3. Impact of PFF Program

The NSF 1999 GPRA[11] Performance Plan (March 1998) identifies four broad policy goals for the Foundation:

- Discoveries at and across the frontier of science and engineering;
- Connections between discoveries and their use in service to society;
- A diverse, globally oriented workforce of scientists and engineers; and
- Improved achievement in mathematics and science skills needed by all Americans.

PFF enhanced [Fellows'] capacity to conduct research, to disseminate research findings, and to provide instruction to undergraduate and graduate students.

While these strategic goals were formalized after the PFF program began, they provide a useful framework for understanding and categorizing the program's contributions to the Foundation's goals and vision. As shown in Exhibit 3-1, the PFF study assessed contributions that individual Fellows made toward each of the goals delineated in the NSF Strategic Plan. PFF is notable because Fellows' activities and accomplishments span the Foundation's four broad policy goals.

Table 3-1 provides an overview of the number of Fellows who reported having conducted a given activity (e.g., working with K-12 students and contributing expertise to private industry). These counts are based on a review of materials provided by 105 (88 percent) of the program's 120 grant recipients.[12] As shown in Table 3-1, these 105 Fellows reported examples of how PFF enhanced their capacity to conduct research, to disseminate research findings, and to provide instruction to undergraduate and graduate students.[13] In addition:

- Seventy percent of Fellows said they had shared their expertise with the public sector.
- Forty-seven percent said they had participated in outreach activities that involved elementary or secondary schools students.

[11] Government Performance and Results Act.

[12] We were not able to locate a progress report or PFF Web page for the remaining 15 Fellows.

[13] The reports are sometimes ambiguous with regard to PFF's role in enabling the activities reported. That is, some activities pre-existed the award but were supported or enhanced by the award; others were made possible because of the support provided.

Exhibit 3-1. — Linkage of PFF Fellow activities and types of achievements to NSF strategic goals

Goal 1. Discoveries at and across the frontier of science and engineering, i.e., the extent to which NSF funds are contributing to progress and innovations in science and engineering. PFF is contributing to discoveries when it enables Fellows to

(1) Enhance Their Capacity to Conduct Research

- Undertake research in a new area
- Take existing research in a new (and risky) direction
- Purchase equipment

(2) Disseminate Research Findings

- Publish findings, e.g., in refereed journals, books, or book chapters
- Earn patents or software credits
- Conduct presentations or participate in conferences
- Provide support to graduate students and others to disseminate findings

Goal 2. Connections between discoveries and their use in service to society, i.e., linking research advances with applications, sharing new knowledge that can accelerate innovations, and generating a productive exchange of knowledge, including knowledge about technologies. PFF is contributing to connections when it enhances Fellows' capacity to

(1) Contribute Expertise to the Public Sector

- Testify before federal/state legislatures
- Participate in White House forums
- Develop briefing papers
- Serve on NSF committees and panels

(2) Contribute Expertise to Private Industry

- Meet with business and community leaders to promote local economic growth
- Develop partnerships with representatives from the private sector/local community

Exhibit 3-1. — Linkage of PFF Fellow activities and types of achievements to NSF strategic goals (continued)

Goal 3. A diverse, globally oriented workforce of scientists and engineers, i.e., developing a cadre of professionals that can fulfill the broad range of responsibilities that will be needed to keep the United States at the forefront of innovation and technological progress. PFF is contributing to creating this diverse, globally oriented workforce when Fellows are able to

(1) Enhance Quality of Instruction for Undergraduate and Graduate Students

- Implement new and innovative courses, curricula, and teaching tools
- Integrate research into teaching
- Provide financial support to undergraduate and graduate students
- Facilitate cross-discipline research efforts
- Develop a departmental research lab
- Hire new faculty and attract new students (e.g., because of equipment purchased with PFF funds)

(2) Promote Efforts to Increase the Representation of Women and Underrepresented Minorities in Science and Education

- Develop initiatives to increase participation among female students
- Develop initiatives to increase participation among underrepresented minority students
- Improve the educational experiences of female and minority students
- Teach in Native American schools
- Host minority high school students

(3) Collaborate With Scientists and Engineers in Other Countries

- Create center for student researchers from North and South America
- Establish partnerships with foreign researchers

Goal 4. Improved achievement in mathematics and science skills needed by all Americans, i.e., fostering the development of essential skills and concepts in math and science at all levels of the education system. PFF is contributing to improved achievement when Fellows are able to

(1) Participate in Outreach Programs Involving Elementary and Secondary School Students

- Conduct outreach programs for elementary students and their parents
- Organize educational activities for inner-city students
- Lecture at local high schools to promote scientific careers

(2) Enhance Quality of Instruction for Undergraduate and Graduate Students

- (Most items under Goal 3 above also enhance the quality of education for students *not* planning to enter the workforce as scientists or engineers)

Table 3-1. — Percentage of Fellows reporting PFF-related activities, by award year: 1992-95

NSF policy goal	PFF-related activity	Award cohort FY 1992 (n=27)	FY 1993 (n=28)	FY 1994 (n=27)	FY 1995 (n=23)	FY 1992-95 (n=105)
1. Discoveries at and across the frontier of science and engineering	Maintain or expand research efforts	100.0	100.0	100.0	100.0	100.0
	Disseminate research findings	100.0	100.0	100.0	100.0	100.0
2. Connections between discoveries and their use in service to society	Contribute expertise to the public sector	74.1	78.6	51.9	73.9	69.5
	Contribute expertise to private industry	22.2	17.9	22.2	21.7	21.0
3. A diverse, globally oriented workforce of scientists and engineers	Enhance quality of instruction for undergraduate and graduate students	100.0	100.0	100.0	100.0	100.0
	Promote increased representation of women/minorities in science and education fields	33.3	39.3	22.2	52.2	36.2
	Collaborate with scientists and engineers in other countries	37.0	50.0	33.3	30.4	38.1
4. Improved achievement in mathematics and science skills needed by all Americans	Participate in outreach activities involving elementary and secondary school students. (See also activity above: enhance quality of instruction for undergraduate and graduate students)	48.2	39.3	33.3	69.6	46.7

SOURCE: Grant award and progress reports, Web pages, and other materials submitted by Fellows (e.g., curriculum vitae collected in fall 1998).

