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When Dr. Kiho Kim, Director of American University's Environmental Studies Program, invited me to speak this evening, he wrote "Our students would appreciate the opportunity to hear your insights on the process of providing a scientific voice in policy-making and how you have resolved contentious issues where science intersects with the needs and concerns of society." He suggested that I might talk about science education too. I'm not sure my own students would have been so interested in these topics, but I am glad to oblige and I will talk about them both this evening.

My understanding of education and science policy is shaped by personal experience as a scientist and an administrator in large research-oriented universities and a national laboratory. I was drawn into administration at an early age, but continued to read and study physics and other sciences throughout my career, so I never lost my self-image as a scientist who had just wandered into administrative and policy positions. My approach to issues of science and society evolved with experience, but for a long time I thought my ideas about these things were so obvious that surely everyone else must think the same way. And perhaps they do, but I so often find myself disagreeing with what I read, hear, and see in the news media that I have come to the conclusion that either these popular sources are misleading, or that my way of thinking is not as universal as I thought. Probably both are true.

This tendency to think everyone ought to see issues the same way leads to a great deal of frustration. We think that simply explaining the reasons for our positions should be enough to lead any reasonable person to agree with us. Especially when we are scientists who have devoted our lives to rigorous training and logical, empirically based approaches to understanding natural phenomena. The miracle of nature is that attempts to build theories to account for her phenomena are improbably successful. That success creates a mental disposition (at least among scientists, but it seems to be universal) to seek order in the chaos of events, and to assume it is there even if it is not visible – indeed, even when there is in fact no meaningful order at all. (Think Rorschach.)

When I became Director of Brookhaven National Laboratory in 1998, neighbors of the lab were outraged that radiological material – tritium, to be precise – had leaked from a research reactor into the ground water. (The leak was actually from the spent fuel pool of the reactor, not from the reactor itself.) The lab scientists knew there was no danger for a variety of technical reasons, so in public meetings they attempted to give careful technical explanations of the relative risk created by the leak. You can probably guess how successful that strategy was. It's not that scientists reason so differently from non-scientists, but there were different interests involved, and a great deal of suspicion about motives. Basically, the scientists wanted to continue to do their work – which was in fact very beneficial to society – and the neighbors wanted to be protected from the hazards of radiation, no matter how important the science was. Before the controversy died out, the Department of Energy, which owned the lab, had terminated the contract with the operating corporation, a consortium of Ivy League universities that had run the lab from its inception in 1947. And the Department insisted that the reactor be shut down permanently, bringing three decades of research across a wide spectrum of sciences to an end. (Important research continues at other Brookhaven facilities, however.)

From the scientists' perspective, the neighbors were demonstrably wrong. From the neighbors' perspective the scientists had shown themselves to be irresponsible and unreliable (because whether the contamination was harmful or not, it violated environmental laws) and they felt nothing the scientists said could be trusted. The scientists thought the neighbors' concerns resulted from inadequate understanding of science. The neighbors thought the scientists were arrogant and dismissive of the health impacts that they perceived themselves and their families to be suffering because of the lab's presence in their midst. The scientists imagined the solution in the long run to be better science education. The neighbors imagined the solution to be greater public accountability for the conduct of science by governmental organizations over which the public had influence through democratic political processes. The scientists viewed the neighbors' solution as unwarranted intrusion of politics and bureaucracy into the conduct of science. The neighbors viewed the scientists' solution as insulting.

I am oversimplifying, of course, but in my experience these attitudes of the contending parties are almost universal in what Dr. Kim called the "contentious issues where science intersects with the needs and concerns of society." "Society" here includes a rather broad spectrum of actors, from individual homeowners and families to elected officials and government agencies at local, state, and federal levels. And do not forget that the scientists themselves are an important part of society. Roles shift with the issues. The immediate issue in such cases is not science or education or even the facts about risks and hazards. The immediate issue is a mutual suspicion and loss of confidence in the good faith of the other side.

