Written testimony to the
United States House of Representatives Committee on Science
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Chairman Boelhert and Members of the Committee, thank you for this opportunity to testify on the *Role of the National Science Foundation in K-12 Science and Mathematics Education*. Specifically I have been asked to discuss my views on the effects and value of NSF's past and present K-12 math and science programs and the future role NSF should play with respect to these initiatives.

These are vital questions for literally tens of thousands of us in the field who are dedicated to the improvement of science and mathematics education outcomes for not only the best and brightest, but for every student who finds a need for science and mathematics in their future—which is just about all of them.

I should disclose that the NSF is largely responsible for my own career path and growth. The NSF has been an instrumental partner in my own work, starting with the Statewide Systemic Initiative, when I served as the Principal Investigator for the award to South Carolina. You asked to what extent could your programs have been created or operated without NSF? NSF program officers used to ask us the same question in South Carolina. What the NSF SSI grant really did for us is to get us to do what we knew we needed to do, but couldn't seem to do for ourselves. South Carolina would never have allocated an additional $10 million of its own resources and built a new

comprehensive professional development system for science and mathematics teachers that continues to thrive today. NSF insists on the highest level of quality. That's why the State continues to support it on its own today.

For almost 20 years, I have dedicated myself to the challenges of universal technical literacy from about every institutional angle: at a University, from a State Department of Education, from a two-year college system, as a PI of several NSF grants, from an informal science institution, and most recently a non-profit learning R&D organization.

In this last instance, at TERC, the organization represents a unique class of organizations in this country, numbering less than a dozen, which grew up with the NSF as non-profit centers dedicated to STEM education research and development of curricula, technology tools, teacher education programs and instructional experiences for students, adults and the public. The advantage of such places, in comparison with other countries that tend to do this work either inside of government ministries or as individual faculty efforts at universities, is found both in their independence and ability to pull diverse and talented teams of scientists, teachers, cognitive psychologists, designers and developers together around large-scale problems and projects in STEM education.

Without NSF's support, these places would have never existed (if we contrast ourselves with the lack of examples from these other countries). What is the consequence? People like Jerrold Zacharias, the Radiation Lab Director at MIT, started places like EDC in the 1960s because he thought the projects too big for one faculty or university.

He envisioned an effort in science education equal to the Manhattan Project that required independent education labs like EDC, TERC and the Exploratorium. In the last 40 years, some of our best curricula, research on learning, teacher education ideas, and innovations in staff development have come from these organizations.

Interestingly, my new home, the Exploratorium is another one of those dozen organizations. Started by the physicist Frank Oppenheimer in 1969 and based partially on his work on the development of NSF supported elementary school science curriculum, the Exploratorium is often best known for its hands-on exhibits and as a public place. It is less well known that the Exploratorium is a premier national teacher education center and research laboratory for science education where dozens of NSF K-12 and Informal Science Education (ISE) funded projects have resulted in exhibits, digital tools, school curricula, media projects and afterschool programming that reaches millions of children and adults across this country. The Exploratorium produces some 100,000 contact hours of teacher professional development a year

Collectively, these experiences have led me to the realization that the total STEM education system is much larger than university and school, and I firmly believe we must expand our set of solutions beyond them as well. NSF intuitively sensed this from the beginning and through its unique peer review funding system distributed its investments for innovative models and ideas across many kinds of institutions, centers and networks that continue to contribute to and support science and mathematics education improvement locally and nationally.

In my written testimony, I will make the claim that NSF covers a unique and essential gap in our STEM education system and that without it, much of what we have accomplished over the last 20 years simply would not have happened. I will outline some of the unique qualities and accomplishments of the NSF from my own experience and offer some suggestions for future directions.

The missing link among research, policy and practice

Education reformers love to talk about the connections among research, policy and practice, as if all teachers, administrators and policymakers needed to do is read the latest research reports! Unfortunately, this is a very poor model of how it actually works. Most basic research on learning and education never makes it beyond scholarly circles. However, new and promising ideas from research do make it to our classrooms—all the time. They most often show-up as a new curriculum, technology tool, teaching program or instructional intervention. The part everyone leaves out when they talk about education reform and improvement is the development and design steps (won't the engineers among us be happy!).

