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ABSTRACT

A major concern today is the need to ensure that future generations will be equipped with the knowledge and skills they need to prepare for high-technology jobs, to become leaders in scientific research, and to exercise the responsibilities of citizenship in the 21st century. This document, carrying on the cover and title page the names of the President and Vice-President, respectively, is based on a forum held at the National Academy of Sciences under the auspices of the Office of Science and Technology Policy, to begin shaping the Administration's goals and strategies for science. The first two chapters summarize the need and importance of educating Americans in the area of science, and provide insight on how science education is interconnected with other strategic goals set by the Administration. Chapter 3, "Setting Our National Goals," describes various specific goals that will require the resources of government and the creative participation of industry and academia. Chapter 4, "Reaching Our Goals," presents a plan for reaching the five goals listed in chapter 3, and describes several projects that are already underway that will enhance science learning and research. The final chapter, "A Shared Commitment," reiterates the need for a broad program for advancing science in the national interest and the need for all Americans to work to reach the prescribed goals. (ZWH)

Science in the National Interest

President William J. Clinton
Vice President Albert Gore, Jr.

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"This country must sustain world leadership in science, mathematics, and engineering if we are to meet the challenges of today... and of tomorrow."

President William J. Clinton
November 23, 1993

August 1994
Executive Office of the President
Office of Science and Technology Policy

Acknowledgements

The *Forum on Science in the National Interest*, held January 31-February 1, 1994 at the National Academy of Sciences, was a milestone in the shaping of this Administration's goals and strategies for science. We thank each of the participants, more than two hundred in number, who generously shared their thoughts with us through position papers, talks, panel discussions, and workshops. The richness of this input is rooted in the experience and diversity of the participants, who came to the Forum from academia, industry, laboratories, professional societies, and government. The flavor of their contributions is captured, at least partly, in the representative quotes sprinkled throughout this statement, all of which were drawn from the Forum participants' reports and presentations.

The Forum was held under the auspices of the Office of Science and Technology Policy, with the assistance of the National Institutes of Health and the National Science Foundation. Other Federal co-sponsors were the National Aeronautics and Space Administration and the Departments of Agriculture, Defense, and Energy. All of these agencies participate in the National Science and Technology Council Committee on Fundamental Science. In addition, the American Association for the Advancement of Science; the Association of American Universities; the Carnegie Commission on Science, Technology, and Government; the Charles A. Dana Foundation; the Industrial Research Institute; the Institute of Medicine; the National Academy of Engineering; the National Academy of Sciences; and the National Association of State Universities and Land-Grant Colleges were co-sponsors. The co-sponsors provided essential assistance from early Forum organization to post-Forum evaluation of participants' written contributions. This broad spectrum of co-sponsors brought a multiplicity of viewpoints to the Forum and thereby informed the Administration about many issues and perspectives on stewardship of fundamental science. We look forward to working with these many constituencies to advance science in the national interest.

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THE WHITE HOUSE

WASHINGTON

Through scientific discovery and technological innovation, we enlist the forces of the natural world to solve many of the uniquely human problems we face — feeding and providing energy to a growing population, improving human health, taking responsibility for protecting the environment and the global ecosystem, and ensuring our own nation's security. Scientific discoveries inspire and enrich us, teaching us about the mysteries of life and the nature of the world.

Technology — the engine of economic growth — creates jobs, builds new industries, and improves our standard of living. Science fuels technology's engine. It is essential to our children's future that we continue to invest in fundamental research. Equally important, science and mathematics education must provide our children with the knowledge and skills they need to prepare for the high-technology jobs of the future, to become leaders in scientific research, and to exercise the responsibilities of citizenship in the twenty-first century.

To reach the goals for the fundamental science and education outlined in this report, we must strengthen partnerships with industry, with state and local governments, and with schools, colleges, and universities across the country. This Administration is committed to making today's investment in science a top priority for building the America of tomorrow.

