

**Dr. Rita R. Colwell
Director
National Science Foundation**

***“Obstinate Issues, Sophisticated Solutions: Environmental Research and Education
for a New Age”***

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As prepared

Good evening to you all. I'm delighted and honored to be speaking tonight, not least because of the fine work the National Council for Science and the Environment accomplishes, and the distinguished speakers who have preceded me at this podium [Sherry Rowland, Mario Molina, and Ed Wilson.]

I am also mindful that all of you have come out on a cold night in January to engage in a dialogue on environmental science and education. I am genuinely pleased to be among people who share a strong commitment to an issue so critical to our future.

And finally, with all Americans, I owe a debt of gratitude to the late Senator Chaffee, whose vision and persistent voice on environmental issues we celebrate. We are fortunate to have had his leadership. He was a tireless campaigner for forward-looking environmental policy, and a longtime advocate for environmental research and education.

Environmental research and education are the topics of this conference, and the focus of my remarks this evening. I want to emphasize both the extraordinary difficulty of the challenges facing us, and the great potential we now have for meeting them. So I have taken my title from a commencement address delivered by President John F. Kennedy, in times similar to our own.

Speaking forty years ago, he described the pressing issues of the time as “more subtle and less simple” than those of the past.

“They relate not to basic clashes of philosophy or ideology,” he said, “but to ways and means of reaching common goals – to research for sophisticated solutions to complex and obstinate issues.”

That was 1962. Confidence in the ability of science to make rapid progress in solving the nation's problems was rampant. John Glenn had just become the first American to orbit the earth. The National Science Foundation, the agency I now direct, had just turned the corner on its first decade of work to advance fundamental research and education in the

sciences. Schools across the nation were building new laboratories, stocking them with cutting-edge equipment, and promoting science as an important career and national need.

We were a nation intoxicated with hope for a brighter future, and science was going to take us there.

Looking back to those times, we may be tempted to despair. The stubborn problems of the past – disease, hunger, and conflict – are still with us. Not surprisingly, new ones have appeared. To the old and familiar scourges, we now add growing concerns about the integrity of planet earth.

We might well ask, “Have science and technology failed us?”

The sometimes gloomy, but ever thoughtful cartoon character, Charlie Brown, expresses this angst perfectly when he says, "Sometimes I lie awake at night, and I ask, 'Where have I gone wrong?' Then a voice says to me, 'This is going to take more than one night!'"

Understanding the mistakes of the past is a necessary and useful part of our learning process. One glance at the news reminds us that not all the changes we humans have brought about are for the better. The ozone hole that now appears over Antarctica every year is a reminder that the cumulative effect of billions of individual human actions can have far-reaching, though unintentional, consequences.

But looking at our possibilities only through the dark lens of past mistakes can distort our vision. We need to move forward to what Kennedy called “a new, difficult, but essential confrontation with reality.”

Science and technology are a significant part of that reality. They have always been a powerful force for human progress. Far from failing us, they can help us find a way through and beyond our circumstances. I will speak tonight about some emerging frontiers in research that are germane to our environmental future, and what we need to do to *realize* the promise they hold: a fresh and vigorous commitment to environmental education.

I believe we stand at the threshold of a new age of scientific exploration, one that will give us a deeper understanding of our planet and allow us to improve the quality of people’s lives worldwide. In the past two decades, our knowledge has exploded, and the pace of science and technology has accelerated with it.

New knowledge drives technological innovation, and so provides us with a richer set of options for the future. It also informs our choices, and through prediction, reduces our risks and enables prevention.

From the viewpoint of science and engineering research, it’s particularly appropriate for us to look toward future environmental horizons. Discovery and innovation are the heart

and soul of the scientific endeavor. Although the details may be unclear, we can already discern the shape of the landscape ahead.

Our new information and communication technologies have transformed the very conduct of research—helping us to handle vast quantities of data, enabling new ways to collaborate around the globe, and letting us visualize what before we could not even imagine.

To the traditional methods of theory and observation, we have added sophisticated modeling and simulation techniques that allow us to probe the complexities and dynamics of environmental systems at all levels. Increasingly, we are able to predict some of the consequences of environmental change.

We are beginning to understand that abrupt change and what we call “emerging” structures characterize many natural phenomena – from earthquakes to the extinction of some species. We know that the impact of humans on natural systems is increasing, but we don’t yet have the full picture of how environmental change – human induced or otherwise – will cascade through natural systems.

These are questions of utmost importance for our environmental future. How vulnerable are natural systems to stress, and how resilient are they in the face of change? The answers bear directly on issues of great concern to all of us, from emerging infectious diseases to bioterrorism to the health of ecosystems, and from local contamination of soil and water to global climate change.