- Thirty-eight percent said they had forged relationships with international colleagues.
- Thirty-six percent said they had taken steps to promote increased representation of women and minorities in science and engineering fields.
- Twenty-one percent said they had shared their expertise with the private sector.

Finally, 63 percent of Fellows indicated on their curriculum vitae or progress reports that they had been promoted since receiving their PFF award (Table 3-2). In some cases, Fellows reported that they had received tenure. In other cases, the promotions elevated Fellows to the rank of associate or full professor. Not surprisingly, Fellows who had been involved with PFF at the outset of the program were most likely to have been promoted by the time of the study. Eighty percent of Fellows who had received PFF funding since 1992 reported at least one promotion, compared with 37 percent of Fellows from the 1995 cohort.

Table 3-2. — Fellows reporting promotions, by award year: 1992-95

Promotion status (as of 1997)	Award year				
	FY 1992 (n=30)	FY 1993 (n=30)	FY 1994 (n=30)	FY 1995 (n=30)	FY 1992-1995 (n=120)
Fellows who had received a promotion	24 (80.0%)	22 (73.3%)	18 (60.0%)	11 (36.7%)	75 (62.5%)
Fellows who had not received a promotion	3 (10.0%)	2 (6.7%)	7 (23.3%)	15 (50.0%)	27 (22.5%)
Could not determine whether a promotion had been received	3 (10.0%)	6 (20.0%)	5 (16.7%)	4 (13.3%)	18 (15.0%)

SOURCE: Grant award progress reports, Web pages, and other materials submitted by Fellows (e.g., curriculum vitae collected in fall 1998).

The remainder of this chapter provides detailed information on the range of PFF-related activities and accomplishments that Fellows reported in their annual report to their NSF program officers. It is organized around the impact of the PFF program on (1) the Fellows themselves, (2) Fellows' efforts to collaborate with researchers and practitioners, and (3) Fellows' efforts to promote opportunities in science and engineering.

Impact of PFF Program on Fellows

PFF appears to have impacted the Fellows themselves in at least four areas. The experience

- enhanced their capacity to conduct research,
- promoted their development as academic scientists,
- improved their skills in disseminating findings, and
- helped them increase their productivity and accomplishments as teachers.

Enhancing Capacity to Conduct Research

The pursuit of innovative scientific discoveries is at the heart of the PFF program. One of PFF's three primary selection criteria was the extent to which nominees had already demonstrated competence and leadership as a researcher, e.g., definitive research accomplishments, articles in refereed publications, or technical books. Fellows' progress reports described a variety of PFF-related research activities and accomplishments.

PFF grants provided Fellows with the flexibility to continue or accelerate the pace of their work and to explore new leads, new questions, and new lines of investigation. Fellows considered this freedom to be one of the primary benefits of their award.

Nancy Butler Songer, a 1995 Fellow from the University of Michigan in science education, agreed with other Fellows that credited PFF for allowing a greater amount of freedom in their work. As she stated in an interview for this report:

> The great thing about PFF is the freedom that it allows in terms of spending. With other NSF money there is a prescribed plan that one has to follow. My other grants were for 3 years and I had to have all the big questions outlined at the beginning of the grant. In the field of emerging technologies for education, it's hard to anticipate 5 years down the road what will be big. PFF money is a wonderful way of trying out riskier things.

As shown previously in Table 3-1, all of the Fellows used their PFF awards to maintain or expand their research activities. These activities have resulted in new knowledge, new uses for state-of-the-art equipment, and new discoveries and inventions.

Fellows report a variety of ways in which the PFF grants gave them the freedom to conduct research at the cutting edge of scientific knowledge.

- Wolfgang Bauer, a 1992 Michigan State University awardee, reported that the award gave him the flexibility to study cancer detection in individual cells using fractal dimension analysis. This technique makes it possible to study the surface of individual cells allowing a diagnosis based on the distinction between patients with hairy-cell lymphocytic leukemia and those with healthy blood lymphocytes. Such a diagnosis allows for early cancer detection and, perhaps, better chances of recovery for the patient.

Expanding Research Capacity

The experience of Shira Broschat, a 1992 Fellow in the Electrical Engineering Department at Washington State University, is illustrative. This young electrical engineer had been conducting research in the area of wave scattering from rough surfaces for several years, but had long been interested in bioengineering applications of her research. She was especially interested in exploring applications for the early detection of breast cancer in young women. In her report to NSF, she commented on the difficulty of "obtaining funding in an area in which you are not already considered to be an expert." The PFF award provided her the means and the freedom to pursue this interest, with good results. Broschat and her students have published several papers in refereed journals on important findings from that research. A start-up company is interested in working with her on an ultrasound holographic imaging system. One of the students who assisted on the project has completed the Ph.D. degree, and three others have completed master's degrees in ultrasound imaging or mammography. Broschat stated that, "none of this would have been possible without the PFF award."