Bill Clinton

Al Gore

Science: The Endless Resource

America's future demands investment in our people, institutions and ideas. Science is an essential part of that investment, an endless and sustainable resource with extraordinary dividends. This investment strategy was clearly articulated fifty years ago in Vannevar Bush's seminal report, "Science: The Endless Frontier:"

"The Government should accept new responsibilities for promoting the flow of new scientific knowledge and the development of scientific talent in our youth. These responsibilities are the proper concern of the Government, for they vitally affect our health, our jobs and our national security."

The bedrock wisdom of this statement has been demonstrated time and again in the intervening half century. The return from our public investments in fundamental science has been enormous, both through the knowledge generated and through the education of an unmatched scientific and technical workforce. Discoveries in mathematics, physics, chemistry, biology and other fundamental sciences have seeded and have been driven by important advances in engineering, technology, and medicine.

The principal sponsors and beneficiaries of our scientific enterprise are the American people. Their continued support, rooted in the recognition of science as the foundation of a modern knowledge-based technological society, is essential. The nation's investment has yielded a scientific enterprise without peer, whether measured in terms of discoveries, citations, awards and prizes, advanced education, or contributions to industrial and informational innovation. Our scientific strength is a treasure which we must sustain and build on for the future.

To fulfill our responsibility to future generations by ensuring that our children can compete in the global economy, we must invest in the scientific enterprise at a rate commensurate with its growing importance to society. That means we must provide the physical infrastructure that facilitates world class research, including access to cutting-edge scientific instrumentation and to world class information and communication systems. We must provide the necessary educational opportunities for each of our citizens. Failure to exercise our responsibility will place our children's future at risk.

Science does indeed provide an endless frontier. Advancing that frontier and exploring the cosmos we live in helps to feed our sense of adventure and our passion for discovery. Science is also an endless resource: in advancing the frontier, our knowledge of the physical and living world constantly expands. The unfolding secrets of nature provide new knowledge to address crucial challenges, often in unpredictable ways.

"Today we are facing a rapidly changing world and we have the opportunity, indeed the imperative, to examine our science policies and decide how to restructure them to retain America's preeminent position in world science."

John H. Gibbons
Assistant to the President
for Science and Technology

"Galileo . . . took an information gathering instrument of war, the spy glass, and, instead of pointing it towards the horizon in search of enemy ships, he pointed it towards the zenith in search of the unknown. Galileo observed that the heavens move in much the same way as the earth, and, with that observation he irrevocably changed our viewpoint on just about everything."

Anne L. Kinney
Space Telescope Science Institute

"As we respond to increasing demands to plan and justify our investments in science in terms of societal goals, it is crucial to recall that the greatest and most influential discoveries have usually been the products of young minds free to think creatively about the natural world, without consideration of practical purpose."

Harold Varmus
National Institutes of Health

These include improving human health, creating breakthrough technologies that lead to new industries and high quality jobs, enhancing productivity with information technologies and improved understanding of human interactions, meeting our national security needs, protecting and restoring the global environment, and feeding and providing energy for a growing population.

The challenges of the twenty-first century will place a high premium on sustained excellence in scientific research and education. We approach the future with a strong foundation, built by the wise and successful stewardship of this enterprise over many decades, and with an investment strategy that was framed during this Administration's first month as three interconnected strategic goals:

- **Long term economic growth that creates jobs and protects the environment;**
- **A government that is more productive and more responsive to the needs of its citizens;**
- **World leadership in basic science, mathematics, and engineering.**

The first goal was elaborated in the Administration's statement "*Technology for America's Economic Growth*," and the second in the Vice President's "*National Performance Review*." Our policies in these areas are already working to prepare the future. The third goal represents a critical long-term investment, one for which we need both vision and a sound Federal policy.

A Time of Change

We face change on many fronts, and change characteristically engenders both opportunity and uncertainty. The end of the Cold War has transformed international relationships and security needs. Highly competitive economies have emerged in Europe and Asia, putting new stresses on our private sector and on employment. The ongoing information revolution both enables and demands new ways of doing business. During the 1980's, our Federal budget deficit grew rapidly, constraining crucial investments for the future. Our population diversity has increased, yielding new opportunities to build on a traditional American strength. Health and environmental responsibility present increasingly complex challenges, and the literacy standards for a productive and fulfilling role in twenty-first century society are expanding beyond the traditional "three R's" into science and technology.

