
PERSPECTIVES ON
BROADER IMPACTS
NSF
National Science Foundation

This publication is a joint development and funding effort of the Office of International and Integrative Activities (OIIA) and the Office of Legislative and Public Affairs (OLPA) in the Office of the Director, and the Division for Molecular and Cellular Biosciences (MCB) in the Directorate for Biological Sciences.

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Executive Summary

Each year, the National Science Foundation (NSF) receives about 50,000 proposals for funding. Because there are many more worthy proposals than NSF is able to fund, the foundation distinguishes among them through a merit review process that incorporates two criteria: Intellectual merit and broader impacts.

Each proposal submitted to the foundation for funding consideration is required to address each of the two criteria fully and in separate statements. With some projects, broader impacts are intrinsic to the research itself. In others, the focus may be on education in science, technology, engineering, or mathematics (STEM), and both intellectual merit and broader impacts are inherent in the educational work. Increasingly, investigators are encouraged to envision an integration of their research with education, so that broader impacts are interwoven throughout.

The *America COMPETES Reauthorization Act of 2010* reaffirmed the importance of the broader impacts criterion and encouraged institutions of higher education and nonprofit organizations to take an institutional approach towards achieving the societal benefits championed via broader impacts. This institutional approach has been embraced by a number of institutions of higher education and nonprofits, who are collectively pooling their expertise and experiences to put in place on their campuses the broader impacts infrastructure that is necessary. The Broader Impacts Infrastructure Summit, held in Arlington, Va., in April 2014, brought together more than 120 professionals from 80 higher education institutions and nonprofits for wide-ranging discussions on broader impacts focused on institutional collaboration, guidance and accountability.[1]

Perspectives on Broader Impacts present some of the highlights from the Broader Impacts Infrastructure Summit, including:

- Perspectives from NSF,
- Perspectives of university leaders, and
- Perspectives of university participants.

Beyond the institutional infrastructure focus of the Summit, principal investigators have independently viewed broader impacts as both the linking of their research to societal impacts and as educational/outreach activities that benefit society. Researchers are increasingly reaching out to the general public as a means of raising awareness and increasing appreciation of the role that science plays in the quality of everyday life. The spread of new media tools has only increased the opportunities for scientists and educators to interact with the public.

The Perspectives of NSF Principal Investigators section includes:

- examples of broader impacts activities focused on education/outreach,
- examples of broader impacts that are intrinsic to the research itself, and
- examples of broader impacts in which educational/outreach efforts are interwoven or closely conjoined with the research itself.

1 Supported by NSF IIA-1437105 and MCB-1313197. IIA is the Office of International and Integrative Activities. MCB is the Division of Molecular and Cellular Biosciences in the Directorate for Biological Sciences.

2

INTRODUCTION

Each year, the National Science Foundation (NSF) receives about 50,000 proposals for funding. Because there are far more meritorious proposals than NSF is able to fund, the foundation distinguishes among those proposals through a merit review process that incorporates two criteria:

- Intellectual merit—the potential to advance knowledge, and
- Broader impacts—the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

NSF's mission is to fund innovative science, and so the foundation does not want to be prescriptive about what qualifies as "broader impacts." The foundation states that "NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These broader impacts may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project."[2]

THE HISTORY OF THE BROADER IMPACTS CRITERION AT NSF

The purpose of review criteria at NSF has always been to ensure that excellent research was being supported and to distinguish among the many proposals worthy of support, given that only a fraction can be funded. Although NSF revised, refined and clarified its review criteria over the years, it appears that broader impacts were considered from at least the 1960s. It did not, however, become a separate and distinct criterion until 1997, when NSF simplified the merit review criteria for proposals from four to two—intellectual merit and broader impacts. In 2007, NSF further clarified these two criteria to emphasize transformative research.[3]

In 2011, the National Science Board (NSB) issued a report on the *National Science Foundation's Merit Review Criteria: Review and Revisions*. In addition to reaffirming the two merit review criteria, the report set forth three merit review principles:[4]

- All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are directly supported by, but are complementary to, the project.
- Meaningful assessment and evaluation of NSF projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated level than the individual project.

PERSPECTIVES FROM NSF

As a federal agency, we need to stay relevant with those who entrust us with taxpayer funds.

