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Thank you Secretary Paige for inviting me to speak at this year's Science Education Summit. Last year you invited me to speak about mathematics, which I love. I described it as the beautiful and powerful language of nature. I also explained last year that although I love mathematics, I am not a mathematician. I am a scientist, and I welcome the opportunity at this year's summit to say a few words about the difference, and offer a few personal remarks about the importance of science and science education for everyone. I would also like to thank you for convening these summits, and for your vigorous efforts on behalf of quality education. The summits address the core of President Bush's education agenda "No Child Left Behind."

About Nature

I spoke of mathematics as the language of nature, which immediately raises the question: What is nature? I suppose that is obvious to most people. We use the word "nature" to refer to everything that exists outside ourselves, and sometimes even to ourselves since we are part of nature too. Nature encompasses the stars and planets, earth, sky, and water. It includes the smallest things and everything that can be made from those things, whatever they are, living or inert. And nature includes not only the animals, vegetables, and minerals, but also their behavior – how they interact with each other and all the rest of nature; how they grow and age and interact and disperse in the endless course of time. The Universe of nature is a grand place, our ultimate home. Each of us wants instinctively to understand our role within it. And that instinct emerges spontaneously when as children we learn the names of things and what they mean to us.

"No Child Left Behind" acknowledges this instinctive curiosity of children, and strives to sustain it through best teaching practices during the learning years. We have a responsibility to all children to give them the tools for understanding the world they live in. One of those tools is science. I think there is confusion about science, and I think being clear about it would help us teach it better. So let me attack this subject for a few minutes this morning.

Science is not nature, math, or nomenclature

Mathematics – the language of nature – is not science, nor is nature herself science. Science is something else. Science is not the names of plants or the bones of the body. The popular science icon Richard Feynman told a story about his boyhood when his father taught him about birds on long walks in the mountains. His friends made fun of him because despite these sessions, he did not know the names of any birds. His father told him "You can know the name of [a] bird in all the languages of the world, but when you're finished, you'll know absolutely nothing whatever about the bird. You'll only know about humans in different places, and what they call the bird." What Feynman did learn were the behaviors and habitats and unique characteristics of the birds themselves. Many people, myself included, have difficulty remembering names, but we are able to function well enough in society despite that handicap. So there is something more to know than names.

And yet naming things is necessary for science, because science is ultimately a social activity and the ability to communicate unambiguously what we are talking about is essential to the progress of science. The point is not that naming things is unimportant – it is essential. But it is not science.

Science is not description, or collected facts

I could go on for hours about what science is not. Like the names of things, however, much of what science is *not* is nevertheless important for actually doing or applying science. Science is not simply a description of things, no matter how accurate. The people of ancient Sumer in what is now Iraq, the earliest civilization known, made accurate observations of the stars and planets, but they were not scientists. But accurate observation is essential to science. And science is not simply a collection of facts about things, partly because what we mean by a "fact" is rather slippery and bound up with the concept of "truth." Is the statement that "this footprint was caused by a tyrannosaurus rex" factual or not? And yet whatever definitions we choose, facts are undeniably a part of science.

Science is a way of improving understanding about nature

"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 conception of science 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.

Science as a universal method

When I became Director of Brookhaven National Laboratory in 1998, 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 – 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.

Prerequisites for learning science

I claim that learning science, real science, breaks down our resistance to new ideas and builds confidence in our ability to learn from experience. Along the way, it teaches us that many things we think we know about the world are provisional, and must be tested continually against what we actually see happening around us. To learn these lessons and apply them for ourselves, we must have more than a slogan, we need certain basic skills and knowledge. We need the language of science, the descriptive framework, the history of previous failed attempts, and the skills of observation. Without these prerequisites, attempts to draw inferences from observation may actually be counterproductive.