Last summer, in a survey of the global environment, the *Economist* decried the current lack of detailed environmental data as “remarkable.” But this will not surprise anyone in this audience. We have understood for a long time that the complexity characterizes environmental interactions and makes measurement a difficult task.

I use the term “biocomplexity” to describe the dynamic web of relationships that arise when living things at all levels, from molecules to genes to organisms to ecosystems, interact with their environment.

Early on, we used the term “ecosystems approach” to describe part of what we mean by “biocomplexity.” Now, technologies allow us to delve into the structure of the very molecules that compose cells – and simultaneously, to probe the global system that encompasses the biosphere.

Biocomplexity lets us take the broader view, giving us a viable multi-disciplinary approach to environmental research. Our new technologies help us to do so.

Tools are now at hand or under development that will change this situation dramatically. Sensors that record minute variations in environmental variables, satellites with ever increasing resolution, and global positioning systems will allow us to begin establishing a baseline against which to measure environmental change. Our new information storage

and computing power gives us the ability to manage and analyze these vast quantities of data.

The information and communications technologies that are enabling discovery today have changed the very conduct of research. Three additional capabilities promise revolutions at least as profound.

They are nanoscale science and technology, advances in molecular biology and genomics, and last, but not least, the convergence of neuroscience and the social and behavioral sciences that is opening new windows on human cognition. I call these “nano, bio, and cogno” for short! Each promises to contribute greatly to our ability to meet human needs and sustain a robust and healthy environment.

First is nanoscale science and technology. Nano takes us down to the scale of phenomena at several billionths of a meter. Individual *atoms* are a few tenths of a nanometer.

Nanostructures are at the confluence of the smallest human-made devices and the large molecules of living systems. We can now manipulate individual atoms at will. Nano capability means that we will be able to design and “customize” materials, products and tools atom by atom -- everything from automobile tires to golf club shafts as thin as fishing line. Scientists envision new resource-conserving products, manufactured by processes that are environmentally benign. Research is also underway on materials to generate energy cleanly and cheaply.

At the nanoscale, the point at which the worlds of the living and the non-living meet, we are also discovering new links in the biological, geological and chemical cycles that support life on earth.

Here’s a simple example. Researchers are investigating nanoscale processes at the surfaces between microorganisms and the physical world. These interactions play a major role in the weathering of rocks, the availability of nutrients in soils, and the transport of heavy metals in groundwater. This work has broad implications for environmental remediation.

Nanotechnology interconnects multiple disciplines: physics, engineering, chemistry, materials science, biology, and more. It will influence every field and industry in the next twenty years.

Genomics and its offspring, biotechnology, are also transforming our future. We are all familiar with advances in plant genetics that allow us to engineer crops that are salt tolerant or drought resistant. Exciting research is well underway to develop foods that are nutritionally enhanced – rice enriched with vitamin A is one example – or that can deliver vaccines efficiently and effectively.

Less well known is the capability our new genomics toolkit gives us to explore biodiversity and ecosystem structure. For the first time, we have the ability to determine

“what’s out there,” and to chart phylogenetic relationships from the smallest of living organisms to our own human evolutionary history.

Genomics has uncovered both a remarkable continuity among the genes of living organisms and vast diversity. For example, there are a variety of microorganisms that inhabit environments that we once believed could not support life – South Pole ice, arctic glaciers, and volcanic lava.

Because microorganisms play a central role in the cycling of carbon, nutrients, and other matter, they have large impacts on other life – including humans. We know little about the vast reservoir of microbial species in soils and in seas, and we are only beginning to probe their ecology with our genetic toolkit.

These microorganisms may well be our “canaries in the mineshaft,” warning us of subtle environmental changes, from the local to the global. We know that biologically active substances – everything from antibiotics to pesticides to steroids – are now routinely found in our waterways and soil. How are these affecting microbial communities? Are they altering the structure of microbial ecosystems? We can now investigate these interactions from the molecular to the ecosystem levels.

Although we sometimes seem to forget it, we humans are part of the natural world we are poised to understand in these deeper ways. Enter human cognition, or, more simply, learning.

Research that spans disciplinary borders in the cognitive, behavioral, neuro, and social sciences is poised to launch a renaissance in the study of human thought and action.

