In honor of Neal Lane's 65th birthday
and in recognition of his contributions to
science, education, and government

BRIDGING THE GAP BETWEEN SCIENCE AND SOCIETY

The Relationship between Policy and Research in National Laboratories, Universities, Government, and Industry

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Education Panel

Science Education: The Challenges Ahead

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I want to talk today about how the National Academies have been focusing on educating our citizens more effectively – both to create better scientists and engineers and to prepare better citizens. The National Academy of Sciences was incorporated during the time of Abraham Lincoln. As a private organization in Washington, we needed a Charter from the President to exist at that time. For reasons left to history, this Charter specified that we could only exist as an honorary association if, in addition, we were willing to advise the government on any matter of science and technology. The famous added phrase – that we must do so "without any compensation whatsoever" – is why we are a great service organization today with some six thousand volunteers who serve on advisory panels at any one time. We call ourselves the National Academies, a name designed to include our operating arm – the National Research Council formed during World War I – as well as the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The last three organizations are honorary societies with a total of about 5000 members.

The National Research Council has allowed us to include lawyers, teachers, and whomever else is needed on our committees, which at their core are scientific, but also incorporate grassroots information from the front lines. We are useful to Washington only because we are completely independent in all of the advice that we give. Even though the government pays our costs for each of the studies it requests, we do not negotiate the answer to the questions the government poses. Instead, we release the final report to the government and to the public at the same time on our web site.

We think of ourselves as preparing two kinds of reports. Most focus on how we use science for policy. For example: What does science tell us about the dangers to humans of different trace levels of exposure to arsenic in drinking water? Other important reports focus on policy for science, which is what I am talking about today. Our most difficult policy for science report ever was the National Science Education Standards, a task generated by the 50 state governors in 1989, led at the time by Governor Bill Clinton. The governors felt that education from kindergarten through high school was faltering in this country, and they requested national voluntary standards for each basic core subject. Who would be assigned this task bounced around for quite a while. Finally, in 1991, with the support of the National Science Foundation and the Department of Education, the National Academies accepted responsibility for the science education standards.

I came in midway to the task, in 1993, when I began my first term as president of the Academy. I cannot tell you how difficult this job turned out to be, except to say that I must have spent nearly half of my time over the course of the next two years working on this project. The next-to-last draft was commented on by 18,000 reviewers, and their reviews took nearly a year to accommodate.

In the end, the National Science Education Standards turned out very well. Their guiding principles are: science is for all students, learning science requires active engagement, and school science should reflect professional science. Basically, the Standards call for a revolution in the way that we have traditionally taught science, both at the K-12 level starting at age 5, and as I will emphasize later, in the first two years of college. Different standards are presented in different chapters. The one chapter I would like everybody to read is only 25 pages long. These are the Science Teaching Standards, which make it clear that teaching is an incredibly difficult and important art.

Several people today have already mentioned that everything depends on the quality of our teachers and how we support them. I agree. Moreover, we have to be more sophisticated about what we think good teaching is; simplistic ideas abound. Because we are talking about a revolution, the National Academies have produced a series of supplements to the Standards. One of the most important ones is about inquiry. What is inquiry, and how does it look in the classroom at various age levels?

The motto for this whole crusade is ‘every child a scientist’, by which we mean that every child should have the ability to use logic and evidence to reason and argue like a scientist – not that he or she will turn out to be a scientist. Figure 1 is a photograph of the Einstein statue in our front yard in Washington, covered with children. This sense of comfort and accessibility is the image we all want for science; but to achieve this goal, there is a very large gap to fill.

I would argue that one of the best places to fill the gap is in our classrooms. We have to make science exciting and accessible in our schools. We know how to do it, but we do not do it in many places. The good news is that inquiry based science education precisely fits the needs for workforce skills that have been widely expressed over and over again by U.S. business and industry. So we have a strong potential ally in this movement, if we can mobilize business leaders and help them become sophisticated enough to be effective. Here is a quote from Robert Galvin, former CEO of Motorola.

“While most descriptions of necessary skills for children do not list ‘learning to learn,’ this should be the capstone skill upon which all others depend. Memorized facts, which are the basis for most testing done in schools today, are of little use in the age in which information is doubling every two or three years. We have expert systems in computers and the Internet that can provide the facts we need when we need them. Our workforce needs to utilize facts to assist in developing solutions to problems."

Motorola should know a great deal about this issue. They had been hiring many high school graduates who were not qualified to work on their factory floors. As a result, they set up their own education system for employees called Motorola University. The quotation therefore comes from long experience with the education that Motorola needs for its lower level workforce, not to mention for its leaders.

