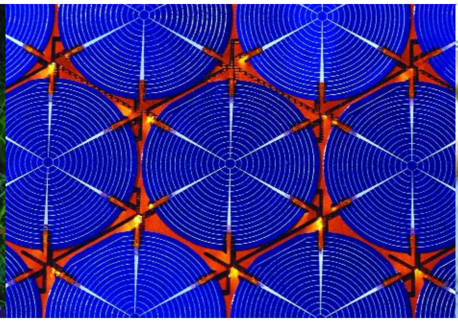
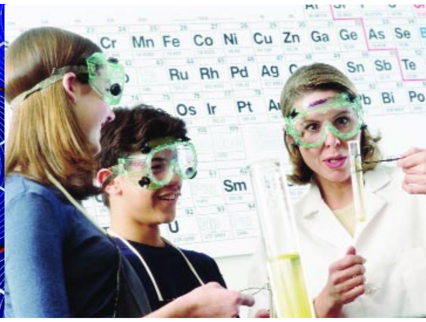
Obstinate Issues, Sophisticated Solutions

Environmental Science and Education for a New Age





Dr. Rita R. Colwell

Director, National Science Foundation

Third Annual John H. Chafee Memorial Lecture
on Science and the Environment

January 30, 2003

National Council for Science and the Environment
Improving the scientific basis for environmental decisionmaking

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Improving the scientific basis for environmental decisionmaking

THE NATIONAL COUNCIL FOR SCIENCE AND THE ENVIRONMENT (NCSE) has been working since 1990 to improve the scientific basis for environmental decisionmaking and has earned an impressive reputation for objectivity, responsibility, and achievement.

The Council envisions a society where environmental decisions are based on an accurate understanding of the underlying science, its meaning, and its limitations. In such a society, citizens and decisionmakers receive accurate, understandable, and integrated science-based information. They understand the risks, uncertainties, and potential consequences of their action or inaction.

Supported by over 500 academic, scientific, environmental, and business organizations, and federal, state, and local government, NCSE works closely with the many communities creating and using environmental knowledge to make and shape environmental decisions.

The Council operates a range of innovative activities in the areas of:

Promoting Science for the Environment

The Council played an instrumental role in stimulating the National Science Foundation initiative to triple its annual budget for environmental research, education, and scientific assessment. The Council presents expert testimony to Congressional committees, consults regularly with key decisionmakers in government, and works to promote funding for environmental programs at numerous federal agencies.

Enhancing Programs at Academic Institutions

NCSE brings members of the academic community together to improve their environmental programs and increase their value to society through the University Affiliate Program, the Council of Environmental Deans and Directors, and the Minority Programs Office.

Catalyzing and Advancing Ideas from Diverse Communities

The Council advances science for more informed environmental decisionmaking through conferences, workshops, and partnerships, including the annual National Conference on Science, Policy and the Environment, the annual John H. Chafee Memorial Lecture on Science and the Environment, and public-private partnerships designed to reinforce the linkages between science and decisionmaking in developing countries.

Communicating Science-Based Information to Society

NCSE is committed to communicating science-based information to decisionmakers and the general public in a way that is comprehensive and understandable. The widely-acclaimed online National Library for the Environment (NLE) includes Congressional Research Service reports, directories of foundations and academic programs, job opportunities, environmental news sources, laws, treaties, and much more. NCSE publishes the annual *Handbook of Federal Funding for Environmental R&D* and the monthly *Science, Environment and Policy Report* for members of the University Affiliate Program. The Council sends science policy updates to over 15,000 interested individuals worldwide.

Developing Science Solutions for Environmental Challenges

The Council brings stakeholders together through its Center for Science Solutions to develop and implement science-based solutions to specific environmental problems. The first program under the Center, the National Commission on Science for Sustainable Forestry, endeavors to develop a better scientific foundation for assessing and improving sustainable forest management practices.

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Environmental Science and Education for a New Age

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**JOHN H. CHAFEE Memorial Lecture
on Science and the Environment**

**Sponsored by the National Council for
Science and the Environment (NCSE)**

PRESENTED AT
3rd National Conference on Science, Policy and the Environment

Ronald Reagan Building and International Trade Center
Washington, DC

January 30, 2003

This volume is the third in a series of books documenting the annual John H. Chafee Memorial Lecture on Science and the Environment.

