SciMathMN 1999 Assembly Keynote Address
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Introduction

Good Evening.
It is an honor and a pleasure to be here today with SciMath Minnesota to talk with you about this important subject—using standards to achieve math and science literacy. I'm going to start with some digressions, but assure you that I'll be getting around to talking about schools, and standards and how, working together, we can build a system that will help all of our children achieve the knowledge and skills that can ensure their happiness and security.

We live, as the Chinese curse would have it, in interesting times. We are about to end a century that began with the Wright brothers first powered airplane flight, saw men walk on the moon, and is ending with satellites giving us nearly instant communications with anyone, anywhere on the planet. There are human-made machines on and in orbit around Mars and Jupiter and heading towards Saturn, plus assorted comets and asteroids. We have discovered planets around stars other than the sun, and determined roughly when time itself began about 10 billion years ago. We have seen heart transplants, DNA fingerprints and clones, and the elimination of small pox and soon polio. We are about to enter a century where our grandchildren and great grandchildren will be able to travel to the moon for vacations—or even choose to live in space. For today's children—the first generation to come of age in the new millenium—the future couldn't be more exciting or complex and challenging, or more different from the world we know today.

Just think of our own experiences and how different they are from those of our parents. Growing up in Willmar, I hardly dared to dream of the adventures that I've had. Think of my grandson's generation. How can we prepare them to thrive and lead in a world that we can hardly imagine? Only by helping them to learn on their own and to think carefully for themselves. We can begin by gaining a bit of perspective on what is really at stake. To set the stage, I'd like to take you on a small tour of the Earth as I have seen it. I hope that by sharing some of these scenes and comments I can give you both a renewed sense of the seriousness of our situation and a cause for optimism. The many facets of my life have each influenced my perspective. This is not only the view of an astronaut, but that of a husband, father and proud grandfather, a scientist, a teacher, and a planetary citizen.

Part I.

Astronauts are often asked, “Was it a spiritual experience? Did you return a different person than the one who walked to the launch pad for the first time?” At first I said, “No, I was not changed. I am a professional who was well trained and performed my job to the best of my abilities. I checked my emotions and feelings at the hatch.” But as time has gone by, as I reflect on my experiences, I know this is not true. When I flew there was a small boy onboard with me, too, who took it all in with awe and wonder and delight. Sometimes he was even a little afraid. And there was also an old man aboard, a man I am just beginning to get to know. I am learning that he was a careful and calm observer, a representative of his brother and sister humans. So the three of us journeyed together, sharing the experiences with each other and with our fellow travelers. And we were all changed.

Launch is the most intense experience. It is the time when there is genuine risk. For three hours before the scheduled lift-off you lie on your back, strapped into the seat, working a little and thinking a lot. Waiting to launch on my last mission, the first flight following the loss of the Space Shuttle Challenger and seven of my close friends, I had plenty to ponder.

Mostly, I thought about risk taking—probably no surprise. I decided that the real risks had been taken long ago when I decide to quit playing my beloved baseball in college to learn to fly airplanes. When I decided to postpone my career as a scientist and apply for the astronaut program. When I told my wife, Susie, that I was going to apply for the astronaut program. After those decisions, the die was cast. The rest was follow though. I was proud to be where I was, playing a small role in keeping the fragile flame of exploration and discovery lit.

The very real flame of the rocket during launch is another matter altogether. When the count-down clock gets to zero and the engines light, there is no doubt that you are going somewhere very fast. The force of the acceleration pushes you back into the seat with three times the force of your own weight. The controlled explosion in the solid rocket boosters fills the cabin with a deafening roar and shakes the vehicle until you can hear the rattle of the equipment above the din of the engines. You hang from the straps of your seat as the Shuttle rolls upside down during the ascent. Looking out the windows, you can see the ground falling away beneath you faster and faster. First you see the launch pad, then the coast of Florida, and soon the whole state.