The media love conflicts of this sort, and tend to simplify the positions of either side, usually favoring the aggrieved public over the embattled establishment. Curiously, however, science itself tends to be respected by all parties. And all parties tend to appeal to science to support their case. In the Brookhaven incident, the most sophisticated attacks on the Laboratory were mounted by an organization calling itself STAR, for Standing for Truth About Radiation. STAR had its own technically credible consultants, one of whom, for example, asserted that a cleaning chemical present at a radiologically contaminated site formed a chelated compound with the contaminant (not tritium in this case) that enhanced its flow in the groundwater. This was announced, not coincidentally, with great fanfare on the very day the new contractor officially took over responsibility for the Lab. Environmental advocacy groups rely on scientific studies to support their contentions that the environment is at risk, while groups whose impact on the environment is questioned rely on science to demonstrate the risk is negligible. Rarely do the parties in these confrontations accept the assertions of the other side, despite the appeals to science.

How can this be? Science is supposed to be based on facts that anyone can check for themselves. Why don't the parties just get all the facts together and accept what they say? Well, for one thing, despite the appeals to science, the disputes are hardly ever about science. At Brookhaven the lab and its neighbors were simply pointing in different directions. They were talking past each other. Eventually we did get to the point where the community began to be interested in the science at the lab, and worked together with lab employees to identify mutually acceptable cleanup strategies. But my dialogue with the neighbors did not begin by arguing the scientific merits of our case. I listened to their concerns and looked for actions the lab could take that actually responded to them. The community needed to see we were serious about taking action that related to their grievances before they were prepared to listen to us. The conflict may have had its roots in a technical misunderstanding, but the anger came from a sense of humiliation – of not being taken seriously.

And for another thing, facts do not speak for themselves. Facts are not science, and science is not facts. Last year at about this time I spoke in a science teaching symposium sponsored by Secretary of Education Rod Paige, and most of my talk was about what science is not. (You can find the whole talk on the OSTP web site. The event was on March 16, 2004.) Science is not simply a collection of facts, nor is it necessarily a description of nature, no matter how accurate. But all these things – facts, descriptions, observations, and some others I mentioned then – while not science itself, are necessary for science. Let me quote some paragraphs directly from last year's talk. And don't worry, I will return eventually to the problem of the "contentious issues."

"Science" has become a word loaded down with meanings. At its core, however, science is a way of continually improving our understanding about nature. It is a method, a practice, even for some a way of life. And it is based on examining nature to test our ideas. This … requires us to assume there *is* a nature that consistently "answers" the same questions the same way. All our experience indicates that is correct, that nature is reliably consistent, as long as we are careful about what questions we ask. But nature is most marvelously intricate, harbors many mysteries, and often fools us with superficial appearances. Science does not answer all questions that we may ask. Nor does it give us truth. Science does not even tell us how nature works. What science does is test *our ideas* about how nature works."

"When I became Director of Brookhaven National Laboratory in 1998, [and I am still quoting from that science teaching speech] Department of Energy officials asked me to introduce "performance based management" practices in the Laboratory. At first, I was only vaguely aware of what that meant, but it soon became clear that I was expected to have well defined plans, to execute work according to the plans, and if the work turned out differently than expected, to change the plans for the next time around. Management experts call this the *cycle of continual improvement*. It goes with a mnemonic that seems to go back to W. Edwards Deming: *Plan, Do, Check, Act*. I like that way of doing things. That is the core method of science, and I explained it to our scientific staff that way. The same ideas form the basis of the *President's Management Agenda*, promulgated by President Bush to improve the performance of all government agencies."

"I have given a lot of thought to why every organization does not embrace this so obviously sensible method. The reason seems to be that making plans and checking performance against them requires a lot of time and energy – not to mention thought – and changing your ideas about how things should be done encounters huge psychological resistance. Good management and good science are neither intuitive nor easy. Science requires *background knowledge* to make useful plans or hypotheses; it requires *discipline* to execute work or experiments that conform to the plan; it requires *patience* and *attention to detail* to observe and document the results; and it requires a combination of *humility* and *creativity* to abandon preconceptions and forge a new path forward."