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The National Council for Science and the Environment is grateful to the following sponsors for making possible the third annual John H. Chafee Memorial Lecture on Science and the Environment:

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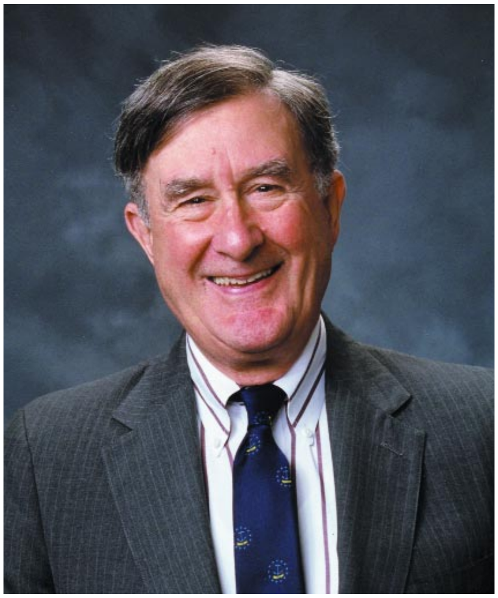
(Yale ’44 classmates of Senator Chafee are indicated.)

Dedication

This book is dedicated to the memory of Senator John H. Chafee who, in his 23 years representing Rhode Island in the U.S. Senate, was a leader in promoting a bipartisan, science-based approach to environmental issues.



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Clockwise from top left: Attendees at the third annual John H. Chafee Memorial Lecture on Science and the Environment; NCSE President Richard E. Benedick presents award to keynote speaker Dr. Rita Colwell, Director of the National Science Foundation; NCSE Board member Richard Bartlett, Vice Chairman of Mary Kay Holding Corporation, with Dr. Colwell; lecture hall at the Ronald Reagan Building and International Trade Center, Washington, DC.

Opening Remarks

Richard E. Benedick, President, NCSE

Distinguished guests, colleagues, ladies and gentlemen: Welcome to the third annual John H. Chafee Memorial Lecture on Science and the Environment. By way of introduction, my name is Richard Benedick. In addition to being affiliated with one of the nation's premier research institutions, the Pacific Northwest National Laboratory, I am also privileged to be president of the remarkable organization that has created this conference, the National Council for Science and the Environment.

Now, I am personally not a scientist. But as a diplomat representing the United States in international negotiations on such issues as climate change, protecting the ozone layer, and the AIDS epidemic, I have come to appreciate the absolutely crucial role that science and scientists play in solving the problems of a world of six billion people which will, in the coming decades, rise to nine billion.

I'm reminded of the Gary Larson cartoon, which many of you may recall, that showed an auditorium such as this filled with all manner of dinosaurs, with their scales and their horns and tails and protuberances. And at the podium, where I am now, was another large dinosaur with a worried expression on his face, saying, "After much research, I have come to the conclusion that we are on the road to extinction. And, to make matters worse, we have brains the size of a pea."

Now, we humans have larger brains. Indeed, as this morning's keynote speaker Jonathan Lash observed, thanks to the marvels of telecommunication, the public is in fact inundated with an overload of information. How to filter out the "spam," how to recognize the self-serving or misled missionaries, the exaggerated or distorted scientific claims, especially when there are inevitable uncertainties in the scientific theories and findings?

Netherlands Minister Jan Pronk this morning correctly noted that it is unwise, and indeed irresponsible, for national leaders to wait for total scientific certainty before undertaking preventive measures. Our organization, the National Council for Science and the Environment, has

but a single and unique vision: to improve the scientific basis for environmental decisionmaking. In implementing this vision, we operate in a non-polemical, nonpolitical manner. As I often said during the ozone negotiations that I was privileged to lead some years ago: If we have a 70 percent case, let's make it that way; let us resist the temptation to stretch it to 100 percent — because in so doing, we only lose credibility and thereby give ammunition to those who oppose taking any action at all. If we present the case fairly, the public and most political leaders are more likely to try to manage the risks in a rational way.

Ladies and gentlemen, Senator John Chafee was a great American and a remarkable statesman. He truly appreciated the importance of science for policymaking. When I was leading the U.S. negotiations on the Montreal Protocol to protect the ozone layer, Senator Chafee was a very close ally in Congress, and I came to know him well. He was an ally in setting a science-based course and in fending off attacks by anti-environmental, anti-science ideologues — people who wanted to weaken our position in the international negotiations. We were vindicated by the far-sighted decision of President Ronald Reagan, who overruled some of his closest friends in endorsing a strong United States position for controlling chlorofluorocarbons. And the result, as you all know, was the remarkably successful Montreal Protocol on protecting the ozone layer. And in a world where we regularly hear much gloom and doom, I am proud and happy to announce here tonight that the most recent observations over Antarctica definitively confirm that the Antarctic ozone hole is now diminishing and is on the road to being healed.