- The PFF award permitted Xing-Wang Deng, a 1995 Fellow at Yale University, to move his research in new directions. Most of his work has been on the molecular and cellular mechanism of light control in plant development. At one point in his studies, "the science dictated that he branch out in several directions such as comparative studies of novel human and mouse proteins." These new directions would not have been supported by other research grants that were limited in scope. Deng noted that the PFF grant gave him the opportunity "to design investigations which can integrate the otherwise specific but somewhat narrowly defined research activities."

- PFF funding also enabled Caro-Beth Stewart, a 1994 Fellow at the State University of New York at Albany, to extend her work into new areas. In her report to NSF, she noted that proper interpretation of her studies on digestive enzymes required her to move into molecular phylogeny. She commented, "although the core of this program is funded by NIH, the PFF award has allowed us the freedom to pursue important lines of research that are not directly funded by this biomedically oriented grant."

PFF grants provided not only the freedom necessary to experiment, but also the state-of-the-art facilities and equipment needed to conduct those inquiries. A few examples illustrate the range of opportunities afforded.

- Marcelo Gleiser, a 1994 Fellow from Dartmouth College in Physics, has focused his research on the interface between high-energy particle physics and cosmology. He used both analytical and numerical techniques to study several topics related to the physics of the early universe. In particular, he has been studying nonequilibrium dynamics of complex systems that undergo phase transitions, a topic that bridges the gap between high-energy physics and condensed matter physics. PFF funding allowed him to purchase powerful workstations and establish a research group at Dartmouth to explore this highly theoretical work.

- Jennifer Lewis, a 1994 Fellow at the University of Illinois, has initiated a PFF-supported activity to design an undergraduate laboratory in materials processing. The aim was to fully equip the lab with state-of-the-art equipment (e.g., an atomic force microscope) and develop hands-on experimental activities. She has also worked with other faculty in her department to leverage the PFF funding to attract additional monies.

- PFF also helped a 1992 Fellow at the University of Wisconsin-Madison to better understand chemical reactions at the atomic level. Robert Hamers has used PFF funds to combine a scanning tunneling microscope with other chemically sensitive probes such as surface infrared and x-ray photoelectron spectroscopy to achieve true atomic-level chemical identification. The PFF award has provided funds to purchase instrumentation (such as an infrared spectrometer) to extend his lab's capabilities.

In addition, Fellows have made important discoveries and developed new inventions. These inventions will help future faculty explore new areas and make new connections. PFF funds were also used to support research on foreign soil that could have wide ranging benefits.

- Margaret Murname, a 1993 Fellow at Washington State University, credits the PFF award with allowing her team to develop a new and emerging laser technology. The team has designed the shortest-pulse laser developed to date. Such short optical pulses are used to monitor the first steps in chemical reactions, to investigate processes such as melting and electrical breakdown, to image through tissues, and for ultrashort-pulse x-ray generation. The laser is now used all over the world by researchers in chemistry, biochemistry, physics, materials science, and medicine.

- Aaron Ellison, a 1992 Fellow at Mount Holyoke College, has focused his research on characterizing animal-plant interactions in mangrove ecosystems. He has been using the PFF award to investigate their role in the spatial and temporal dynamics of the tropical coastal forests in Belize, Central America.

- Marge Aelion, a 1994 Fellow from the University of South Carolina who also works in the environmental sciences, has been working on remediation of contaminated ground water using combined physical and biological technologies. She has worked on coastal and estuarine pollution, examining the impact of oil spills in France as well as coastal development in South Carolina. PFF has allowed continuation of her long-term research projects by supporting the technical personnel required for such labor-intensive field projects.

Supporting Discoveries and Inventions

The research of Rebecca Richards-Kortum, a 1992 Fellow at the University of Texas at Austin, has led to an important discovery that holds great promise for the future. Her work focuses on the application of light for the automated, non-invasive diagnosis of pre-cancerous tissues. She is studying reflectance, fluorescence, and Raman spectroscopies to extract information about the physio-chemical properties of turbid tissues. Richards-Kortum developed instrumentation to measure spectroscopic images in vivo and works with physicians to derive and validate automated algorithms for the interpretation of such images. The PFF award has enabled her to develop new fiber optic imaging methods, which yield greater contrast images that can be related to tissue pathophysiology more directly.

Promoting Fellows' Development as Academic Scientists

A core objective of the PFF program is the promotion of the Fellows' development as academic scientists who will not only conduct research of the highest quality, but achieve the further recognition of having their research findings published in well-recognized acedemic sources. All of the Fellows' progress reports and curriculum vitae contained citations for products that were published (e.g., articles in refereed journals, books, or book chapters). Some examples of the quality of publications achieved by PFF-supported Fellows are noted below:

- June Ni (1994) conducted research on precision engineering, some of which was conducted in collaboration with an industrial consortium. He received the American Society for Mechanical Engineering's "Best Paper Award" for his September 1998 paper, "Thermal Bubble Formations on Polysilicon Micro Resistors" published in the *ASME Journal of Heat Transfer.* Some of his other journal citations included: *IEEE/ ASME Journal of Microelectromechanical Systems, Microsystem Technologies Journal, Thermal Sciences and Engineering, Microelectronics Journal,* and *Sensors and Actuators.*

- The research conducted by Emir Macari (1992), which informs analysis of earthquake hazards, has been published in a number of journals, including *Geotechnical Testing Journal*, *International Journal of Mechanics of Cohesive-Frictional Materials, Journal of Computing, Journal of Geotechnical Engineering*, and the *Transportation Research Record*.

- Some other periodicals that published student research papers include such wide ranging publications as *Geology*, the *American Journal of Physical Anthropology*, and *Water, Air and Soil Pollution*.