I developed this theme in a recent talk to the National Association of Science Writers, also available on the OSTP website:

"The cycle we all learn in school of hypothesis, experiment, feedback, and modification is very much alive in science and dominates practice in every field. That said, some fields are more congenial to this method than others. All scientists would love to succeed as physical science does in predicting the behavior of physical and chemical systems. The laws are relatively simple, and the systems can be characterized with few enough variables that they can all, or at least enough of them, be controlled in experiments."

"Unfortunately, some of the fields most important for society do not lend themselves easily to controlled experimentation. In health, environmental, and behavioral sciences the number of variables is huge, the systems exceedingly complex, and our ability to measure and characterize them very weak. In these fields, only when a single cause obviously outweighs all others do empirical methods give unambiguous results. The challenge of science in these fields is to devise experimental approaches that reduce complexity and narrow choices. When the subject is a naturally occurring condition, such as an ecosystem, or the world's climate, the only option is to examine simplified models that ignore huge numbers of variables."

"In these cases of extreme complexity, that "sociological baggage" [of science I mentioned] becomes very important. Even experienced and sophisticated professionals can be misled by prevailing ideas and their own prejudices and expectations into forming hypotheses that are not supported by empirical data. Spotting and correcting such errors is what science is all about. Making them in the first place is expected. The reason science requires publication and communication is that every hypothesis is suspect all the time. The challenge to science [teachers,] journalists, [and public officials] is to convey this tentative nature of all hypotheses in the face of confident statements from the scientists themselves, and especially by their sponsors, about the significance of their results."

"In these complex cases, the data rarely, if ever, speak for themselves. Interpretation of data within a hypothetical framework is always necessary, and that framework is always [*necessarily*] subject to doubt. Sociological factors are very strong especially when the object of the science affects wealth, or health, or cultural values. It is not uncommon for large coalitions of opinion to form within communities of knowledgeable people in favor of one or another hypothesis, none of which are supported unambiguously by data. These truths dictate the strongest and most systematic kind of skepticism about conclusions drawn and expressed in these fields. My physics colleagues poke fun at post-modernist critics who say science is nothing but a subjective product of negotiation among scientists. I am very sorry to say that in these fields that are both highly complex and highly important to society, the baby of true science is sometimes difficult to discern in the murky bathwater of negotiated positions."

Many people seem to think these complexities make my job as a politically appointed science advisor very difficult. I would not say my job is easy, but the difficulties do not come from this direction. The contentiousness of the highly visible issues usually does not pose a problem for science because these issues have very little to do with science. What is contentious about climate change is judgments about economic impacts and regulatory philosophy. What is contentious about embryonic stem cells is the ethical principles that should guide the research. What is contentious about many environmental issues is the interpretation of laws. Yes, there are some cases where science can play a resolving role, but fewer than you may think. The contentiousness comes from people speaking at cross purposes and not listening to each other or respecting each others' concerns.

A good example of a difficult issue I have tackled where, in the words of Dr. Kim, "science intersects with the needs and concerns of society" is the response to international terrorism. Following the 9/11 terrorist attacks the State Department changed its instructions to consular officials all over the world regarding the processing of entry visas, including visas for students and scientists. The new instructions resulted in a flood of referrals of visa applications to Washington for additional screening, which clogged the system and created havoc for many students and visiting scientists. My office, and many others, immediately flagged this as a serious problem, and began working to resolve it with the Departments of State, Justice, and Homeland Security, which (after it was set up) had inherited the responsibility of clearing visa holders at the borders. The problem of course, is that a large fraction of graduate enrollments in science fields at U.S. universities are visa holders. And the conduct of science at all levels has always been an international enterprise. Restrictions in the international flow of scientific visitors or immigrants has a negative impact on the quality of scientific work.

I will not go into details here about what my office and I did on the visa issue, and I will not try to sort out the contributions of all the other offices we brought together to help, but the process did work. The President himself took an interest in the visa issues, and the three agencies worked with each other and the White House to reduce hassle and processing time without weakening the scrutiny of applicants.