Our organization, the National Council for Science and the Environment, has but a single and unique vision: to improve the scientific basis for environmental decisionmaking.

Ladies and gentlemen, at this third John H. Chafee Memorial Lecture we will have the pleasure of hearing from three delightful people: Mrs. Georgia Chafee Nassikas, daughter of the Senator; Don Langenberg; and Rita Colwell.

I had the pleasure of getting to know both Don Langenberg and Rita Colwell through our mutual work on NCSE's Board of Directors. I'm sure they both recall the times, some seven or eight years ago, when we were still trying to get this fledgling institution established and to obtain recognition and endorsement for our organization and for our mission. Together with our Executive Director Peter Saundry, we called on skeptical administrators in government agencies who at that time did not want to hear very much about us. I think that if someone, on those difficult days of the past, had magically shown us a photograph of the present, of today in this splendid setting, with many of those same organizations now official funding sponsors of this great conference, we all would have probably fallen away in a dead faint! This just shows how things can turn out unexpectedly for the better.

For me as a nonscientist, Rita Colwell — whom Don Langenberg will introduce — epitomizes in her distinguished career the essence of the multidisciplinary and interdisciplinary science that the NCSE seeks to promote. She holds degrees in bacteriology, genetics, and oceanography and — particularly impressive — a geological site in Antarctica has been named in recognition of her polar research: the Colwell Massif!

And now, ladies and gentlemen, I have the great pleasure to present the first of these three splendid people whom I have gotten to know in recent years, and that is Mrs. Georgia Chafee Nassikas, the daughter of Senator John Chafee. For the second consecutive year, Georgia will represent the Chafee family at this celebration. Mrs. Nassikas, like her father, is an individual of many interests and many talents: artist and designer, organic gardener, and not least, mother of four.

Georgia, my pleasure.

Georgia Chafee Nassikas

Good evening. On behalf of the Chafee family, I am thrilled to see such vibrant and stellar participants here at the lecture. We are honored to have Dr. Colwell as our speaker. The National Council for Science and the Environment's motto is "improving the scientific basis for environmental decisionmaking." Dr. Colwell's work embraces that motto.

How fitting that the theme of this year's conference is "Education for a Sustainable and Secure Future." Thank you for your hard work and unflagging commitment to that goal.

Now, especially, that commitment is required.

Laws that were passed to ensure a sustainable future are being rolled back. Environmental policies that were hammered out to achieve security are now threatened. Time is running short on many ecological and environmental fronts. Yesterday's accomplishments are today's challenges.

How pleased John Chafee would be with the vigor and tenacity with which you rise to meet those challenges.

Thank you.

Richard E. Benedick

Thank you very much, Georgia, for those gracious comments.

And now I have the privilege of introducing Dr. Donald Langenberg: eminent physicist with renowned achievements in condensed matter physics and superconductivity; distinguished science administrator as past Deputy Director of the National Science Foundation; and outstanding educator as Chancellor at the University of Illinois in Chicago, and later, as Chancellor of the University System of Maryland — which, under his guidance, has risen to the top ranks of American universities.

Ladies and gentlemen, Dr. Donald Langenberg, Vice Chairman of the National Council for Science and the Environment.

Introduction

Donald N. Langenberg, Vice Chairman, NCSE

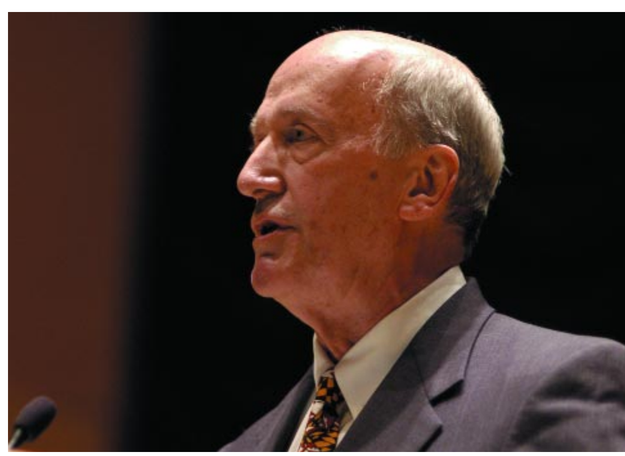
It is my great personal pleasure to introduce to you this year's Chafee lecturer, Rita Colwell, a friend and a colleague. You have all been provided with a summary of Rita's remarkable career, so I won't go through it all. But let me mention a couple of things that I think are among the remarkable things that Rita has done.