Disseminating Research Findings

The Fellows' progress reports and curriculum vitae detailed a wide range of presentations that occurred during the PFF award period. Shira Broschat (1992) stated in an interview for this report:

> The PFF award generated a lot of visibility for the university, and there was a snowball effect. There were articles about me in research and research society newsletters. I was asked to be involved in forums about science and the national interest, panels, and National Academy of Engineering symposia – because I was a PFF.

Some Fellows also indicated that providing new dissemination opportunities to their students was an important contribution of the PFF award. Most of these student products were traditional—research papers suitable for publication or presentation at professional meetings. Examples of presentations include the following:

- A student of Cheng Zhu, a 1993 Fellow at the Georgia Institute of Technology, presented a conference paper at an international conference in Singapore with PFF support.
- Three students of Anne Grauer, a 1993 Fellow at Loyola University of Chicago, presented their research at the Midwest Bioarchaeology and Forensic Anthropology conference.
- Two students participated in workshops at the National Center for Ecological Analysis and Synthesis, which were organized by James Clark, a 1994 Fellow at Duke University.

Disseminating Findings

PFF has given Emir Macari, a 1992 Fellow at the Georgia Institute of Technology, the opportunity to develop publications as well as participate in national forums that are shaping the conceptualization of science and engineering. Macari's research areas include a range of specializations such as computational mechanics, assessment of liquefaction potential, and geo-environmental issues related to sustainable technologies. For example, Macari's PFF-funded work included a project that deals with integration schemes for constitutive elasto-plastic soil models (multi-surface models). His team is developing a fully coupled variational formulation that can mimic the response of saturated soils (soil-fluid) under dynamic excitations. The intent of this project is to properly model the response of soils that may potentially liquefy under seismic loads. Since receiving the PFF award, Macari has been interviewed for newspapers and television on a variety of topics ranging from his specific research interests to encouraging minorities to pursue scientific and engineering careers.

Promoting Productivity and Accomplishments as Teachers

The Foundation has long supported efforts to promote the development of a cadre of scientists and engineers who can keep the United States at the forefront of innovation and technological progress. Such a workforce requires a sufficient diversity in expertise and perspective to cover the important functions that scientists and engineers serve in our society. It also requires the capability to function effectively in a globally interdependent environment.

While previous NSF efforts to support young tenure-track faculty had been designed to promote this goal, the PFF program clearly placed a special emphasis on advancing teaching practices, integrating education and research, increasing the number of the traditionally underrepresented in science and engineering fields, and preparing scientists and engineers to participate in a global environment. Unlike its predecessors, the PFF program's selection criteria emphasized a nominee's competence and leadership as an educator, including

- implementation of new curricula,
- design of courses,
- authorship of educational books,
- participation in cross-discipline research efforts,
- recognized contributions to educational reforms, and
- noteworthy service to the institution or the community on behalf of the institution.

Consequently, Fellows came into the PFF program with a proven track record as teachers and educators. Fellows reported a variety of PFF-related activities and accomplishments in the following areas: (1) enhancing the quality of undergraduate and graduate instruction; (2) promoting increased representation of women and minorities in science and education fields; and (3) collaborating with researchers and scholars in other countries.

Enhancing Quality of Undergraduate and Graduate Instruction

All of the Fellows used their PFF funds to include graduate students in their work, and 62 percent invited undergraduate participation in their projects as well. In fact, undergraduate students receiving PFF support were frequently supervised by or worked alongside graduate students. The following examples illustrate how PFF funds were used to enhance students' educational experiences.

- Aaron Ellison (1992) used PFF funds to take several of his undergraduate students on an 8-day expedition to the Florida Everglades to study mangroves. In addition, he used PFF funds to enable 13 students to participate in field research in Belize, Central America, during the summer or spring breaks.
- The Virtual Reality Geotechnical Laboratory at the Georgia Institute of Technology serves as both a research and teaching facility. Developed by Emir Macari (1992), the lab permits students to test the behavior of soil samples. Students can try out a variety of options and receive real-time feedback on the testing procedures they used.

- Marge Aelion (1993) and one of her doctoral students have been using radiocarbon to estimate the biodegradation of petroleum. Since this area had not been investigated previously, it would likely not have been funded by other means. In short, because of PFF, she can now offer students more financial support than before the award.

PFF funds were also used to support small- and large-scale curriculum enhancement efforts. Small-scale efforts generally involved redesigning or developing individual courses, while large-scale initiatives focused on redefining entire course sequences or areas of specialization. Often, curriculum development efforts were aimed at building stronger connections between research and teaching. One course made this connection by emphasizing areas that were undergoing rapid development due to contemporary research (Marija Gajdardziska-Josifovska, a 1995 Fellow). Others courses simply used examples from their research to illustrate course concepts, e.g., using examples from bioengineering research to illustrate basic concepts and show their relevance to health issues (Rebecca Richards-Kortum, 1992).

Several of the course improvements reported by Fellows involved making technology an integral part of instruction. Technology served two functions in these cases: motivating students, and engaging them in the kind of active, hands-on learning that promotes deep understanding of scientific content.

- Peter Wipf, a 1994 Fellow at the University of Pittsburgh, developed an interactive program to help students visualize three-dimensional structures. This kind of visualization is one of the most challenging intellectual tasks faced by students in organic chemistry. The program permits students to manipulate these structures on holographic displays to better understand the basic set of 25 reactions that form the mainstream of sophomore-level organic chemistry.

- Thomas Anderson, a 1994 Fellow at the University of California at Berkeley, developed a new software package for teaching undergraduate-level operating systems. The software permits students to explore engineering design choices in all areas of modern operating systems: thread systems, file systems, multi-programming, virtual memory, and distributed systems. This course is now widely used by institutions throughout the country.