A science lesson

I recall a painful incident from my eighth grade science class. We were learning about weather, and during a class discussion I remarked that I thought warm air was more moist than cold air. I don't recall my reason for saying so. Others in the class disputed it. The teacher herself (not trained in science) was skeptical but proposed an experiment. We moistened two handkerchiefs and placed one on the steam radiator that was heating our classroom, and the other outside the window in the frigid winter air. The inside handkerchief dried and the other remained wet. Everyone in the class immediately clamored that the experiment had proven me wrong. The handkerchief in the warm air was dry, and that in the cold air was wet, so the warm air was dryer than the cold air, right? The teacher solemnly declared that the experiment had decided the question against me. I was devastated, and my further arguments were dismissed by all as sheer stubbornness. Of course I was right, but I didn't immediately understand how to argue my case. Everyone else, including the teacher, had read the experiment wrong. It was a bitter lesson for me, and it took me years to get over my anger at myself for not being quick-witted enough to state my case properly.

This is what teacher education is all about. Science is not a simple thing. It occurs in complex settings where even simple questions lead quickly to deep ideas. (Example: Why is the sky blue?) Its methods are not entirely obvious, and even simple experiments require skill in execution if they are to give unambiguous results. For many students the laboratory portion of introductory science courses is a lesson in frustration. The lab activities are very different from the "book learning" and the contrived problems students do for homework or on exams. The real world is messy, and students approach it with a wide diversity of prejudices based on their personal experiences.

Styles of learning

As a young physics professor I was approached by some artists to give a course on "science and technology for art." It would be open only to art students in the University of Southern California's School of Architecture and Fine Arts, and I agreed to the project. At one point, I brought the students into a traditional physics laboratory to learn about electricity. There were oscilloscopes, power supplies, signal generators, and so forth on all the lab benches. The artists were fascinated by this equipment. They hooked wires here and there, making sparks and turning knobs to see what would happen. They were excited and having tremendous fun. I was stunned by their reaction. It was totally different from my experience with students studying to be scientists or engineers. By contrast, faced with the same setup, the science students were shy with the equipment. They wanted to know if what they were seeing was what they were supposed to see. The art students cared little about what they were supposed to see. They discovered things about the equipment in ten minutes that the science students would not discover for weeks.

This striking difference in the laboratory behavior of young artists versus young scientists made a deep impression on me. I interpreted the difference as originating in prior experience. Students who aim for an art degree may have much more experience with materials and equipment than their science-oriented counterparts. The artists were more pragmatic than the scientists, more fluent with the messiness of the real world, more prepared to learn its behavior so they could use it for expression. The art students did not become scientists, but they learned about the phenomena and quickly mastered them for their own purposes.

Science discloses patterns in nature

What the art students did *not* learn was the conceptual structure that tied together the various elementary phenomena that made the equipment work. They did not know about Ohm's law, or the math of oscillating circuits, or Newton's laws of motion. So they failed to perceive the deeper harmony of nature that science knowledge brings. Their artist's views of the connectedness of real things failed to penetrate the surface, and their projects, while intriguing and sometimes beautiful in appearance, employed the superficial phenomena for effect, and ignored the deeper beauty of the underlying laws.

This sense of deep connectedness in nature, of reliable patterns of cause and effect that we can learn from careful observation, is one of the great rewards of science education. It is an experience that gives power, and reduces the alienation so many seem to have from the world of inhuman things in our environment. Let me close with another personal experience.

We need to motivate young people to learn science and enable them to succeed in it

Young people are not motivated to learn science because it is good for our nation's economy. But if young people do not learn science it will be bad for our nation's economy. To realize the ambitions of "*No Child Left Behind*" we must give our teachers the tools they need to help them create experiences for young people that awaken the desire to know more about their world. And we need to give our young people the skills and knowledge they will need even to begin to understand what science is all about.

Few federal agencies have succeeded as well at motivating young people toward technical careers as NASA. Our nation's investment in space exploration and space science is being returned daily in the enthusiasm of schoolchildren for the Mars rovers Spirit and Opportunity.   Investments in President Bush's vision of sustained space exploration will produce many future returns through the young minds it recruits to technical careers. It is my pleasure to introduce the man who is responsible for implementing these important ventures, NASA Administrator Sean O'Keefe.