In her first official speech as NSF Director, France Córdova addressed the April 2014 Broader Impacts Infrastructure Summit held in Arlington, Va.[5] She emphasized the need for the broader impacts criterion, stressing the importance of communicating the relevance of science and NSF's commitment to public outreach. She stated that "As a federal agency, we need to stay relevant with those who entrust us with taxpayer funds. We need to reach out to Congress and other stakeholders and be proactive in explaining what NSF is about and why we are vital to the nation's future… Not enough of our fellow citizens understand how relevant the research... conducted is to their daily lives... In both formal and informal venues, we need to engage the public in order to help improve understanding of the value of basic research and why our projects are worthy of investment."

2 The National Science Foundation, 2013. Proposal and Award Policies and Procedures Guide Chapter III.A.1 (NSF 14-1), available at http://www.nsf.gov/pubs/policydocs/pappguide/nsf14001/nsf14_1.pdf

3 Rothenberg, Marc, "Making Judgments about Grant Proposals: A Brief History of the Merit Review Criteria at the National Science Foundation," in Technology and Innovation, 2010, 12: 189-195.

4 National Science Board, 2011. National Science Foundation's Merit Review Criteria: Review and Revisions (NSB/MR-11-22), available at http://www.nsf.gov/nsb/publications/2011/nsb1211.pdf.

5 Supported by NSF awards 1437105 and 1313197. More information about the Summit is available at www.broaderimpacts.net.

Image credits: Jeff Mauritzen

We need to shift our approach from public communication to public engagement.

Dr. Alan Leshner, Chief Executive Officer of the American Association for the Advancement of Science and a member of the National Science Board (NSB), was part of a 2010 NSB task force that reviewed NSF's merit review criteria. He noted that the *America COMPETES Reauthorization Act of 2010* mandates NSF to have a broader impacts criterion. However, the understanding of and guidance on broader impacts is often unclear. Leshner emphasized two points: (1) That broader impacts could be viewed at the institutional level rather than at the project level, especially for small projects; and (2) that the targets for broader impacts are purposefully not prescribed, but left open to innovation from the field. The public wants to be sure that its money is spent wisely. He emphasized the need for public engagement—communicating *with* the public rather than *at* the public on scientific research.

Broader impacts make obvious the relevance of funded research.

John Wingfield, assistant director for NSF's Biological Sciences Directorate, noted that relevance is critical for research funding, but sometimes research is not obviously relevant, at least not at first. That is where broader impacts are important: They explain how the research is relevant in ways not immediately apparent and yet can make fundamental contributions to the bigger science picture. He stressed the importance of another aspect of broader impacts—citizen science, where the public contributes to the scientific research endeavor to enable analyses that would not be possible without the participation of hundreds, even thousands, of people observing and recording events.

How do you move the needle on large broader impacts issues? Through facilitation, leveraging, and coherence.

Pramod Khargonekar, assistant director of NSF's Engineering Directorate, spoke about the impacts of NSF-funded science on society: technological advancements, economic competitiveness, health and security. These are all examples of broader impacts.

He stressed the need for facilitation, leveraging and coherence. Facilitation can open new and creative ways in which basic research can couple with broader impacts. Leveraging—whether within the university, in local or regional economies, or with professional societies—increases impact. Coherence, aligning broader impacts with university strategic goals and directions, allows the university's research to have a greater overall impact.

We need to conceptualize broader impacts as essential to supporting the research funded by NSF.

Image credits: Jeff Mauritzen

Wanda Ward, head of the Office of International and Integrative Activities, emphasized that broader impacts are an essential component of the work of NSF as an innovation agency at the frontiers of knowledge. She noted that collaboration among the foundation, America's colleges and universities, nonprofits and other partners, has the potential to address the challenges associated with broader impacts, including those posed by an institutional approach:

1. In support of an institutional approach, how would support for a broader impacts infrastructure convey its added value for advancing societal outcomes?
2. What would be novel and/or creative about implementing broader impacts activities at an institutional level?
3. What is the flow of logic for the implementation of broader impacts activities and how will success be defined and reported?
4. How will the institution be transformative in terms of its resources (human, instrumentation, fiscal and social capital) to deliver high-quality, cutting-edge broader impacts events and activities?
5. What is leadership's commitment to broader impacts efforts during and after NSF funding? What about commitments to leveraging?