Enhancing Undergraduate Education

Zorana Popovic, a 1993 Fellow at the University of Colorado at Boulder, set up an arrangement for involving students in her research activities. She worked closely with 10 Ph.D. students who, in turn, worked closely with four undergraduate research assistants. The graduate and undergraduate students were organized into research teams that met in blocks of 4-6 hours every week. On one team, the senior graduate student managed the project and worked on the theoretical aspects of the study's design, while the junior graduate student took the lead on measurement activities; the undergraduate took charge of manufacturing and fabrication. In this way, the graduate students gained experience as teachers and mentors, while the undergraduates gained experience conducting authentic research in a specific topic area.

Fellows also undertook larger scale curriculum projects. For example, Zorana Popovic (1993) developed a new sequence of undergraduate electromagnetic courses at the University of Colorado at Boulder. The first course is taken by all electrical and computer engineering students and the second by students with a stronger interest in the field. The two new courses start with simple mathematical tools, some discussion of applications, and laboratory work. One of the goals in redesigning the course sequence was to engage and retain bright students, who, in the words of Popovic, "start looking for the door after the first class, as soon as the instructor writes Maxwell's equations on the board."

Assisting SMET Students

A 1994 Fellow at Stanford University, Connie J. Chang-Hasnain, developed and implemented a novel teaching tool—simulated device animations—for two undergraduate core courses. Realizing the limitations of traditional classroom teaching methods in conveying abstract material, she complemented regular course material with animated simulations of various basic electronic devices, e.g., a junction diode, a metal-oxide-semiconductor field effect transistor, a bipolar transistor, etc. The goal was to use animated movies to provide a visual aid to understand complicated concepts, to give students a clear grasp of physical parameters, and to stimulate the interest in the course material. In addition, by implementing the movies on computers in the engineering center and dormitories, students can conveniently use the interactive animation at their own pace. The animation is now being used in both undergraduate and graduate-level electronic device courses and is also available on a 30-minute videotape for dissemination to other universities.

Courses have been designed by Fellows to motivate students already interested in science and engineering. Several PFF-supported curriculum efforts were also developed for students majoring in other fields. These courses attempt to demystify science, raise the general level of science literacy among non-science majors, and attract more students to the sciences.

- At Washington State University, PFF funds were used to develop a new computer literacy course for non-science majors that share these objectives. A major emphasis is the impact that technology has on daily life. Shira Broschat (1992) developed the course and hopes that this exposure will increase public awareness and support of technology.
- Dartmouth offers a course developed by another PFF Fellow, Marcelo Gleiser (1994), that is also aimed at undergraduate students with majors in other areas. The course, "Physics for Poets," has been very well received.

Finally, several Fellows commented that the prestige attached to the PFF award facilitated their efforts to improve their departments. For example, Shira Broschat (1992) remarked that, "the PFF award has a great impact on less prestigious universities in that it makes them better known, helps them go after more money, and attract faculty." David Zumbrunnen (1992) also stated that one benefit of PFF was his enhanced capacity to advocate for changes at his home institution (Clemson University). As he stated in an interview for this report, "the award gave me a stable platform to affect change at Clemson—harmonizing research and undergraduate education." He met with deans and reported on problems impeding progress in education and research arenas. Zumbrunnen was able to do this, as he stated, "because as a PFF I didn't fear retribution—I was an agent for change."

Impact of PFF on Fellows' Efforts to Collaborate with Other Researchers and Practitioners

The Foundation defines its goal on Connections as the extent to which "the results of NSF awards are rapidly and readily available and feed, as appropriate, into education, policy development, or use by other federal agencies or the private sector. . . . Exceptionally strong performance is characterized by NSF staff and grantees actively reaching out to potential users, and NSF-supported work playing critical roles in important innovations or problem solving for society" (NSF FY 1999 GPRA Performance Plan, March 1998). The PFF program explicitly encouraged young investigators to seek out relationships that would put their ideas to work in solving society's important problems. Fellows were encouraged to support this goal by forming partnerships and sharing their expertise with representatives from public, private, and international organizations.

The PFF program explicitly encouraged young investigators to seek out relationships that would put their ideas to work in solving society's important problems.

Contributing Expertise to the Public Sector

NSF has always encouraged scientists to participate in public policy forums to assure that federal initiatives involving science and technology rest on a solid research base. Seventy percent of Fellows used their progress reports to describe their efforts to testify before national or state legislatures, prepare documents for public officials, serve on NSF panels and selection committees, and consult with government agencies. In fact, the 1992 PFF class met as a group in Washington, DC, in June 1992 to develop strategies for influencing local, state, and national policy issues important to research and education in science and engineering. The group was made up of 30 scientists and engineers from geographically diverse institutions ranging from small, private liberal arts colleges to large, public research universities. Topics discussed included the future direction of scientific funding and educational issues. The concerns of the group were presented for Congress' consideration through both written and oral testimony.

A Sampling of Fellows' Contributions to Public Policy

- Ingrid Burke, a 1993 Fellow at Colorado State University, was invited to give testimony before the Senate Committee on Commerce, Science, and Transportation. She appeared at the hearing concerning computational biology. The committee was interested in finding out about this new biology subdiscipline as it related to the future of science in the United States.
- Mary L. Lowe, a 1992 Fellow from Loyola College in Maryland, served on a planning committee for the "Forum on Science in the National Interest," organized by the White House Office of Science and Technology.
- David Zumbrunnen, a 1992 Fellow from Clemson University, developed a briefing paper, which along with papers submitted by other invited scientists and engineers, formed the basis for the White House publication, "Science and the National Interest."
- Ephrahim Garcia, a 1993 Fellow from Vanderbilt University, consulted with the Office of Research and Development of the Central Intelligence Agency on applications of technology to intelligence gathering.