The bad news is our inertia. We have incredible inertia in our education systems and, as I will emphasize, the universities are a major part of the problem. Most of the scientific societies have also been too passive here. It is not just others who are at fault. We are all in this together. Figure 2 presents a diagram of our education system that comes from a report of the National Academies published several years ago. As a chemist, I see this as an equilibrium diagram that explains the inertia, so that we cannot do anything by fixing any one of the actors in this diagram. Nevertheless, many of my academy members will blame almost anybody for the sad state of science education in the United States today, except us (for example, the textbook publishers or the unions).

I want to emphasize the faculty of arts and sciences at the university level, where the science professors (I was one for thirty years) think that that we have nothing to do with this issue – that the K-12 system is somebody else's problem. Of course, when you think about this more carefully, as emphasized by Malcom, it is at the college level that we define what science teaching and the focus of science education should be. I claim that we at universities are misdefining both of these by our poor performance in our early science courses.

I am a biologist, and biology may present the worst case, because every year the amount of information in biology goes up by perhaps 10%, and we still try to teach all that in one year. Textbooks are enormously thick and heavy. The way that we define science in our big lecture classes has nothing to do with the definition of science that we came up with in the National Science Education Standards. At a minimum, we need to fix the first few years of college, if we are going to achieve the badly needed revolution in science education at lower levels in the United States. This is the conclusion that I have reached after trying many other approaches over the course of the last ten years.

We urgently need to change to an inquiry-based teaching of science and its relation to society for all college students, and to convert those cookbook science laboratories that we have been forcing students through for 50 years into an experience with science as inquiry. Especially at our research universities, every student should have some involvement with inquiry during their freshman year, just to acquaint them with what we really want in the way of educational performance. This fits a vision for our introductory science courses published by the Academy several years ago; the National Science Foundation published a similar report at the same time.

The hardest group to change in the whole education system may be the college professors. Because I was a department chairman at two different universities, I should have known this before I came to the Academy. How are we going to create change in college science departments? I realize now that we need to get more evidence. For example, we need to know exactly what the effects are of the large lecture courses in biology. Why are they causing so many of the best students to drop out of science? In the first few years of college, we are losing half of the students who had thought that they wanted to major in science. These are not the worst students; they are students with talent equal to those who stay in science. If the science faculties had clear evidence of the effects of their teaching that we could present to them in a meaningful way, I believe that my former colleagues could be mobilized to teach differently.

A major mission at the National Academies is to "make a science of education". An important report that we produced to begin this new focus was called "How People Learn: Brain, Mind, Experience, and School". It basically takes the last thirty years of what we have learned about learning in academia – in psychology departments, and elsewhere – and asks: "What are the implications of what we know from that scholarship for our schools?" Strangely enough, this translation of knowledge had not generally been made, showing how completely the world of academia has been disconnected from the world of our schools.

To create a continuously improving educational system, we will need a much more effective system of education research. I completely agree with Tom Kalil. We need to focus much of this research on classroom settings; there has to be much more respect for the scholarship that helps us to understand what is actually happening in our schools. It is critical that, as in science, we accumulate a commonly accepted body of knowledge of what works and why, based on confirmable evidence. Otherwise we will continue to have what we have today: school systems where the teachers are jerked around in every direction by the latest education fad. Every new leader seems to have his or her own new program. You cannot build an education system on politics, and that is what we are trying to do today. I am from California; I should know.

So what is good research in education? The National Academies recently published an important report called "Scientific Research in Education." You may find it hard to believe, but this issue has generated a very hot political debate in Washington. This is amazing, who would have believed it? Our report should set the standard for this important topic to help get us all back on the same page.

Among the research that is urgently needed is that on the effects of teaching science as inquiry in school classrooms. Part of the reason why there has been resistance to moving our agenda forward is that we do not have enough evidence about what works, why, and how we can do a better job of implementation – as well as what the effects are on the long-term attitudes of children and their abilities. We have lots of anecdotes; we need to do a much better job of collecting solid, objective evidence.

I want to end this talk on a personal note. I care deeply about this problem. I was in San Francisco for 17 years, having a wonderful time as a professor at the University of California, San Francisco (UCSF). A special nominating committee of Academy members phoned to ask me if I wanted to be considered as a candidate for president of the National Academy of Sciences. This was in spring 1992, and I said "No!" In the fall of 1992, they phoned me again and said, "I know you did not want to be considered for this job, but we chose you anyway. Please just come and talk to us about this possibility." In part, they had chosen me as president because of my strong interest in science education. I had been working with the San Francisco schools, and they suspected that, because of this interest, I would move to the Academy in Washington if offered this full-time job.