As we climb through about 100,000 feet an amazing transformation takes place. Directly over-head, a black circle opens in the blue sky. In just a few seconds the black expands and the blue collapses until all that remains visible of the Earth’s atmosphere is a tiny blue ribbon lying on the edge of the planet, thinner than the peel of an apple. It is our first glimpse of the transforming views of the Earth that we will see from orbit. In eight and one-half minutes we have accelerated from rest to orbital velocity, 17,500 miles per hour, and the engines are stopped. At that speed it takes only 90 minutes to circle the Earth. Ninety minutes to pass from sunlight into darkness and back into sunlight again. Sixteen glorious sunrises and sunsets every twenty-four hours! With each sunrise and sunset a rainbow of color races across the spacecraft ending quickly in the blinding white of the sun or the absolute black of night.

At the same time you race forward you are falling, just enough to follow the curve of the Earth bending away underneath. Never getting either closer or farther from the surface. Since everything is falling with you, it appears that you are all, everything, floating inside the cabin of the spaceship. And you are. To experience this is worth the price of the ticket. It allows us to perform exquisitely delicate experiments in physics and materials sciences, to learn more about how humans and other living things function by changing gravity, one of the "constant" variables in Earthbound laboratories. It also turns the cabin into a playground. A place for summersaults and floating "blobs" of Tang, where you can stand on the ceiling and sleep floating free with only the occasional gentle bump against the walls to constrain you.

As I said, spaceflight changed me. One change, I have found, is common to everyone who has participated in the privilege of spaceflight, from every country and background. All of us — test pilots, congressmen, scientists, Saudi princes, and Japanese doctors — are aware of the Earth as a fragile, finite planet and are concerned about its condition, both political and physical.

We are all stewards of the Earth. It is my hope that we can maintain the physical well being of our planet so that our grandchildren's grandchildren will live in an environment where they can lead happy and healthy lives. That prospect is by no means assured, though. Each step forward seems to be followed by a lurch back.

You learn to discern the places on the Earth by color. Each view is unique; even the individual oceans are a slightly different hue. So after a while it is possible to tell your location over the planet by just glancing out of the window and noticing the color of the land or water beneath you. And it is always beautiful. On board we often stop for a short time to wonder and comment on how different the perception is from 400km above the land than from its surface. It is true that you cannot see politics from space, but you can see international borders because of differing land use practices by neighbors — North and South Korea, Haiti and the Dominican Republic, the United States and Mexico for example. The day will not come soon enough when the world's leaders can share this perspective of the planet first hand.

Tambura is a volcano in Indonesia. When it erupted in 1815 it blew so much material into the atmosphere that it changed the global weather for two years. The years following the eruption of Tambura are known as the years without a summer. In New England it snowed every month of the year. Crops failed and people went hungry. After two years the material settled out of the atmosphere and the weather returned to normal. Tambura is a reminder of the fragility of the Earth's atmosphere and how local changes can effect the entire globe.

Today, another, larger force is impacting our planet—six billion people. On the night side of orbit, cities are beautiful clusters of fires and electric lights. They are also the human equivalent of Tambura in their impact. Today, it is the city's hunger for electricity and transportation and conditioned air and building supplies that is changing our climate and the very chemistry of our atmosphere. Our insatiable appetite for oil and coal and the power they generate is increasing the amount of carbon dioxide in the atmosphere. The international scientific community now agrees that this increase in carbon dioxide from human activity is at least in part responsible for the slow increase in the Earth's average temperature — global warming.

The Caribbean Sea comprises the dark waters of the Gulf Stream and the warm shallow waters around the islands. The sea is the cradle and sustainer of life on Earth. We do not completely know the effect of global warming and ozone depletion on the sea. So far this century sea level has risen about 15 centimeters — half from melting glaciers and half because water expands as it warms.