- Chris Jacobsen, a 1992 Fellow at SUNY-Stony Brook, testified to a House subcommittee on science during NSF's reauthorization hearings in late 1992. The testimony covered the following topics: the future direction of the NSF, the balance between curiosity-driven and strategic research at the NSF, the lack of official emphasis on teaching excellence in the tenure and promotion policies of higher education institutions, and the use of block grants to fund academic departments or related research groups.
- As a result of the June 1992 meeting in Washington, DC, David Culler, a 1992 Fellow at the University of California at Berkeley, drafted a letter to the Clinton Administration that reiterated some of the ideas that were expressed in the meeting. The letter also expressed a concern for preparing the United States for the next millennium. In his words, such preparation "requires not only continued advancement of ideas through pure and applied research, but the training of a workforce with a far deeper understanding of science and engineering principles."
- Aaron Ellison (1992) presented a letter to the National Science Board that represented the views of a number of PFF grantees. The letter stressed that there should be no compromise in supporting basic research and emphasized the importance of educational reform. Specifically, the Fellows requested that support for science education be expanded to incorporate the development of new teaching tools and methodologies, retraining of faculty in the teaching of non-traditional students, and re-tooling faculty to teach new disciplines.
- In January 1994, Emir Macari (1992) was invited to participate in the Forum for Science in the National Interest organized by the White House Office of Science and Technology Policy. This forum assembled a group of science and engineering experts from across the Nation to discuss and present recommendations to President Clinton for his administration's science policy document. In August 1994, he was invited to the release ceremony of "Science and the National Interest," the document that resulted from the January meeting. The position paper that Macari presented encouraged cooperation between the scientific research communities of the Americas.

Contributing Expertise to Private Industry

Collaborations with industry are quite important for moving projects from basic research to product development and utilization. Twenty-one percent of Fellows described their work with representatives from the private sector. The following examples illustrate the efforts of some Fellows that have contributed to private industry:

- Margaret Murname (1993) and her research group entered strong interactions with industry, based on several important breakthroughs the group made in the technology of ultra-fast lasers. These lasers generate short pulses that can be used to monitor the first steps in chemical reactions, investigate processes such as melting and electrical breakdown, and image through tissue. She has worked with many optical component companies on product improvements based on her research. The lasers also are commercially available and are being used by researchers worldwide.
- Other Fellows are building bridges between their research laboratories and industry by helping to broaden the education of scientists and engineers employed in the private sector. For example, Siu-Wai Chan, a 1993 Fellow at Columbia University, offered on-site graduate courses to employees of local companies. Three of her courses (elements of materials science, thin films and layers, and electron microscopy of materials) have been conducted via the Columbia video network (CVN). The CVN program provides working engineers an opportunity to increase their productivity through continuing education.
- Peyman Givi, a 1992 Fellow, taught courses from SUNY's mechanical and aerospace engineering curriculum at a local automotive plant. Engineers who took the class earned university credits. According to Givi, the teaching relationship helps bridge an important gap between industry and academe. In his words, engineers learn to "appreciate the need for 'basic' science and mathematics in dealing with 'complex' engineering problems."

Collaborating with Private Industry

Jun Ni, a 1994 Fellow in the area of precision engineering at the University of Michigan, devised an approach that could improve machine accuracy by 4 to 10 times. For some time, efforts in precision engineering have focused on developing tools and techniques that can enhance the performance of machine tools. By collaborating with an aerospace company, Ni was able to test his error detection technology in a real production environment. This relationship also was instrumental in the young scientist's taking the lead in an industrial consortium formed by three automotive and six machine tool manufacturers. The consortium's goal is to develop a new generation of intelligent work units.

Collaborating with Researchers and Scholars in Other Countries

PFF Fellows also reported collaborations with researchers and scholars in other countries. Thirty-eight percent of Fellows worked with international colleagues and participated in international events. PFF awards also made it possible for Fellows to attend prestigious international meetings in a variety of scientific fields. Some specific examples follow:

Supporting International Outreach

One of the most unique international outreach activities made possible by the PFF program was initiated by Jose Escobar, a 1992 Fellow at Cornell University. He organized the first summer school in mathematics ever held in Colombia, South America. These summer schools provide students with access to mathematicians from the United States, Europe, and Latin America. Since the program started, 15 Colombian students who attended these summer schools have come to the United States and five others have gone to Brazil to continue their studies in mathematics. According to Escobar, "this is an unprecedented phenomenon in Colombia, where the number of mathematicians with a Ph.D. degree is very low."

- PFF enabled Aaron Ellison (1992) to spend the first six months of sabbatical leave working with colleagues at marine laboratories in Guam, Australia, Malaysia, and South Africa. Ellison spent the remaining part of his leave teaching seminars on tropical ecology in Guayaquil, Caracas, Kuala Lumpur, Penang, Calcutta, and Capetown.
- Marge Aelion (1993) attended the Tenth International Conference of Women Engineers and Scientists held in Budapest, Hungary. With three other faculty from her university, she traveled to Novosibirsk and Irkutsk, Siberia, to promote a Russian-American partnership in environmental science education and training.
- Gareth McKinley, a 1995 Fellow at Harvard University, visits England every summer to lecture and talk with students at the London International Youth Science Forum. This gathering includes 350 11th and 12th grade students from 46 countries who spend two weeks in London learning about research and science. McKinley lectures on "nonlinear dynamics and chaos in the world around us" and uses demonstrations from physics, chemistry, meteorology, and medicine. The goal of these efforts is to reach budding scientists interested in research and stimulate them with a variety of contemporary ideas.