Well it has been ten years, and I only have two years left to solve this education problem, so I hope that all of you out there are going to help me, because there are a lot of problems left to solve. There are three major issues at the center of this debate that keep me up at night. First, there are the problems of testing. We all believe in accountability, but to a large extent, nobody differentiates between one kind of test or another. If you test in fifth grade for science learning with a multiple choice science fact list, as we are apparently doing now in the public schools in San Francisco, then you will get the kind of science teaching that will drive everybody out of science; the students will hate it. That image I showed of all the kids on Einstein, you can forget about it. We will remain where we have been for far too many years. If we instead had a different kind of science test, one that tests for how students can solve problems, we might be able to drive the system in a productive way.

You should know that every state is required to have a set of high stakes science assessments in place by the 2007-2008 school year, as part of the No Child Left Behind federal legislation. But who is giving feedback from the real world of the schools so that the people who make education policy will know whether our new testing requirements are working or not? There is no effective system of feedback from the shop floor operating in our education system today.

My second major issue is that the U.S. business community has been quite ineffective in advocating for their own interests. Most business leaders remain largely ignorant about the two different kinds of science education I describe. They certainly want more and better science education, but they do not discriminate between multiple choice tests for accountability and the kinds of testing and science education standards that would produce the workforce that Robert Galvin needs. This leaves science education vulnerable to political and economic forces that continue to buffet the system, thereby continuing to threaten our long-term national security. I just came back from ten days in China. That nation has its act together and is moving in a uniform, focused direction. They are using our National Science Education Standards, and they may have printed more translations than we have printed in English. Their leaders have placed science and technology at the center of China's economic and political development, from President Hu Jintao on down. We need to wake up and get our act together here in the United States.

The third and last issue that keeps me up at night is that our best science teachers, and there are many of them out there, need to have much more influence on the education system to which they have devoted their lives. Current trends – the kind of multiple choice testing I am talking about, or their work loads – will drive our talented teachers into more lucrative and respected careers. Their influence and wisdom are needed at every level – from the national level all the way down to the state and district level. Right now, our best teachers have almost no voice in any of the decisions that are made about our education systems.

For the past few years, a pressing question for me has been: how can we change this terrible state of affairs? In my view, providing a strong new voice for our best teachers may be the only way that we can inject long-term stability and wisdom into education decision-making – the wisdom that will need to create the continuously improving educational system that our grandchildren deserve.

My latest experiment is establishment of a Teacher Advisory Council at the National Academies. This Council is composed of some of the best teachers in the nation, twelve of them, each spending at least half of their time in a classroom. This group of incredibly energetic and wonderful people were the reason why I was late getting to this meeting. We had our own meeting in Washington of the Council, and I promised that I would be there. The mission of this group in the broadest sense is to provide a much stronger voice for our nation's best science, mathematics, and technology teachers in national education policies. This will also require connecting these kinds of teachers to business and industry leaders, so we can get all our forces in line to move our education systems forward in an effective way.

The Teacher Advisory Council of the National Academies has thus far met about four or five times. They are now recommending that we help to form associate Councils to provide a voice for teachers at the state level, where most education policies are made, as well as to better connect our states to the national group.

I end with an advertisement for our web site, www.NationalAcademies.org. We have devoted a lot of resources to making all of the reports we have produced – whether science for policy or policy for science – freely available for everyone to read on the Web. And we are making a special attempt to connect the resources we have, including those for teachers, to the great national effort to improve education everywhere. Thank you.

Questions and Answers

Question:
I have been involved with a group called HENAC, Hispanic Engineers National Achievement Awards Corporation, which is one of many groups dealing with the issue of K-12 education and diversity. My question is: Is it time for some coordination, some leadership, some identification of winners and losers, some investment and improvement assessments and so on. And if so, who should provide that and who can provide that leadership and coordination?

Answer:
Bordogna
That is exactly what I was talking about with this priority area, or initiative. This is an effort to integrate across the many different investments by lots of different people. It has three parts to it: one is integrative institutional collaboration – a fancy name for what you are talking about. This is to get the money in a competition, by having those of a track record integrate somehow and compete, and then trying to get the best of them to accelerate their productivity in this area. The second part is faculty of the future. We are talking about K through professors – we decided not to say teachers. We decided to say faculty to get them to mix together well in a variety of ways. And the third has to do with research that was talked about here by the Academy of Sciences. So this is an effort, which is very holistic, very connected. And we are trying to filter out those things that work best and accelerate them.