PERSPECTIVES OF UNIVERSITY LEADERS

Broader impacts should be conceptualized as 'of the community.'

Nancy Cantor, chancellor of Rutgers University-Newark, spoke about the public mission of anchor institutions (higher education institutions that are large employers, have a large presence in the community, and are important to the local economy and culture), the need for innovation, public support for science and accountability. She stressed the need for such institutions to be "of the community," meaning that the community and university come together to commit to innovation and social mobility.

She sees broader impacts as critical to the STEM (science, technology, engineering and mathematics) enterprise, rather than just an add-on or afterthought to a proposal: Broader impacts need to be embedded in the research. STEM should intrinsically have broader impacts as related to the fostering of talent, environmental sustainability and opportunities such as economic development, education, broadband superiority, health, arts and culture.

Broader impacts need to be part of the university culture and the culture of science.

Freeman Hrabowski, president of the University of Maryland, Baltimore County, stressed that broader impacts often have limited impact because the activity has been an add-on. He believes that broader impacts need to be part of the university culture and the culture of science. It should be part of who you are, what you value and what your goals are. What is good for all of us is what is good for America. Greater diversity, including the richness of diverse perspectives, makes all of us better. Universities need to demonstrate their commitment to broader impacts and provide greater incentives for people to promote broader impacts.

PERSPECTIVES OF UNIVERSITY PARTICIPANTS

There is a need for accountability, guidance and collaboration in broader impacts.

Image credits: Steven Buhneing, NSF; (right bottom) Jeff Mauritzen

Several themes emerged from discussions by university faculty, researchers and staff at the Broader Impacts Infrastructure Summit (pictured): the need for accountability, the need for university guidance and the need for collaboration.

Accountability involves how to measure broader impacts as well as the reward structure within universities. Many stressed the difficulty in measuring broader impacts for smaller, especially one-time, projects. Potential solutions include meta-analyses and evaluations of aggregated projects.

University guidance includes having a broader impacts infrastructure office, training and motivating researchers to include broader impacts in research, identifying exemplars, having a team of evaluators available to researchers, and broadening the perspective about what broader impacts can involve.

Collaboration includes not only partnering with other organizations that have greater expertise in, for example, public outreach or evaluation, but also collaboration with the community and society in which the university is situated.

These themes generated much discussion among participants at the Summit, including Susan Renoe of the University of Missouri–Columbia and Kemi Jona of Northwestern University (pictured below).

ACKNOWLEDGMENT

Special thanks go to the University of Missouri for taking a lead role in demonstrating the feasibility of an institutional approach towards a broader impacts infrastructure. The work of an inaugural summit, hosted by the university in 2013, and the subsequent April 2014 Broader Impacts Infrastructure Summit has continued through the formation of a national network of institutional broader impacts offices.

The newly instituted Broader Impacts and Outreach Network for Institutional Collaboration (BIONIC)[6] has as its goal the creation of a community of practice that fosters the development of sustainable and scalable institutional capacity and engagement in broader impacts activities. BIONIC has emerged from strong grassroots enthusiasm and a rapidly growing national community that, as of August 2014, had 160 individual members from 94 universities and other nonprofits. Founding members include:

- Susan Renoe, University of Missouri—Columbia
- Jane Horwitz, University of Pennsylvania
- Kemi Jona, Northwestern University
- Amy Pratt, Northwestern University
- Kevin Niemi, University of Wisconsin—Madison
- Diane Rover, Iowa State University
- Megan Heitmann, Iowa State University
- Kaye Storm, Stanford University

Through its collaborative network, BIONIC seeks to facilitate work on broader impacts across institutions; leverage previously developed, relevant resources; and support investigators at the institutional level through improved understanding of the broader impacts review criterion and increased access to collaborators who can help them design, implement and evaluate their broader impacts activities.

6 Supported by an NSF Research Collaboration Network (RCN) award (MCB-1408736) to the University of Missouri-Columbia, principal investigator Susan Renoe.