There are "well farms" in central Saudi Arabia visible from space. Each well irrigates a circle about one kilometer in diameter. Grass is grown and goats are raised. The water in these wells is "fossil" water. It has been trapped under the ground for millions of years and is not being replaced from the surface. Therefore, when this water is gone—in an estimated 50 years or so—it will be gone forever. The irrigation will stop and the desert will reclaim the land. Even though 70 percent of the Earth is covered with water, drinkable fresh water is one of our major limits to growth. Lack of safe water is one of the biggest problems we face today. It will only become more severe in the future unless the next generation is given the resources to devise and implement a solution.

The Rio Negre and the Amazon come together in Manaos, Brazil. If you look closely at the rain forest around the city in photos of the area taken from space you can see the dendrite-like pattern of roads that have been driven into the land. This is the pattern of deforestation, which is occurring around the world. At night huge fires can be seen throughout the entire region, glowing deep orange in arcs many kilometers across.

It is hard to blame the people of Brazil for wanting to clear land for subsistence farming just as we did here in America, but the consequences of rain forest destruction on biodiversity and global economics could be severe.

I took a picture of South America on my last mission in the fall of 1989. It is of most of the continent looking from east to west. During this time of year the fields in Argentina are burned to prepare them for the next crop. In Brazil there are always huge fires in the rain forests. The net result was that on the day I took the picture almost the entire continent of South America was under a pall of smoke from human-made fires.

It is striking that everywhere you look out the windows of the Space Shuttle you can see some evidence of human activity. Ships with wakes, airplanes with contrails, fires, electric lights, agriculture and engineering. At the same time, is remarkable to see how much open space is left. Most of it not productive, yet, but still room to expand, albeit with some difficulty and hardship.

Of course not every scene is depressing. We spend some time on orbit looking for potential vacation spots and identifying the most attractive looking locations. Hawaii is one of my favorites. The overwhelming beauty of the Earth is a continual source of optimism. We are fortunate to inhabit such a wonderful and bountiful planet!

Part II.

One of the reasons that I left the astronaut office to return to academia is to dedicate myself to the education of the next generation. Although you probably know how fraught with frustration working for change in the schools at all levels can be, I can think of no higher calling. Developing a generation of careful thinkers with the skills to access the information and assimilate the knowledge necessary to make informed decisions is our one best hope for the future. Every week I work with committed and skilled educators who are pushing, pulling and driving for improvements in schools that will give our young people the best opportunities to learn. And the habits of mind of science are high on my list of the essential components of every child’s education.

In our complex and complicated world, the problems are deep and real, but the potentials are limitless. For me, the continued progress of science and the public understanding of the nature and role of science is one key to our future. This is more than the Information Age. It is the age of continuous discovery—of breathtaking new knowledge and possibilities. But to take advantage of these possibilities in the factories, on the farms and in the marketplace requires a workforce that knows not only the basics of today’s science and technology, but also how to learn even more.

We cannot meet the challenges we face without a deeper understanding of our world by everyone. But knowledge of science and technology is insufficient without understanding of and skills in making strong connections with society and politics; not just with agencies and institutions, but with people; you and me and most importantly our children. And not just within the United States but globally. Biologist Lewis Thomas wrote: “We have a wilderness of mystery to make our way through in the centuries ahead and we need science for this, but not science alone. Science will, in its own time, produce the data and some of the meaning in the data, but never the full meaning. For getting the full grasp, for perceiving the real significance when significance is at hand we shall need minds at work from all sorts of brains outside the fields of science — most of all the brains of poets, of course, but also those of artists, musicians, philosophers, historians, writers in general.”

But as C. P. Snow argued in his famous essay, “The Two Cultures,” these minds cannot work together unless they understand each other. And that is the role of education writ large—schools, parents, churches, and communities. For our species to thrive in the next century we must, through deliberate education, create a universally literate society. And the definition of literacy must be expanded to include not only reading and arithmetic, but also the core knowledge and skills of the arts, sciences, mathematics, and technology. And this literacy goes well beyond the mechanics of reading, writing, and computing. It must include critical thinking, reading to learn, problem solving, and the ability to communicate.

