characterization. For many, this serves as a first introduction to laboratory skills that can be used to carry out independent research.