Image credits: Jeff Mauritzen

PERSPECTIVES OF NSF PRINCIPAL INVESTIGATORS

NSF principal investigators have viewed broader impacts as both educational and outreach activities, and as the linking of research to societal impacts. Scientists are increasingly reaching out to the public because of encouragement from funding agencies, a desire to influence decisions on science-based issues, and the spread of new media tools.[7]

Varieties of approaches are used by NSF-supported principal investigators to incorporate broader impacts in their research. Some focus mainly on education or outreach. For others, broader impacts are intrinsic to the research itself. Still others strive to interweave or conjoin educational or outreach efforts with the research itself, towards goals that emphasize the integration of research and education. The following examples, drawn from recent NSF awards and independent of the Broader Impacts Infrastructure Summit, illustrate the variety of approaches that principal investigators use to ensure the scientific and societal relevance of their research.

The following are some examples of broader impacts through education and outreach:

The **New York Hall of Science** and its collaborators created a traveling exhibition, "Human Plus: Real Lives + Real Engineering (Human +)," that displays the extraordinary technological advances being made to restore and extend human abilities. The exhibition, for which one entry is pictured below, tells compelling stories of engineers and users who design technologies to help themselves and others achieve their goals. Human + showcases the creativity of the engineering process that embraces such tools as wheelchairs for off-roading and neuroprosthetic limbs controlled by users' thoughts. (**Principal investigator Eric Siegel**, award #1010507)

7 National Science Foundation, 2009. NSF Discovery story "More and More Scientists Serve Up Science for Mass Consumption," available at http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=114406&org=NSF.

The CERN Summer Research Experience for Undergraduates (REU) 2011 – 2014, operated by the **University of Michigan** (UM) provides students with the opportunity to work at a premier global laboratory, the European Organization for Nuclear Research (CERN) in Geneva. Students spend nine weeks with some of the world's leading physicists. The NSF-supported REU CERN program, operated by UM for more than a decade, has a significant track record: Most of the students go on to graduate study in physics, mathematics or engineering. Pictured here is the 2014 REU class. (**Principal investigator Homer Neal**, award # 1062024)

The Florida Advanced Technological Education Center (FLATE) connects Florida's manufacturers, teachers and students with its workforce. Housed at the Brandon campus of **Hillsborough Community College**, FLATE is considered by many as the "go-to" place for manufacturing and advanced technical education, best practices and resources that support the skilled workforce needed by the state's manufacturing industry. A "Made in Florida" outreach campaign touts a positive image of manufacturing, promotes technical STEM education to a broad and diverse student demographic, and educates students, teachers and counselors about STEM career pathways focused on advanced manufacturing. (**Principal investigator Marilyn Barger**, award # 1204751)

Image credits: (left) Andrew Kelly/NY Hall of Science; (right top to bottom) University of Michigan Department of Physics; University of Michigan CERN REU program; Marilyn Barger, Florida Advanced Technological Education Center (FLATE)

Tuskegee University's Research Experience for Undergraduates in Nano-Bio Materials Science and Engineering, launched in 2014, provides students with an opportunity to learn critical thinking, qualitative reasoning, and mathematical, analytical and research skills. Undergraduate minority students spend 10 weeks in the summer doing research in nano-bio materials science and engineering (seen below). Research activities focus on a wide range of topics including synthesis of nanoparticles for biomedical applications and antimicrobial properties. (**Principal investigator Shaik Zainuddin,** award #1358998)

The **University of California, Merced,** a Hispanic-serving Institution with a large population of underrepresented racial/ethnic minority and first-generation college students, developed a program in data-enabled and computational analysis in 2013. The DESCARTES Scholars Program, a four-year research, training and education program for undergraduate applied mathematics majors and for high-school mathematics teachers from the region, provides an opportunity to learn the computational tools needed for modeling and simulation of complex systems, and for analysis of large datasets. Regional businesses and industry will benefit by having access to a well-trained pool of prospective employees. (**Principal investigator Arnold Kim,** award #1331109)

The following examples illustrate broader impacts that are intrinsic to the research itself:[8]