Impact of PFF on Fellows' Efforts to Promote Opportunities in Science and Engineering

PFF Fellows reported being actively engaged in a number of efforts directed at increasing opportunities for a variety of audiences in the fields of science and engineering. These included

- Promoting increased representation of women and minorities in science and engineering;
- Working with elementary and secondary schools;
- Supporting teacher education and professional development; and
- Creating science enrichment opportunities for K-12 students.

Promoting Increased Representation of Women and Minorities in Science and Engineering Fields

Thirty-six percent of the Fellows used their PFF awards to promote increased representation of women and underrepresented minorities in science and education fields. For example, 20 percent of Fellows described their work as mentors, faculty advisors, or research supervisors to women and minority students. The relationships of these students to the sponsoring Fellow were typical of mentoring relationships. The female or minority student was drawn into PFF-supported research projects, provided with opportunities to learn the fundamentals of research, and offered guidance on their academic careers.

In some cases, special minority programs were created and coordinated by PFF Fellows.

- Anne Grauer (1993) chaired a university committee that offered a summer internship for freshman and sophomore women who were not majoring in a science. The program for talented students who suffer from "science anxiety" was designed to introduce participants to various means of scientific inquiry.

- Through the "Women in Engineering Program" at Drexel University, Athina Petropulu (a 1995 Fellow) visited local high schools to give demonstrations on speech processing and its uses. Using a mobile computer laboratory, she provides students with the opportunity to have hands-on experience via the computers, cameras, and microphones included in the lab.

- Through a "Success in the Sciences" program, black and Hispanic students at Rutgers University conducted independent research projects under the guidance of Jing Li, a 1995 Fellow. The expectation was that this closely supervised experience would help students succeed in their college courses.

- Neuroscientist Chiye Aoki, a 1992 Fellow at New York University (NYU), mentors a female student in neuroscience research through the Hughes Undergraduate Summer Research Program. One of the students has returned for two succeeding summers to conduct an honors research project sponsored by the NYU Medical School.

- At the University of California-Davis, underprivileged minority undergraduates who majored in mathematics or physical science were paired with faculty members such as Louise Kellogg, a 1992 Fellow, for individual attention and mentoring throughout their undergraduate careers. This

Creating Special Minority Programs

Hilary Lackritz, a 1993 PFF Fellow at Purdue University, developed a program for minority students that served two functions. The first was to provide a support system for students within the department. The program offered additional (minority) teaching assistants for the courses that traditionally proved most difficult for minority students, supplied minority role models from the engineering community, provided information on industrial and graduate school opportunities, and paired each student with an individual faculty advisor to create additional personal support. The second function served by the program was to aid in the recruitment of additional minority students. Program participants visited high schools with large minority populations to interest students in the University's chemistry program. According to Lackritz, through this involvement "the undergraduates act as positive role models within the community, gain self-confidence, and [obtain] security in their own position. This is an excellent method for letting current students have 'hands-on' experience in counseling, communication skills, and personal development. It will also be an important recruiting tool for the University."

program, originally sponsored by NSF, is now funded completely by the university.

Creating Special Minority Programs (continued)

Another significant program for underrepresented groups, directed by 1995 Fellow Christopher Johnson, offers scholarships and mentoring for women who show promise in science and engineering. Originally funded by NSF, the program now is supported fully by the University of Utah. Each year, the program awards scholarships to 20-25 young women. During the summer before entry, participants take an interdisciplinary science course with components in biology, chemistry, mathematics, physics, and computer science; tour various laboratories; attend seminars given by professional women in science and engineering; and meet with career counselors. In the fall, participants begin work in research labs, where, in the words of the sponsoring Fellow, "they experience some of the excitement of cutting-edge research and gain an appreciation (and relevance) for the, sometimes dull, freshman science and engineering courses they are taking." PFF also enabled Erich Everbach, a 1992 Fellow at Swarthmore, to spend a semester teaching mathematics at a community college on an Indian reservation. Everbach reported that the experience helped him to become a more effective teacher generally, improved his teaching of minority students in particular, and increased his understanding of Native American issues.

Working with Elementary and Secondary Schools

The Foundation defined its goal on improved achievement as the extent to which NSF awards are used to foster the development of essential skills and concepts in mathematics and science at all educational levels. Fellows contributed to this goal by participating in outreach activities involving elementary and secondary school teachers and students. In fact, as shown in Table 3-1 on page 26, 47 percent of Fellows had taken steps taken to contribute their time and resources to pre-college science education. Examples included providing pre- and in-service education to K-12 teachers, creating or coordinating special enrichment programs for K-12 science students and their teachers, and participating in school-wide outreach activities aimed at generating interest in science and engineering careers.

Supporting Teacher Education and Professional Development

A significant number of Fellows described their efforts to provide professional development to K-12 teachers.

- Jing Li (1995) and several colleagues at Rutgers set up a summer research program in chemistry for local high school teachers. The program was designed to (1) forge stronger connections between colleges and local high schools to advance the sciences, and (2) provide teachers with the tools for guiding high school students toward careers in chemistry, physics, and mathematics. The activities gave high school teachers an opportunity to "refresh their knowledge, explore new ideas, learn new techniques, and gather new information on current developments in science and technology."
- Mary Lowe (1992) used PFF funding to organize an all-day academy for 12 high school mathematics, science, and technology teachers. The academy, which focused on computer applications suited to participants' classrooms, was designed to help participants and their colleagues effectively integrate computers into their teaching. At the close of the academy, attendees took part in a conference for several thousand Maryland science teachers conducted with computers. In exchange for the training and equipment, the 12 teachers continue to collaborate with Lowe on developing workshops and conducting presentations for other groups of teachers.