Basic research in the learning sciences is developing quickly, but never translated into classrooms raw. The process depends on a robust development community that creates useful and valuable things that take the latest in research and translate it into something that works for regular teachers and classrooms.

Whereas schools provide direct educational experiences for students, and districts and states implement policies and programs for instruction, improvement requires students have greater access to and

engagement with good teaching, better designed materials and tests, more opportunities with high quality out-of-school learning experiences, etc. The improvement of classrooms, and strengthening the systems that support them, requires a capacity for improvement – a capacity that might be called the nation's educational improvement infrastructure.[1] NSF invests in the people, ideas and tools that comprise this infrastructure and that support the capacity for ongoing improvement in STEM education.

NSF has a 50 plus year history, still running, which has resulted in accumulated knowledge and generations of people that enable better and better improvement efforts, stronger management of systems, breakthrough ideas and valuable tools. It is not reasonable to expect thousands of school districts, colleges and universities and informal learning institutions to take on this special R&D role for themselves. To wit, the programs at NSF in STEM education remain the envy of the world. There are lots of reasons cited by our counterparts in other countries for this perception, but it is more than just the monetary support and investments provided by the NSF. It is the accumulated wisdom, knowledge and experience contained within an independent scientific agency.

For example, too often reformers attempt to do something on the cheap, and it's not done in a scientifically rigorous way. A free and voluntarily produced curriculum, such as some websites attempt to do, almost always lacks any of the instructional design, cognitive and learning research, and scaffolding components necessary for a

[1] Mark St. John, President of Inverness Research and independent evaluator of scores of NSF projects deserves much of the credit for these ideas about an STEM education improvement infrastructure.

superior curriculum, let alone the prototype testing, iterative testing and all the rest that goes into a carefully produced, classroom-ready instructional program. Quality curriculum development is far more complicated than the typical person appreciates, is expensive and takes several years to complete. NSF has earned this wisdom through large-scale curriculum projects such as Physical Sciences Study Curriculum (PSSC) and Elementary Science Study (ESS). Almost everyone in STEM education still knows these curricula. Many versions of them are still in existence today. A few historians even credit these initial curricula efforts from the 1960s as the genesis of the science center movement, a claim with some merit when you notice that several of the most popular exhibits in science centers started out as simple experiments in those texts. However, it never came cheap. Noted education historian George Hein estimates in today's dollars that CHEM Study cost $11.9 to develop and (ESS) an incredible $41.7 million.[2]

Therein lies another very nice quality of the NSF. It is in the habit of treating grant awards like experiments, in the best scientific sense. That means learning as much from our failures and mistakes as from our clear successes, and revising hypotheses as the data come in. So for instance we now understand that staff development that is not connected with a specific student curriculum that teachers are asked to teach is not as effective for student learning gains as professional development programs that are explicitly tied to that curriculum—both its content and expectations about ways of teaching it. This is a major finding from years of NSF funded work. Without it, the standard of

[2] From a talk given by George Hein at the Science Education for a Thriving Democracy conference in Cambridge, Massachusetts on November 18, 2005 entitled *Science Education 1965 and 2005: Myths and Differences*

extensive workshops (totally 60 hours or more) focused on particular content and concepts from the student-taught curriculum, extended over one or more years time would not exist in contrast to the one-hour or one-day workshops that so dominated what constituted staff development experiences in school systems 20 years ago.