I’ve said that you don’t have to be a rocket scientist, but you should be able to think like one. It is not acceptable that over half of the population at the end of the 20th century doesn’t know that the Earth orbits the sun or how we figured out that it does. Almost no one can explain what the phrase “orbits the sun” even means. Worse still, few can distinguish between an explanation of how the physical world works, like orbits, say, that is based on evidence and one based on opinion. The kind of clear and honest thinking demanded by science is a skill for every citizen in the 21st century. With the exploding impact of science and technology on every aspect of our lives, especially on personal and political decisions that sustain our economy and democracy, we cannot afford an illiterate society. George Bernard Shaw said it best when he wrote, “civilization is a race between education and catastrophe”.

So how are we doing? Not well, I’m afraid, especially in science, mathematics and technology. You see we have had an unwritten social contract among the K-12 schools, parents, communities and colleges, almost a “dirty little secret”. Over the last 50 years or so, the curriculum has become an ever-expanding accumulation of facts, vocabulary, and hollow activities. As long as some of the students can absorb and reemit this “information” —usually without much mental processing—we agreed that this represents "learning". The science literate population is a tiny—but generally well paid—minority. Today, it really isn't until those few upper division or graduate students majoring in science or engineering begin taking serious science and mathematics courses that they are faced with learning the ideas, concepts and habits of mind that are so important to literacy. This leaves out most people —especially future elementary and middle school teachers.

That is where Project 2061, SciMath Minnesota, and standards come in. In 1985, in response to the report "A Nation at Risk," AAAS brought together leaders from the country's science and education communities to provide a vision of science literacy. This vision was presented in the form of recommendations to the nation of what every adult should know and be able to do in the areas of science, mathematics, and technology. They are laid out in a little book called *Science for All Americans* written for a non-technical audience. I highly recommend it. *Benchmarks for Science Literacy* and the *National Science Education Standards* that followed represent the work of thousands of educators and scientists to define specific learning goals at different grade levels that lead to literacy described in *Science for All Americans*. These, along with the *Mathematics Standards* from the National Council of Teachers of Mathematics became the foundation for the Minnesota standards that you are all now struggling, as you say, to "implement."

The standards are not intended as an add-on to today's curriculum, but as guidelines for building a whole new curriculum that will result in students really learning—in their minds and hands—the facts, principles and skills that are described in the standards. The standards are intended to usher in a new way of thinking about school. For 100 years we have had the paradigm of instruction, now we are proposing a new paradigm of learning. We estimate that the standards contain only 40% of the sheer volume of information that is in today's "intended curriculum." But they also contain more. The expectation for deep understanding that is evidenced by the retention of key ideas years after the test is taken and the ability to apply the knowledge and skills to acquire and analyze new information and solve unique, real-world problems.

You hear talk of "raising the bar" and of "first-in-the-world." In terms of achieving Minnesota's standards, that doesn't mean **teaching** more and harder science, instead it means students actually **learning** the most important science. It does not mean dumbing down the curriculum or raising performance of the lower achieving students at the expense of the high achievers. It means increasing the literacy of all. Gifted students using a "standards-based" curriculum will learn even more than they are today of what is necessary to excel in school and life. Even though the standards represent a floor, not a ceiling for learning, very few students today are learning at the level of these standards. Someday, in the hopefully not-too-distant future, I look forward to thinking hard about defining the important learning that goes "beyond the standards."

“First-in-the-world” is really quite a meager goal. From the TIMSS tests we can conclude not only that some nations’ students perform a little better than those from Minnesota, but more importantly, nowhere in the world are students achieving at the level envisioned by the standards. In terms of TIMSS or other tests, if students were able to achieve at the level of the standards, they would perform at off-scale-high levels on TIMSS and be the envy of the world. That is the goal Minnesota has set for itself.