- Jennifer Lewis (1994) organized workshops for teams of university faculty members, high school physics and chemistry teachers, and students. Each team created modules to supplement instruction in high school science courses. The modules, which can be downloaded from a university website as publication-quality documents, have since been distributed to high schools nationwide.

Creating Science Enrichment Opportunities for K-12 Students

Several Fellows described steps they had taken to support individualized research opportunities for middle and high school students.

- Xing-Wang Deng, a 1995 Fellow at Yale, used his molecular and physiological plant laboratories as a training ground for local high school students. These students worked on specially designed research projects with graduate students in the program serving as their mentors. One of these high school students used the lab to develop a project that earned second place in a state science competition.

- Shira Broschat (1992) invited even younger students into her lab. During one year, she served as mentor to a 14-year-old middle school student, with whom she met every week for a full semester. The student learned the fundamentals of research—from library work to conducting experiments—by working on two of the Fellow's laboratory projects.

In addition, a number of Fellows served as mentors to elementary and secondary female or minority students. Two Fellows at different universities (Broschat, 1992, and Carreiro, 1995) involved high school students in summer research projects.

- Broschat served as mentor for a Vietnamese American and an African American student. In their second year, the two girls spent 8 weeks using the knowledge they had gained in the previous year creating a video on recycling for K-12 students. One of the girls later enrolled in an undergraduate electrical engineering program, and the other planned to begin her education in engineering after completing a tour with the Marine Corps.

- Margaret Carreiro mentored two high school juniors who worked in her urban ecology lab. One high school mentee studied the foliar nitrogen content and patterns of herbivory on the tree-of-heaven, while the other studied the effect of light on seed germination and seedling growth of the

Changing Pre-Service Education

Robin Pemantle, a 1992 Fellow at the University of Wisconsin at Madison, has helped a group of educators make fundamental revisions in the sequence of mathematics courses taken by elementary students. The revisions, intended to align the teacher preparation program in mathematics with the professional standards adopted by the National Council of Teachers of Mathematics, were designed to "ensure that the teachers are well enough grounded in the elementary math content to discuss it articulately, teach it to others, solve difficult problems, use it in unfamiliar contexts, and treat it with confidence and mastery." Courses were structured around small-group problem-solving activities and demonstrations of models for good classroom practice. The courses also gave individual attention to the special needs of each prospective teacher, addressing specific gaps in mathematical knowledge or understanding.

Norway maple and the tree-of-heaven. Students in the summer program completed their projects and presented their results at a colloquium. This work will likely form the basis of future publications for the students.

Fellows also used their PFF funds to create other kinds of structured enrichment experiences for students. Other enrichment opportunities organized by Fellows included participating in a summer workshop for gifted middle school students and working with student organizations to create awareness of opportunities in scientific careers.

Creating Enrichment Opportunities for Students

One project, developed by Rebecca Richards-Kortum, a 1993 Fellow at the University of Texas at Austin, was offered to improve the quality of high school mathematics instruction and to encourage minority high school students to consider careers in science and engineering. The project was developed in collaboration with a mathematics analysis teacher at a local high school. Students were given the task of analyzing the design of fiber catheters used in biomedical optics. All problems had to be solved using trigonometry. Electronic mail was used to assign and submit homework assignments. Once the assignments had been completed, students took field trips to the university, where they attended one of the Fellow's freshman classes and worked in the lab with catheters to validate results they predicted.

- James Nowick, a 1995 Fellow at the University of California at Irvine (UCI), developed the UCI Chemistry Outreach Program to increase students' interest in chemistry. Over 80 graduate students have performed demonstrations and given lectures, reaching in excess of 6,000 students.
- Nancy Songer (1995) has trained graduate students to mentor middle school students in a program called "Kids as Global Scientists." The program also involves developing curriculum, support materials, and software for teachers, students, and scientists. She states, "With PFF funds I've been able to scale the program up to a much larger number of kids." As of March 1997, she had "4,000 kids from all over the world sharing data and information about time and weather imagery." In addition, Songer has developed an 8-week middle school weather curriculum for the program using a great deal of imagery to capture students' attention and illustrate concepts.
- Wolfgang Bauer (1992) teaches a 2-week physics class for 60-90 gifted middle school students each summer. In addition to teaching in this program, he has participated as an event supervisor in the Michigan Science Olympiad for middle and high school students.
- John Coulter, a 1993 Fellow at Lehigh University, regularly organizes tours of his laboratories to inform high school students about careers in science and engineering. In addition, members of his student research group hosted a research symposium that targeted K-12 students during "engineer's week." Several hundred local students and their parents attended.
- Gary Bernstein, a 1992 Fellow who served as faculty advisor for the student chapter of the Institute of Electrical and Electronics Engineers (IEEE), developed a program to bring the fundamentals of electrical engineering and career awareness into local high schools. A unique aspect of this program was that most of the work was done by students in a local IEEE chapter. Under the Fellow's supervision,

IEEE students created instructional units on several topics, designed corresponding experiments, built and repaired equipment needed for the experiments, and taught the units in local high schools.

- Mats Selen, a 1995 Fellow at the University of Illinois Urbana-Champaign, operates a "Physics Van" that visits elementary schools. The program's aim is to stimulate the scientific curiosity of young children "through a set of visually exciting demonstrations." Physics and engineering undergraduates, who volunteer their time to the project, staff the vans. In its first year of operation, the Physics Van presented over 60 "shows" to schools in the surrounding area, reaching over 5,000 students and 250 teachers.