NSF's other unique qualities

First and obviously, NSF holds all of its grant recipients to exceptionally high thresholds of quality and performance. I like to think of the NSF as a public venture capital firm. It is smart, strategic and sophisticated. It asks the right questions, asks for evidence, and looks for high leverage ideas. For example, it recognized that a new kind of position was appearing in many school districts and schools across the country: that of a "data facilitator." As more and more districts embraced the use of data for making instructional decisions, the NSF realized both the complexity of using data in scientifically appropriate and valid ways and the problem that most "facilitators" inherited the role, along with their other school or district duties, and were never provided any formal training for it. Seizing the opportunity, NSF provided TERC with a grant to begin national training institutes for data facilitators that have led to substantial gains in mathematics and science test scores in several districts, including Canton City, Ohio; Johnson County, Tennessee; Salt River reservation in Arizona; and Colorado Springs, Colorado. Again, this is in contrast to the more common practice of CTOs sending raw test data to classroom teachers or department heads and asking them to "do something" without a formal process for verifying causes, formulating hypotheses and rigorously testing out different possible interventions.

Likewise, there are more than 2 million teachers of mathematics and science in this country, if you count elementary level teachers. The numbers appear overwhelming. However, the number of persons responsible for staff development of mathematics and science teachers is much smaller, perhaps in the thousands. It begs the question, who is responsible for the professional development of the professional developers? Seeing a chance to leverage its other investments, the NSF awarded a grant to the Exploratorium to create a national center—in essence a professional development school for staff developers and project leaders to experience and study professional development designs in science, and then to take back to their own teacher workshops. Part of the center's legacy is a new generation of more than 1000 professional developers who are able to multiply and expand on what they learned at the Exploratorium.

In another example from the Exploratorium, eight years ago the value of beginning teacher induction programs began to catch the attention of state educators and policymakers. Recent research suggests that what kind of teacher you become has more to do with what you learn in the first or second year of practice than even what you learned in your college program. Teachers are on the steepest part of their learning careers in these first few years and essentially there exists no organized system of support. And even where beginning teacher programs exist—and the states are starting to pay attention and pour some money in—when the Exploratorium got started, it could find no other example of a discipline-based teacher induction program. That is, no beginning teacher program just for history teachers, language arts teachers, or science and mathematics teachers.

The NSF started the Exploratorium with a “proof of concept” grant—which to our great fortune allowed us to make some substantial modifications from the first to second year of the program. We thought our initial model was about 2/3rds designed, when in reality it was a totally different kind of program than what you do in normal inservice program and it required a major overhaul after one year of hard-earned experience. NSF support—not just financial but programmatic expertise—made a critical difference. They insisted that the new program be thoroughly studied by Suzanne Wilson and her colleagues out of Michigan State University. Now discipline-specific teacher induction programs are the rage and many policy groups point to the Exploratorium as the model for middle and high school science teacher induction, of which the NSF is justifiably proud for recognizing and starting first there.

There is also the value of the NSF brand. Its support has been key for many to experiment and innovate, and to start new trends for entire fields such as it has over and again for the 600 science centers found worldwide. For many teachers and school district administrators, an NSF-funded project carries a strong signal of its likely quality and positive impact. Without NSF, I dare to say that the science center field ten years ago almost tipped in favor of experiences with a greater entertainment value because of market pressures. However, NSF’s investments in informal education demanded bona fide educational experiences based on real science and reversed this unsettling trend. NSF’s influence on the field remains pivotal.

The NSF is still unique in its ability to pull together the traditions of science and the nation’s scientific and educational expertise as the

premier general science and engineering research funding agency in the United States with the major responsibility for both the strength of America's research portfolio and the development of the science and engineering workforce. As my colleague Rob Semper said recently,

> Science education improvement is too unique to be left to the work of general education by itself. Not only is the world of science and therefore the requirements of good science education changing at a rapid pace, the very nature of science as a discipline requires involvement of the science community in its educational development. This is because as physicist John Layman says "the special character of science—that it is at once a body of knowledge and a dynamic questing activity."[3]

The NSF takes chances on experimental ideas, an attribute that is increasingly more difficult to find in the funding community.