But there is legitimate confusion among teachers, parents, and others because today the system is out of synch. Standardized tests, including “achievement” tests like the Iowa Test of Basic Skills and college admissions and advanced placement tests, are still mired in the old ideas of mechanical operations and memorization and regurgitation. Who can blame students, teachers, parents, and especially administrators for being wary of changes to a system that many still think “works”—at least for those most empowered? But as another former Minnesotan has told us, “the first ones now, will later be last, for times they are a-changin’.” Achieving true literacy in mathematics, science, and technology is not an option for students in the 21st century it is a necessity. And preserving the educational status quo won’t help any of our children reach that goal. This is especially true for the soon-to-be majority of students. We are failing to prepare 1/3 of the nation’s students—15 million African American, Native American, Hispanic and other minority students—to participate in any future. The economic and social costs of this failure are intolerable.

Part III.

So how do we proceed? I hope you’ve noticed that I’m finally coming around to talking about what’s in the title of the speech. We are talking about science literacy, not the most popular subject for many of our generation—and not a requirement for us as it is for our children. And we’re talking about literacy for all students, not just future scientists and engineers. And we’re talking about change. Always a hard sell.

I’ll give you my list of five things that have to be in place to achieve the improvements in learning that the standards envision. Then I’ll say a little about a couple of them and wrap up so we can talk. Of course the list is not unique. You can describe the system in lots of ways; this one will work for now.

First on the list are the standards themselves. The learning goals must be clear and coherent. Minnesota has a “pretty good” set of standards—more than good enough to get started. But just having standards is not enough. They must be studied and understood and accepted as the core learning goals by everyone in the system. Standards first, then if there is time, more.

Second, are curriculum materials, including textbooks, and assessments that are "aligned" with the standards. By aligned I mean that students are able to learn the concepts and skills spelled out in the standards by working with the textbook under the guidance of a competent teacher. An aligned curriculum is "unburdened"—confusing trivia, developmentally inappropriate topics and unnecessary redundancy is removed—freeing up the time needed to master the key ideas and skills. Similarly, well-aligned tests measure students' progress towards mastering those same concepts and skills, not only for accountability, but also as feedback to teachers to help improve classroom materials and teaching.

Third, we need teachers well prepared and supported to teach for literacy. Teachers with the time they need to learn to use these new materials, to collaborate, and to be life-long-learners themselves.

Fourth, the total curriculum—that is, the assembly of everything a student experiences as she goes through grades K-12—must be coherent and purposefully designed to result in literacy.

Finally, we need communities—administrations and school boards, parents, business and industry, churches, state and local government etc.—who understand and support long-term improvement and can keep politics from interfering with children. This includes commitment to equity and the social reforms necessary to ensure that students arrive at school ready to learn and that they are held to high expectations and given the support they need to succeed. If these conditions are not met all of our work on standards and curriculum will come to little for those who need it most. Uri Triesman, a math professor at the University of Texas who founded and runs a successful program to teach calculus to minority students warns, "In too many cases, people fight their political and cultural wars on children's playgrounds. As in all wars the first casualty is truth, the second casualty is children. We have to stop fighting cultural wars that endanger the lives of children."

I want to say something more about two of these, curriculum materials and teachers. Project 2061 has been studying curriculum materials for four years now. Last month we released the results of a detailed analysis of middle school mathematics programs to assess their potential for having students learn important concepts and skills from our benchmarks. You can find the reports with additional information on our web site: http://project2061.aaas.org/. Later this spring, the middle school science reports will be released. There is good news and bad news here. We found some excellent mathematics materials. Unfortunately, most classrooms are using materials that we rated as unsatisfactory and the NAEP and TIMSS scores reflect this level of learning. At the same time, realize that we are not offering a "magic" solution. We have assessed the **potential** of the programs to promote student learning. The excellent new materials call for teachers who both know the mathematics at a deep level and can use the materials as they are designed. If they are used in a traditional manner, the traditional lack of learning will be the result.