Question
I found your discussion of initiatives very interesting, but initiatives are kind of hard to do, and I wonder if maybe you have some suggestions as to how you would implement them. How would you efficiently implement the initiatives you were talking about?

Answer:
Kalil
One thing that needs to be done is to indicate from the very beginning that some of the goals and initiatives are going to take a long time. So when President Clinton gave a speech on nanotechnology at Caltech, he was very careful to say some of the goals and initiatives I am talking about may take 10-20 years to achieve, which is why there is an appropriate role for the federal government. In terms of structuring these, it is important to have a portfolio approach where you maybe identify some things that are going to happen in the near-term, but you also identify some of the longer-term challenges that are going to require sustained support for fundamental science and engineering.

Question:
I think it is all well and good to get our young K-12 students excited about science, but I feel that when they reach the university system, the university system is failing them. I would like your remarks about how we might be able to incorporate more professional development for future teachers at the beginning of the degree program instead of at the end.

Answer:
Alberts
This gives me a chance to talk about a program that I think provides a very good model. The University of Texas at Austin has a program called "U-Teach". It is run by their Division of Natural Sciences to attract and prepare science and mathematics majors for K-12 teaching careers. They incentivize entering students by giving them free credits: all the science and math majors can take a first-year course for about four hours a week that takes them into the schools to see what science teaching is like, working with some of the best teachers in the area. This gets them familiar with what it is like to be a science or math teacher before they actually commit to their major and their plans. U-Teach is a four-year program that produces about 100 science and math teachers a year. The courses were designed not only by the professors, but also by some of the best K-12 teachers in the area, who helped with the curriculum for several years.

You could think about this kind of program in many other areas. You could bring in professionals to try to design a program that would, very early in the college years, acquaint interested students with that profession. As said earlier, half of the people who get education degrees decide by the time they get their degree that they do not want to teach. This is a crazy waste of resources. Generating a closer connection at universities with professionals would make a lot of sense, enabling students to make career decisions early so that they can make the appropriate investments in their own education.

Question:
One of the things I have found though is that, especially being a non-traditional student coming from business into science, is that there is an overwhelming mindset amongst research universities that the professors are training future professors, not scientists.

Answer:
Alberts
Well I am sorry to say that the Academy has obviously failed. We have been working on this issue for about eight years. We produced a booklet called "Careers in Science and Engineering: A Student Planning Guide to Grad School and Beyond." After it was published, I was invited to many graduate student symposia where the graduate students told me "Well the problem is that I want to do this or that using my science degree, but I don't dare tell my professor because the professor will disown me and won't pay any more attention to my work." So then we produced a second booklet called "Adviser, Teacher, Role Model, Friend: On Being a Mentor to Students in Science and Engineering". Knowing that professors would never read it on the web, we suggest that the students buy it and put it on a professor's chair in the middle of the night. Obviously not enough people have been doing that; so let's sell some more books!

Answer:
Bordogna

NSF has two criteria that all proposals have to be reviewed against, and one of them of course is: “What is the intellectual value of all this?” and the other one is “What’s the greater impact of it?” And that greater impact has many little ticks under it that you can do. You can concentrate on diversity; you can produce some infrastructure that might be useful across the nation. One has to do with getting into the kind of thing you are talking about. There are many things you can have a greater impact on. One is to have a greater impact on a student’s career by being more professional and so on. So there are ways for professors to write and get money to do some of these things.

Answer:
Moore
The problem you have is a huge one. There are still many faculty members who still believe that their only job is to make more faculty members, and they should practice birth control. You can train one to replace yourself, and that is it.

Answer:
Bordogna
Malcom mentioned it this morning as one of the things that is sort of torquing the system. You have to integrate research education, and you have to do a lot of things we are talking about to get this award. That program is not just starting off the single investigator in research. What it is creating is a faculty member for the 21st century academia who is kind of the person you talking about here.

Question:
Duncan Moore, given the statistics you have, especially in the physical science, would it be almost impossible to absorb any significant increases in research development given the state of the population, and secondly, won't the recent reported increases in tuition across the country exaggerate that?

Answer:
Moore
The second one first, probably, but I am not sure it is going to hurt science anymore disproportionately than any other field. I think it is going to hurt all fields. When I looked at one of Jack’s view graphs this morning, on the Apollo program, at least 50 percent of the people in this room got excited about science during that period because students follow the money. If there is a lot of excitement over a program, students will move into it. So the question I thought about asking Jack was is there any way short of having some huge program, like Apollo, that will actually get a lot of students to go into the field? If we continue along the 10% solution, will we just keep going that way with no way out?