Nonetheless, our STEM education agenda is unfinished. New understandings and important knowledge are being generated by the learning sciences. Some believe we are on the edge of a cognitive science revolution that can mean as much for the practice of education as the modern advances in our understanding of biochemistry had on medicine. For instance, we now understand that a 6 year-old's understanding of "which is more" in comparing two numbers has high predictive power in how well they will be doing in 3rd grade mathematics, *regardless of their backgrounds*. For students who don't come with this understanding into kindergarten, as long as they still leave kindergarten with it, they will do as well as their peers who understood it before, and much better then others who still don't understand it by the end of kindergarten. With known interventions, it is possible that nearly every child can leave kindergarten with it.

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[3] Rob Semper, Associate Executive Director of the Exploratorium, to the National Science Board in testimony delivered on March 9, 2006 in Los Angeles, CA.

At the same time, we are redefining the essential skills and thinking abilities required for a 21st century economy and democratic society which challenge our traditional practices in STEM education. And we have yet to reach all entrants, ethnic groups, and a majority of women fully capable of participating in STEM-related careers, let alone universal scientific literacy. We continue to need an R&D infrastructure that turns advances in our knowledge into useful and effective things for teachers and learners that address these grand challenges.

In the pursuit of these significant goals, we have accumulated our share of well-intentioned missteps and mistaken hypotheses, but we've had some astounding successes to point-out as well.

For instance, in a recent analysis conducted by Uri Triesman from University of Texas in Austin, he examined NAEP data from 1990 to 2005 from several major urban areas. What he found surprised him. If you look at the mathematics performance of students by race, compared with national NAEP averages by race, some cities like Austin, Charlotte and Boston consistently out-perform the national averages for black and Hispanic students by large margins. Moreover, black and Hispanic students in some cities were matching performances of white students elsewhere. And Hispanic students in Texas today are out-scoring white students from Texas on the same test in 1990. His main point: demography is not destiny.

So what gives in Charlotte, Austin and Boston? He points to several possibilities. Each committed to higher-level mathematics programs—

many funded in development by NSF—and stayed with the new program for more than 5 years. Sustained and significant professional development for teachers followed the curriculum in each grade. Interestingly, not all of these cities received direct support from the NSF. However, my hypothesis is if you did a survey of each of these cities, you would find any number of artifacts and tools—curricula, teaching programs, staff development tools—developed elsewhere with NSF support. I would venture to say that the mathematics gains from the last 15 years, especially in many of the country's urban areas, are very much a credit to NSF's long line of work in this area, starting with a number of NSF sponsored research studies conducted in the 1970s.

Likewise, informal education institutions are easy to overlook. But the NSF never did overlook this unique resource, not just as an out-of-school resource but also as major teacher development and curriculum development institutions in their own right. The informal science infrastructure is really very strong. NSF deserves most of the credit for building the capacity of the informal science learning community. It may come as a surprise that in a survey conducted by Inverness Research and Associates in 1996 that 40 percent of all professional development provided for elementary teachers in science of any intensity (defined as more than a week) was provided by informal institutions. More recent research conducted last year by the Center for Informal Learning and Schools (CILS) found almost 75 percent of the informal science institutions, including zoos, aquaria, and museums provide programs, workshops, materials or curriculum support for K-12 science education beyond the one-day field-trip. Nationally these institutions serve approximately 62 percent of the total number of schools. Even today the NSF is making aggressive

funding investments in the nation's afterschool provider networks and infrastructure, the most rapidly growing sector of informal education.

We are coming around to the notion that learners learn science all the time every where, and we cannot separate school from the rest of the settings and avenue where students are turned on to learn science. With significant support and help from NSF, we are beginning to appreciate the importance of the total science-learning environment. And NSF, for its part, is perhaps the only federal agency with its hand in every part of the total system from university science labs to Sesame Street.

Recommendations

I am very supportive of the comments made by NSF Director Arden Bement in his testimony before this committee on March 30. Our views about NSF's role in K-12 education are very consistent and I believe the proposed program changes and reorganization with the Education and Human Resource Directorate open up more opportunities for the field to innovate, experiment and test new ideas.