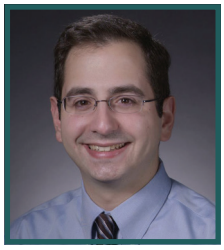
Hurricane Sandy, which hit the East Coast in 2012, was one of the deadliest and costliest storms to ever hit the U.S. To potentially prevent such devastation from happening again, **Jenni-Louise Evans** of **Pennsylvania State University** is studying Sandy's structural evolution and life cycle—knowledge that can protect lives and property from future storms. Having a better understanding of Sandy (whose aftermath is pictured below) may also improve theoretical knowledge and operational models of weather systems, storm forecasting and resilience planning. (Award #1322532)

Steven Fletcher, a scientist at the Cooperative Institute for Research in the Atmosphere at **Colorado State University,** uses mathematics and statistics to improve predictions of severe weather, such as this tornado forming over a sleepy town. His research will improve the ability to observe moisture fields—like humidity—and how they interact with other atmospheric components, potentially enabling more reliable forecasts. (Award #1038790)

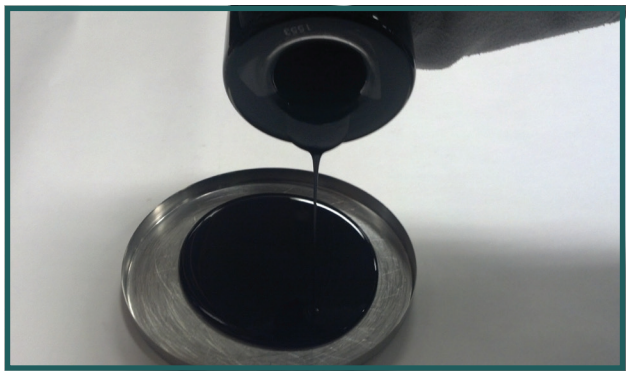
8 Some of these projects also include education components.

The Center for Research and Education in Optical Sciences and Applications at **Delaware State University,** a historically black university, engages in cutting-edge research in optical sciences with the potential for profound impacts on human health and on counterterrorism. Interdisciplinary research in optics and biological sciences that detects, identifies and classifies biomolecules is providing a stronger scientific foundation that can yield new technologies for medical diagnostics of early signs of disease and for detecting pathogens used to fight bioterrorism. (**Principal investigator Noureddine Melikechi,** award #1242067)

One of the computer processing industry's biggest challenges is boosting performance and scalability against the constraints of energy and programmer efficiency. **Joseph Zambreno** of **Iowa State University** works to develop ways to surmount these challenges and develop more flexible, scalable and secure processors. Such research that advances the state-of-the-art in computer architecture has the broad potential to improve energy efficiency and battery life, and to advance fields that rely on high-performance computing. As part of Zambreno's research, he has built video game scripting engines, like the one pictured below. (Award #1149539)



What if solid waste materials could be converted into road surfacing material? **Magdy Abdelrahman** of **North Dakota State University** in Fargo is working to do just that. He researches ways to convert recycled materials, such as tire rubber, into new and improved pavement. Ground tire rubber blended with asphalt—seen here—makes for longer-lasting, quieter road surfaces. (Award #0846861)



Neuroprosthetics are more than just substitute limbs. These devices replace damaged body parts and interact directly with the nervous system. **Jose Contreras-Vida** of the **University of Houston**—pictured here wearing a Brain Cap he created—is working to build upper limb prostheses that allow for ample control. This research not only improves the understanding of brain-computer interfaces, but potentially improves the lives of amputees and people with neurological diseases. (Award #1219321)

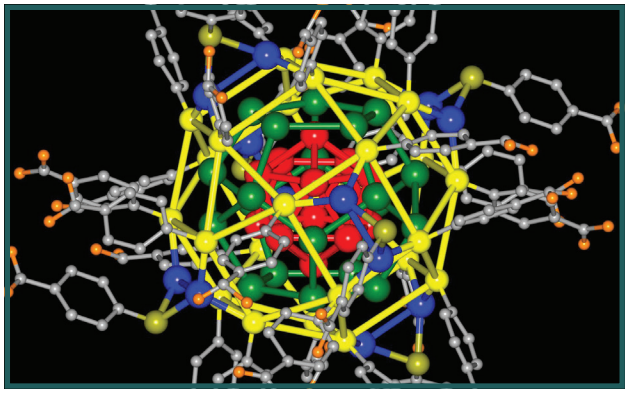
Some investigators view broader impacts both in terms of the intrinsic nature of the research and as educational or outreach efforts as shown in the following examples.