Training and supporting teachers to improve learning is a special challenge. In our research with university science and education faculty, we have found that most students who do not intend to major in science or engineering enter college at the 6-8th grade level of our benchmarks. Again, this includes most future elementary and middle school teachers. After completing the one or two required survey courses in science and math most students graduate from college still at the 6-8th grade level. How can we hope to graduate science literate students from high school if we can't graduate literate teachers from college? Higher education—and not just the schools of education—has to take responsibility for breaking the cycle of illiteracy within its own walls!

But what about supporting teachers as they try to improve student learning by implementing "standards-based" changes in their own classrooms? Here is a comment received recently from a teacher in Oregon who spent ten days with Project 2061 last summer learning how to deliver our workshops. We sent him a note asking what impact we had had on his own classroom.
He wrote,

> " There is no doubt that I'm doing things differently this year, as a direct result of my training with 2061. For the first time, I'm using *Benchmarks* extensively in planning each unit, and I'm trying everything I can to assess real understanding in my students. Interestingly enough, I'm feeling that this year is my least successful year as a teacher. Now don't panic…I've puzzled over the reason for some time now, and I think I've got a handle on it. Always before I've done rather traditional teaching, planned traditional and expected scope and sequences, and assessed using traditional tests. I got traditional responses and traditional grades from my students. Everything was fine, and my teaching was comparable to any of my colleagues.
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> As a result of our discussions of real understanding and of my own developing awareness of what learning goals (standards) really are, I'm trying to teach so my students REALLY get key concepts. I'm testing them on the key concepts, and I'm reteaching as necessary. As a result I'm way behind my fellow teachers in the traditional pattern, and because I haven't become the master teacher of my dreams yet, I'm spending rather significant amounts of reteaching time and am frustrated at how little my students actually understand. Had I used the old model exclusively, I would have had a more predictable year, and I could have soldiered along never knowing how little my students actually knew. So this frustration and

> lack of success is a GOOD thing. I feel like I'm pulling my head, bit by bit, out of the sand, and seeing that things aren't as sunny as I might have expected! But it's damned uncomfortable to be confronted with the fact that I'm not all the teacher I thought I was! I do comfort myself with the realization that I can't change everything all at once, and that seeing the truth of my student's understanding can be the start of my own classroom reform efforts.
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> But I'm a convert. How will a more skeptical teacher react if she reluctantly tries to use the 2061 tools and is confronted by this lack of understanding? It could possibly cause her to declare that the changes are "too hard" and to retreat back to her old ways. To help guard against this, I'd highly recommend that you make sure that the message is clear to workshop participants. They may not see success in the first year and that they may have to confront the painful truth that their students really don't "get it" at the level of true understanding…Above all we need the teachers to be enthusiastic realists about the program.
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> But we all have to start somewhere. Given that teachers are busy, that students are complex, and that teachers have multiple pressures to respond to, if we can get them to just see what their students know and compare it to what the teachers think they know, that would be a clear starting victory. Can they accomplish more the first quarter, semester, or year of their efforts? I don't know, probably not alone, but I wonder what a department or school could do, if all were trained together. There might be some interesting energies that emerge. "

This kind of change takes time and collaboration. Patience and realistic expectations are critical. But so is urgency because if we don't start down the path to improvement today, we'll find ourselves in the same place with the same problems and the same learning next year—and the world is not waiting for us.

Those of us who have been fortunate enough to see Earth from space share the commitment to walk softly on the Earth, to limit our impact, to preserve and enhance and restore, so that our descendants can speak of us with gratitude and respect. I wish you could all have shared these experiences with me. It is a view you would have enjoyed. By providing the kind of education envisioned by SciMath Minnesota for all students, we can do our part to create a century that will improve the lives of all of Earth's children. It is the children who will build and travel the path into the future. All we can do is provision them as best we can for their journey and send them off with our love and our best wishes.

Thank you for listening.