In terms of specific guidance on prioritizing certain activities related to professional development and teacher quality, I will note these three:

1. Professional development that is specifically tied to the instructional program or student curriculum in use at the school;
2. comprehensive and systemic beginning teacher programs that are discipline-specific, focused on common instructional issues, and leaves little up to chance for a new teacher's education; and

3. a special focus in the near term on middle school teachers where students are moving from informal notions to more formalized understandings about science and where the greatest number of out-of-field mathematics and science teachers are found.

More broadly, if you accept my claim that the agenda is unfinished, that the R&D step between research and practice is imperative, and NSF is uniquely suited to that role, then where might we make the most strategic investments with potential for the highest leverage and biggest payoffs?

Among my top recommendations:

1. Seriously invest in R & D for the next generation of STEM curricula, assessments, instructional approaches, preservice and inservice professional development programs, exhibits, media, texts, digital technologies, novel teaching programs, etc. based on the emerging cognitive revolution in the Learning Sciences, so new innovations are constantly tested, improved, abandoned or moved into commercial or public markets. This is especially true for stimulating development and experiments with the new digital learning technologies as the last active federal program dedicated to them went out of business in 1996 (i.e., the Technology Test-bed Program at NSF).

2. Tie these activities to a roadmap for improvement infrastructure development, that NSF could develop and manage, that includes support for national centers of excellence focused on key problems or grand challenges to facilitate rapid consolidation and dissemination of progress and knowledge. An essential part of this roadmap is the clear

articulation of NSF's role vis a vie the other federal science agencies and the large-scale state and district implementation efforts supported by the US Department of Education. For instance, one might imagine a relationship between the NSF and Dept. of Education similar to that of the NIH to the FDA. The NSF provides most of the applied research and clinical trials from basic research while the Department of Education is responsible for large-scale effectiveness studies to determine the ultimate benefits of new approaches on learners compared with existing approaches. In this way, everyone avoids the appearance of conflicts of interest and confusion about roles.

3. Stimulate rapid adoption of two-year intensive teacher induction programs that compares favorably with our best medical residency programs for every teacher of mathematics and science so that they not only stay in the profession but also learn how to become a competent, confident and successful teacher as quickly as possible. I believe this is the most cost-effective way to address our concerns about teacher quality.

4. Expand the investment, experimentation and resources for community and technical college education, especially as many teachers and most teachers of color start their collegiate education in 2-year institutions and because developmental math courses prove to be the second greatest gatekeeper to technical careers (high school algebra being the first). In addition, provide extensive staff development for 2-year college teachers, whose participation in NSF programs to date is much lower than for K-12 teachers.

5. Accelerate growth and capacity of the informal and out-of-school education sectors as vital participants and providers in the total K-12 science education system, including comprehensive teacher development programming, while continuing to innovate ever more creative ways to motivate children and adults of all ages to engage in everyday questions of science, mathematics, engineering and technology.

6. Keep at least some fraction of the NSF EHR portfolio dedicated to teacher institutes and large scale teacher enhancement efforts. NSF has a unique role in supporting the development of a leadership cadre of highly developed science and mathematics teachers through fostering critical collaborations with science rich institutions such as university science and mathematics departments, informal science education institutions such as museums and science and education research laboratories. The quality and reputation of these experiences for thousands of teachers over the last several decades creates in large part its credibility and reputation for teachers and in the eyes of Congress. This should not diminish the need for other federal agencies, states, or local districts to provide similar support for teacher enhancement, given the overwhelming numbers.

7. Leave some fraction of the investment portfolio aside for field-initiated proposals. True to the nature of doing science, there should be room for innovation and transformative ideas from the field that are not anticipated by the Foundation, which may be high risk but lead to significant breakthroughs.

Because of its natural connection to the science and mathematics academic community, its focus on field driven research and innovation, and its long standing relationship with all of the necessary players of this improvement infrastructure, NSF has a unique role to play in fostering each and every one of the above recommendations.

Thank you, Mr. Chairman and members of the Committee, for your attention. I would be happy to respond to any of your questions.