She is the first environmental scientist to direct the National Science Foundation. She has been a tireless campaigner and spokesperson for enhanced funding of science generally and of the National Science Foundation in particular. The NSF budget is now up to about $4.8 billion. I like that number.

As the Ambassador said, I served time at NSF a few years back at the transition between the Carter Administration and the Reagan Administration. During that period the NSF budget reached $1 billion. It did so three times: first, going up; then, going down; and finally, going up again. Now that we have the so-called NSF doubling bill, an authorization bill passed by the Congress with great bipartisan support and signed by the President, it's obvious that the next great threshold for NSF is 10 billion dollars.

Of direct importance to NCSE, Rita shepherded the National Science Board Report, *Environmental Science and Engineering for the 21st Century*. This cast a new role for NSF in environmental science and engineering as a priority with a much more interdisciplinary and socially relevant focus. We will see far more in the way of exciting important results as that focus carries on into the future.

One of the most salient things in Rita's career has been her vision. And by vision I don't mean the ability to see what's happening, or what is going to happen, but rather the ability to see what *should* happen in the future, and then to work aggressively to make it happen.



She did that with the University of Maryland Biotechnology Institute in the mid-1980s. She got it established and she served as its founding director and president until she left for the National Science Foundation. And I believe she's doing that at the National Science Foundation, to the benefit of all of us.

It gives me a great deal of pleasure to introduce to you the third John H. Chafee Memorial Lecturer on Science and the Environment, Rita Colwell.

Obstinate Issues, Sophisticated Solutions

Environmental Science and Education for a New Age

Dr. Rita R. Colwell

Director, National Science Foundation

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.*

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 Chafee, 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.

**Nobel Laureates Sherwood Rowland and Mario Molina, and Pulitzer Prize winner E.O. Wilson*

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* described 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 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.

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.

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.

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.

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 which 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 at 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, 60 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.

As M.R.C. 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."

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 M.R.C. 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.

Questions & Answers

Q **I very much appreciated your highlighting the beginnings of the integration of cognitive science and behavioral science and their potential and implications for learning environments. Can you give us some success stories in those areas?**

A One of the success stories that is unfolding is simply the recognition of the importance of the social and behavioral sciences. I do know there are champions in Congress who are strongly supportive of more research in the social and behavioral sciences — and for greater investment in them. And more importantly, they happen to be on the NSF appropriations committee! It is always a plus to have a champion who is on your appropriations committee. This support is critical because, more than ever, we need to understand human behavior and we need to understand human learning.

Another example is the investment that NSF is making in Science of Learning Centers. We hope to make awards for three or four centers that are modeled on NSF's Engineering Research Centers and Science and Technology Centers. These are new centers that will bring together scientists who study learning, ranging from the social and behavioral contexts of learning to the chemistry and functioning of the brain. These centers will draw from the latest technology in understanding learning, including recent advances in functional MRI research. Our aim ultimately is to bring these efforts and information together with higher education, school systems, industry and the community as partners. These centers will investigate how people learn and how information is retained so that we can understand how to teach better and how to educate our citizens more effectively. This will be a very important activity for the National Science Foundation. The Social, Behavioral, and Economic Sciences Directorate is coordinating it, and its scope extends to the entire Foundation.

Let me give another example. Post 9/11, the National Science Foundation — I'm sure some of you will be surprised to learn — was the science agency among those present at Ground Zero. Our engineering teams were there analyzing the rubble before it was taken away. They have since developed a computer model of the event and have already begun investigating new materials that can be used to build skyscrapers in the future. Very quickly, we also had social and behavioral scientists on the ground. We had economic scientists there, assessing economic impacts. And, thanks to NSF's program of small grants for exploratory research, we had scientists there to analyze terrorism and to develop research techniques to improve understanding of the behavior of terrorists.