An illustration of this new research is close to hand. The Nobel Prize in economics was recently awarded to Daniel Kahneman – a psychologist – for his pioneering work across the borders of cognitive science and economics, and to Vernon Smith for introducing experimental methods in economic analysis. The National Science Foundation has supported the work of both these distinguished economists. One NSF award went to Vernon Smith for integrating biological research on the brain into his course work in economics! Our understanding of the way we make the choices at the core of our consumer society is beginning to change.

New research on cognition will enable us to design better learning environments. It can shed light on how we plan and adapt to change. We can begin to understand which institutional arrangements meet human needs and reduce risks to the environment and ourselves. These very human activities and systems will help determine whether our future on the planet is sustainable.

You may have been wondering if I was ever going to discuss environmental education, the focus of this conference! Our new capability to investigate and understand learning will be vital to environmental education programs at all levels.

Over the next two days, many of you will be addressing strategies for improving environmental education. I believe this is an issue of utmost importance to our nation and the world. But inadequacies in our current educational systems could be significant stumbling blocks on our path to a sound environmental future.

The challenge is far-reaching: how do we ensure that *all* our citizens – both young and old, from all professions and sectors – can make the informed choices that will shape our environmental future?

Let me go straight to the heart of the issue. Today, and for the far future, the well being of individuals and of the nation will depend on knowledge and skills in science, engineering, and technology. How well we prepare *each* of our citizens in these areas will determine how well we are prepared as a nation to confront the obstinate environmental problems that we face in this new century.

NSF's Advisory Committee for Environmental Research and Education recently completed an important study detailing a 10-year research agenda for environmental research and education. The title is telling: "*Complex Environmental Systems: Synthesis for Earth, Life and Society in the 21st Century.*"

Our understanding of complex environmental systems depends upon a set of mutual interactions that includes not only science, engineering and technology, but social, political and economic interactions as well. The emphasis on "synthesis" reflects this understanding.

We also know that our children will need not only increasing levels of math, science, and technical skills to thrive in our competitive, knowledge-based economy, but also to prevail as informed citizens safeguarding the environment. One Commerce Department study concludes that in less than two decades, sixty percent of jobs will require technical skills possessed by only 22 percent of today's workers. This is a serious challenge to our nation's prosperity, security, and also for the long-term health of the environment.

In addition, we need a robust science and engineering workforce to maintain the momentum of discovery and innovation.

In fact, we need to reexamine our assumptions about education across the board. That will require putting aside the tattered and worn fabric of old identities and stale academic divisions and working together to find sophisticated solutions.

As you discuss new strategies for environmental education over the next two days, I urge you to think beyond traditional categories, and search for innovative and imaginative ways to address these issues.

Make no mistake, this will be hard work. Each and every one of us must take an active role in addressing this problem. Pointing fingers is not enough. As MRC Greenwood,

the Chancellor at the University of California-Santa Cruz, puts it, “You can’t wring your hands and roll up your sleeves at the same time.”

A fresh and vigorous commitment to environmental education can lead the nation in this effort.

Clearly, I am “bullish” on the prospects that science and technology promise for the future. But the great potential that new tools and knowledge promise should not blind us to the possibility of missteps. The greatest question of our times may be how we can avoid the pitfalls, and still grasp the opportunities that science and technology hold.

We need balanced and thoughtful consideration of the consequences of deploying our new knowledge. But this does not mean stopping dead in our tracks. Unless we anticipate and shape the territory of the future, we are in danger of arriving in a strange land not to our liking – the victims of environmental change and of its unintended consequences.

One of the most important contributions we can make is providing our citizens with the knowledge and skills they need to make wise environmental choices.

Historically, the value we place on science and technology has been framed within the larger context of society’s needs. In *our* times, a most fundamental societal need must be understanding and safeguarding environmental health and stability. Our larger vision as a nation must include this fundamental commitment. I believe science and technology are still our best helpmates, and education our best means to that end.

The great 19th century American poet Emily Dickenson once said, “to live is so startling it leaves little time for anything else.” We can say, in the same spirit, “to learn is so startling it leaves little time for anything else.” This is the way of progress and wisdom, and an assured path to survival and prosperity.

Learning is humanity’s quintessential contribution to the great unfolding story of life’s evolution on earth. We have learned enough in our brief human journey across the pages of time to know *where* we want to go. We have the knowledge and tools in hand – if not today, then soon in the future – to help us along the way.

But our journey will falter, even fail, if we do not seriously take up the challenge of environmental education. Our collective concern and responsibility is to teach a new generation of citizens to understand our interdependence with all life on earth – to recognize the evolutionary processes through which we arrived on the scene, to preserve the ecological balances that sustain us, and to see the vulnerability of the planet and our co-inhabitants on it as *our* vulnerability.