Malika Jeffries-EL of Iowa State University is exploring the use of organic, rather than metallic, semiconductors, which can significantly reduce the cost of electronic devices. Her project also provides interdisciplinary research experiences for both undergraduate and graduate students, and fosters interest in polymer science through a

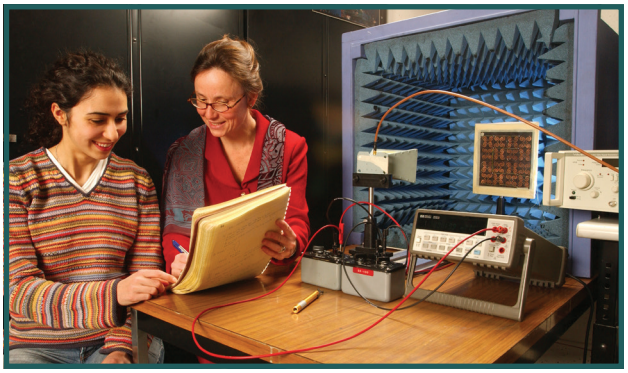
Image credits: (left top to bottom) Noureddine Melikechi, Delaware State University; Joseph Zambreno, Iowa State University; (right top to bottom) M. Abdelrahman; John Consoli, University of Maryland

creative outreach effort (chemistry ambassadors) that targets underrepresented students in grades eight - 12. (Award #0846607)

Terry Bigioni, University of Toledo, has a project that utilizes a new approach to greatly improve photovoltaic technology, with the potential to improve solar cell efficiency and reduce costs. Pictured here is one of the ultrastable nanoparticles he created using silver atoms. Such nanoparticles can be used to make a solar panel dye 10 times more light-absorbent than current available dyes. He also incorporates many educational activities, infusing alternative energy and nanotechology research in the undergraduate and graduate curricula, engaging undergraduate and high-school students and teachers in chemical and materials research, and teaching the general public about energy concepts through online videos. (Award #0955148)



Zoya Popovic of the **University of Colorado at Boulder** is researching a better way to monitor internal body temperature, a crucial step in preventing illness and monitoring the health of people under stress. Her ultimate goal is to create a wearable, disposable and inexpensive device. In addition, her project incorporates multi-disciplinary education (seen here) at the undergraduate and graduate levels, K -12 outreach and international collaboration. (Award #1202193)



Fedor Nazarov of **Kent State University** engages in a collaborative mathematics research project with Sergei Treil and Alexander Volberg. The research lies in the domain of harmonic analysis (related image pictured below), which has fundamental applications in other disciplines; for example, the analysis of large datasets, image processing, and the study of wave propagation. The project further provides a training ground for graduate students, as well as for mathematicians at the beginning of their careers. (Award #1265623)

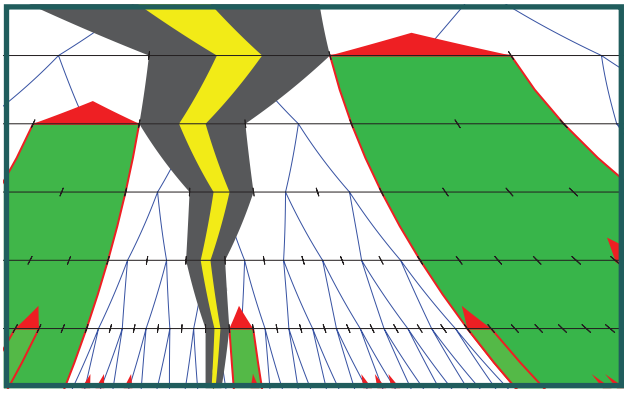
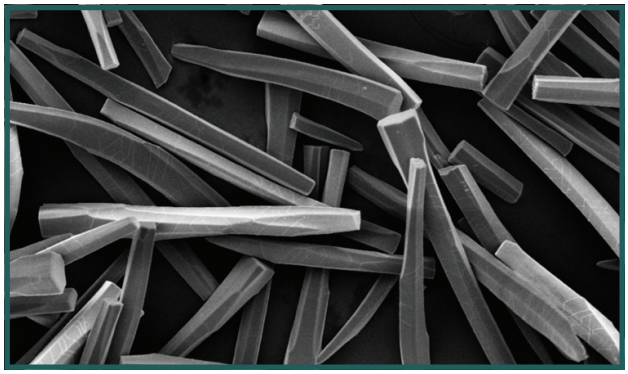