So, fundamental research conducted by social and behavioral scientists is a very important part of any research team. These are just a few of the many examples that I could give.

Q Can you talk about how nanotechnology or biotechnology might enable us to monitor natural systems in almost real time?

A Well, you have given me the chance — and I didn't plant this question — to talk about NEON, the National Ecological Observatory Network that has been in the planning stage for several years now. It is fairly typical that major equipment projects at NSF go through very intensive planning workshops, and are proposed and revised several times before they actually get funded, and that is NEON's history.

NEON will provide ecological observatories around the country that will use the most sophisticated technology — for example, the E-nose and the E-tongue. These are very sophisticated sensors that will allow us to collect information on weather patterns and on chemicals in the environment and to do DNA profiles of microbial populations in the soil and water and on other biota. Investigators will be able to integrate and share these observations using information and communications technologies. The result will be an enormous database that is constantly updated and that can be tapped, and the data analyzed, so that we can tease out the fundamental properties of ecosystems, as well as determine those properties specific to individual ecosystems.

NEON will serve as an early warning system, let's say for an emerging infectious disease. And remember, pathogens are a threat not just to humans, but also to our agricultural crops and livestock — for example, foot and mouth disease in cattle. We need to be able to detect these kinds of events rapidly and determine whether they are natural, part of the oscillations and cycles of nature, or have been malevolently introduced.

We are putting together this network of observatories, taking advantage of all the technological advances that have been made, particularly in information technology. It is a very exciting time and a very exciting future for National Science Foundation-funded scientists, and it is very nice to see the NSF budget slope at a 45-degree angle upwards!

Q I found today, in the course of our discussions on the greening of the campuses, a significant concern with the overload of information and how to process that — like the old joke about knowing more and more about less and less, and so knowing everything about nothing at all. I think I would pose my question to you in this fashion: is it clear that there are transformative thresholds in the processing of information?

If we get it right, we're capable of creating partnerships to deliver exceptional value to future generations. Could you give us some thoughts about how the Foundation proposes to encourage our schools and universities and the business community — which will garner the talent from those institutions — to begin to develop a vision for teaching about whole systems and to seek out those transformative partnerships that will create long-term value?

A NSF sponsored a very interesting two-day conference just last week focused on the transforming sciences, essentially the subject of your question. One of the things we are doing at the National Science Foundation is building digital libraries — that's a major effort in two of NSF's Directorates: Education and Human Resources, and Computer and Information Science and Engineering — in order to make information available in many forms for many people, for example, programs that will allow a virtual walk through the Louvre to see the art exhibits from any town in America. At the same time, we support programs to transform huge masses of data, like census data, into wisdom. On a grander scale, we need to understand how we have transformed ourselves as a society.

And we are now launching a new cyberinfrastructure effort that will eventually connect many of the nation's universities and research sites to high-end computing facilities so that every institution, whether education, industry, or government, will be able to use the tools of information technology to extract wisdom from mountains of data.

NSF has been funding information technology research as a priority area for the last four years, very extensively, at over $200 million annually. A good half-billion dollars of that funding have been invested in software development in order to create the tools we need to transform information into wisdom.

NSF is moving very appropriately, very thoughtfully, and very deliberately in making the investments for which Congress has appropriated the funds for science and engineering. The most important investment is development of information technology as a tool, not as a substitute for learning and teaching, but for advancing learning and teaching in the 21st century.

I liken our current educational system to a slide I often show, which depicts a classroom in 1900, in 1950, and in 2003. It hasn't changed much. Whereas in transportation we've progressed since 1900 from horse and buggy to space travel, yet we still use chalk and blackboards in our classrooms. In medical treatment of diabetes, we've gone from treating only symptoms in the 1900s, to treatment with extracted insulin in the 1930s, and treatment with exogenous insulin. But in the 1970s, we were able to clone genes coding for insulin and insert those genes into a microorganism so that we could produce pure insulin. Today, we are close to the point of being able to do a biopsy of the pancreas of a diabetes victim, correct the error in metabolism, reintroduce the cells, and cure the victim of diabetes.

We need to accomplish this kind of transformation in education. So, the question that you raised is a very important one. The task that all of you have set for yourselves for environmental education is a critical part of the solution.

Appendix I

Biography of John H. Chafee (1922-1999)

Senator John H. Chafee (R-RI) was born in Providence, Rhode Island, in 1922. He held degrees from Yale University and Harvard Law School. Upon the United States' entry into World War II, Chafee left Yale to enlist in the Marine Corps, and then served in the original invasion forces at Guadalcanal. In 1951 he was recalled to active duty and commanded a rifle company in Korea.