The nation's counter-terrorism actions do have an impact on some science. Current law requires a license and security clearances to study any of a set of pathogens called "select agents" that might be used by terrorists. And terrorism is not the only concern of society that intersects with science. Concerns about nuclear proliferation and so-called dual use technologies have led to laws governing the export of certain technologies and even the transfer of information related to these technologies. Universities are very nervous about the impact of these laws on science and their interpretation in regulations issued by the responsible agencies. Concerns about the ethical treatment of human and animal subjects in experimentation have led to heavy regulations requiring extensive record keeping, committees, inspections, and standards of care.

I see my responsibility in these cases as similar and complementary to the Office of Information and Regulatory Affairs within the White House Office of Management and Budget. This is the office that performs cost benefit analyses of regulations proposed by Executive Branch agencies. Negative impacts on science are a cost that needs to be taken into account when forming regulations. The impacts are not always easy to determine. Prediction, Yogi Berra must have said, is very difficult, especially when it is about the future. And it is here that the methods of science can come most directly into play in these areas of contention between science and society.

What does all this have to do with science education? Recall that the Brookhaven scientists thought it was ignorance of science that caused their neighbors to fear the health effects from minor radiological contamination at the lab. Many commentators seem to believe that greater science literacy will make it easier to resolve issues of public concern about negative side effects of science and technology. I am not so sure about this. In my experience the concerned public is able to learn technical material very quickly when necessary. I wish more people were more aware of what things are made of and how things work, from their own bodies to the grand machinery of the cosmos. But it is not that kind of knowledge that seems to me most lacking.

The greatest weakness in the public understanding of science is not the content of science, but how science itself works, and we do not teach that very well, even to our own young scientists. Science has its own ecology in the larger environment of society. It needs people, money, institutions, and an elaborate infrastructure of communication, evaluation, and consensus taking. Although we do not teach it in the science curricula at any level, much has been written about these aspects of science, and much of it is worth reading. But the literature of the ecology of science is mostly addressed to academics, and the lessons it can teach us are missing from the public discourse.

I once gave a talk on science advocacy in which I described the priorities of science reporters. They care first about the significance of discoveries, second about the scientists who made them, little about the institutions in which the work was done, and not at all about how and where the money came from. That is beginning to change in view of concerns about conflicts of interest, but that is not the main issue. About a third of the research and development activity in this country is funded by the United States government through a surprisingly large number of agencies and programs. The other two-thirds comes from a diverse private industry. Who does what for which parts of science, and why and how they do it, are important and, I would hope to many people, interesting questions. These questions are so important as to warrant some passing reference in every news story.

Even many scientists are ignorant of the processes by which sustenance comes to their laboratories. They know part of the chain, but not the whole, and they – perhaps I should say "we" – tend to focus on their (our) own field and ignore others. One consequence is that scientists are often not effective advocates for their own interests. Another is that policy advice from scientists often fails to close gaps critical to its implementation. Science writers and journalists are in a position to relate the forest to the trees, and have a responsibility to do so. The challenge of dealing with an intricate and non-intuitive ecology of science is growing larger with the scale and complexity of research, and the information technology revolution that is affecting science as profoundly as any other sector.

Knowing about what I have called the ecology of science is more important for Americans than for citizens of other countries because our system for funding science is much more complicated than elsewhere. We do not have a single science ministry. The National Science Foundation "owns" only about ten percent of the non-defense research and development budget. The National Institutes of Health, all 27 of them, collectively own about half the non-defense pot, and NASA owns about fifteen percent. The Department of Energy, with a science budget a little less than NSF's is the largest single sponsor of physical science research, and the Department of Defense has been the main supporter of R&D for engineering. The nation's science portfolio is spread among dozens of federal agencies and appropriated by most of the appropriations subcommittees in Congress – ten out of the thirteen under the old system, and eight of ten (I think) in the system just adopted by the current Congress. Within every agency but NSF the science mission competes with other agency missions, so the preparation and funding of a unified science budget is very difficult.

You may not think of these topics as part of science education, but in my opinion they are as important for the general public to know about as cells and stars and molecules. If we are living in an age of science, then we need to know how science is linked to society, and what it needs to thrive. The health and future of our nation depend upon her people knowing how the nation functions.

I know you will have many questions about the themes I have touched on in these remarks, and I look forward to answering them if I can.

Thank you.