Image credits: (left top to bottom) Bob Elbert, Iowa State University; Terry Bigioni, University of Toledo; Bokwon Yoon; (right top to bottom) Zoya Popovic, University of Colorado, Boulder; Fedor Nazarov, Kent State University

Scott Peck of the **University of Missouri-Columbia** researches innate plant immunity. When plants recognize a potential bacterial pathogen, an immune response is initiated. Achieving a desirable level of host resistance, however, is a challenge. A response that is too slow allows the offending pathogen to overwhelm the host. A response that is too fast or intense can impair cell fitness and even result in cell death. At the present, relatively little is understood about how the initial responses are regulated or integrated to promote resistance. Advancing that understanding is the focus of Peck's research. The project has the potential for illuminating possible strategies for enhancing resistance against bacteria in crop plants. It also provides advanced training for both a postdoctoral researcher and students, including minority students. (Award #1051286)

Lara Estroff of **Cornell University** develops the use of crystal growth in gels, potentially leading to biomaterials for bone and tooth repair. Her research delves into a new class of composite materials that can lead to new formulations of pharmaceutical drugs or materials for energy generation and storage. Pictured here is a scanning electron micrograph of calcite crystals, one of the crystals she studies. The project also incorporates strategies for (a) introducing K-12, undergraduate and graduate students to the interdisciplinary fields of biological and bio-inspired materials; and (b) recruiting more female students to the Materials Science and Engineering Department at Cornell. (Award #0845212)



Patricia Kuhl of the **University of Washington** studies how children learn, with a special focus on early language and bilingual brain development. Her research has implications for early and bilingual education, literacy and diagnosing developmental diseases. As the co-director of Washington's Institute for Learning and Brain Sciences, she also collaborates with organizations and policymakers to develop science-based programs that help children maximize their ability to learn. Seen here is a non-invasive brain scanner—completely safe for infants—that allows Kuhl and others to study babies' brains while they engage in a task. (Award #0835854)

Image credits: (left top to bottom) Roger Meissen, University of Missouri; Estroff Lab, Cornell University; (right) Institute for Learning & Brain Sciences, University of Washington

Resources

Broader Impacts Infrastructure
http://www.broaderimpacts.net/

Center for Advancement of Informal Science Education (CAISE)
http://informalscience.org/

Institute for Broadening Participation
http://www.ibparticipation.org/

Framework for Evaluating Impacts of Broadening Participation Projects: Report from a National Science Foundation Workshop
http://www.nsf.gov/od/broadeningparticipation/framework-evaluating-impacts-broadening-participation-projects_1101.pdf

NSF Grants Conference: Merit Review
http://www.nsf.gov/bfa/dias/policy/outreach/grantsconf/meritreview_march13.pdf

The National Science Foundation Proposal and Award Policies and Procedures Guide (NSF 14-1)
http://www.nsf.gov/pubs/policydocs/pappguide/nsf14001/nsf14_1.pdf

Revised NSF Merit Review Criteria Effective for Proposals Submitted or Due on or After January 14, 2013
http://www.nsf.gov/bfa/dias/policy/merit_review/overview.pdf

National Science Foundation's Merit Review Criteria: Review and Revisions (NSB/MR–11–22)
http://www.nsf.gov/nsb/publications/2011/nsb1211.pdf

Science Festival Alliance
http://sciencefestivals.org/

Survey of Undergraduate Research Experiences (SURE)
http://www.grinnell.edu/academics/areas/psychology/assessnebts/sure-iii-survey

The 2010 User-Friendly Handbook for Project Evaluation
http://informalscience.org/documents/TheUserFriendlyGuide.pdf

Beyond Rigor
http://beyondrigor.org/

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NSF 15-008