Chafee began his political career by serving for six years in the Rhode Island House of Representatives, during which time he was elected Minority Leader. He was then elected Governor by a 398-vote margin in 1962. He was reelected in 1964 and 1966 — both times by the largest margins in the state's history. In January 1969 he was appointed Secretary of the Navy and served in that post for three-and-a-half years. He was elected to the U.S. Senate in 1976.

As Chairman of the Environment and Public Works Committee, the Senator was a leading voice in crafting the Clean Air Act of 1990. He lead successful efforts to enact oil spill prevention and response legislation and a bill to strengthen the Safe Drinking Water Act. Senator Chafee was a long-time advocate for wetlands conservation and open space preservation and was the recipient of every major environmental award.

As senior member of the Finance Committee, Senator Chafee worked successfully to expand health care coverage for women and children and to improve community services for people with disabilities. In 1990, Senator Chafee spearheaded the Republican Health Care Task Force. He went on to lead the bipartisan effort to craft a comprehensive health care reform proposal in 1994.

Senator Chafee also was a leader in efforts to reduce the federal budget deficit and co-chaired the centrist coalition which produced a bipartisan balanced budget plan in 1996. He was an active proponent of free trade and was a strong supporter of the North American Free Trade Agreement (NAFTA). He served as Chairman of the Republican Conference for six years.

The Senator received awards and endorsements from such organizations as the National Federation of Independent Business, the American Nurses Association, the League of Conservation Voters, the Sierra Club, Handgun Control Inc., Planned Parenthood, Citizens Against Government Waste, and the National PTA.

On October 24, 1999, Senator John H. Chafee died from congestive heart failure. He is sorely missed.

Appendix II

Biography of Dr. Rita R. Colwell

Dr. Colwell became the 11th Director of the National Science Foundation on August 4, 1998. Since taking office, Dr. Colwell has spearheaded the agency's emphases in K-12 science and mathematics education, graduate science and engineering education and training, and the increased participation of women and minorities in science and engineering.

Her policy approach has enabled the agency to strengthen its core activities as well as establish support for major initiatives, including Nanotechnology, Biocomplexity, Information Technology, the 21st Century Workforce, Mathematical Sciences, and Social, Behavioral and Economic Sciences. In her capacity as NSF Director, she serves as Co-chair of the Committee on Science of the National Science and Technology Council. Under her leadership, the Foundation has received significant budget increases, and its funding recently reached a level of more than $4.8 billion.

Before coming to NSF, Dr. Colwell was President of the University of Maryland Biotechnology Institute from 1991 to 1998, and she remains Professor of Microbiology and Biotechnology (on leave) at the University of Maryland. She was also a member of the National Science Board from 1984 to 1990.

Dr. Colwell has held many advisory positions in the U.S. government, non-profit science policy organizations, and private foundations, as well as in the international scientific research community. She is a nationally respected scientist and educator and has authored or co-authored 16 books and more than 600 scientific publications. She produced the award-winning film, *Invisible Seas*, and has served on editorial boards of numerous scientific journals.

She is the recipient of numerous awards, including the Medal of Distinction from Columbia University; the Gold Medal of Charles University, Prague; the UCLA Medal from the University of California, Los Angeles; and the Alumna Summa Laude Dignata from the University of Washington, Seattle. Dr. Colwell has also been awarded 26 honorary degrees from institutions of higher education, including her Alma Mater, Purdue University. Dr. Colwell is an honorary member of the microbiological societies of the UK, France, Israel, Bangladesh, and the United States and has held several honorary professorships, including the University of Queensland, Australia. A geological site in Antarctica, Colwell Massif, has been named in recognition of her work in the polar regions.

Dr. Colwell has previously served as Chairman of the Board of Governors of the

American Academy of Microbiology and also as President of the American Association for the Advancement of Science, the Washington Academy of Sciences, the American Society for Microbiology, the Sigma Xi National Science Honorary Society, and the International Union of Microbiological Societies. Dr. Colwell is a member of the National Academy of Sciences.

Born in Beverly, Massachusetts, Dr. Colwell holds a B.S. in Bacteriology and an M.S. in Genetics from Purdue University, and a Ph.D. in Oceanography from the University of Washington.

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