As our institutions anticipate, manage, and respond to change, we must continue to focus on the enduring core elements of our national interest: the health, prosperity, security, environmental responsibility, and quality of life of all of our citizens. At the same time, we must respond to the changing character of the challenges presented by each of these core elements. For example, as the nature of today's external security threat has shifted profoundly, we have come to recognize economic and technological strength as integral to national security. Likewise, improved science and mathematics education for all citizens is now recognized as a strategic imperative for our individual and collective futures.

We must reexamine and reshape our science policy both to sustain America's preeminence in science and to facilitate the role of science in the broader national interest. Each core element of the national interest requires strong commitment to scientific research and education:

• **Health** requires the understanding, prevention and treatment of disease and the assurance of an adequate, safe, and nutritious food supply. These activities have become more and more dependent on the discoveries of fundamental biology research, often at the molecular level. Knowledge of the molecular basis of genetic diseases, for example, will permit design of effective new treatments such as gene therapy. The importance of broad strength in science is evidenced by the increasing role in biology and medicine of tools developed in the physical sciences, such as magnetic resonance imagers whose beginnings were in nuclear physics, or lasers that originated in fundamental atomic and molecular physics research, or the accelerators and instrumentation developed in the quest to understand subatomic particles. Research is also essential in the social and behavioral sciences for developing effective public health strategies for preventing disease.

"After decades in which defense was the priority of Federal science and technology policy, now our goal is to use the talents of our Nation's superb scientists and engineers to help generate what's at the core of life, liberty, and the pursuit of happiness for Americans — enough good jobs and growth for all."

John D. Rockefeller IV
United States Senate

"We must do far more basic research in strategic areas. Those doing this research must recognize there's a national purpose for their work."

Barbara A. Mikulski
United States Senate

• **Prosperity** requires technological innovation. Basic scientific and engineering research is essential for training innovative scientists and engineers, for many technology improvements, and for achieving the revolutionary advances that create new industries. Biotechnology and optical communications are two examples, and others will follow. For example, fundamental science and engineering will yield capabilities, unimaginable only a few years ago, to design and build new materials whether electronic or biomolecular. Applications will span areas as diverse as civil infrastructure improvements and environmental restoration.

• Our **national security** has long been based on technological superiority bred of scientific and engineering innovation and a strategic commitment to both breadth and excellence in basic research. This will be even more important with a reduced military establishment facing new and varied security challenges such as verification methods for nonproliferation of weapons of mass destruction. For example, remote acquisition and rapid analysis of huge data streams and a new generation of imaging technologies will be essential. These capabilities will require advances in fundamental science and engineering, and will have important dual uses in military and civilian applications.

• **Environmental responsibility** requires much better understanding of the complex interrelationships among components of the biosphere and among human activities and the world around us. We must carry out the necessary fundamental research and develop appropriate technologies to detect and correct environmental problems, to manage natural resources, and to sustain the environment. The levels of population, economic, and industrial growth suggested by current trends and patterns of development point to an urgent need to improve industrial processes and products and to provide food, energy, and natural resources with greatly reduced environmental impact. Understanding biological and physical processes is vital to maintaining biodiversity and healthy ecosystems.

• **Improved quality of life** of our citizens involves all of these elements and more. Culture, inspiration, and full participation in the democratic process are important for our citizens' lives and for setting directions for America. Scientific and technical literacy are crucial for understanding and appreciating the modern world. Sometimes, the rewards come directly from the leaps of science and engineering that inspire us as one people and spark the imagination of our children. Only months ago, we experienced this with the bold repair job on the orbiting Hubble telescope and the remarkable clarity of the resulting images. Such moments are themselves an important public benefit of science, helping to satisfy humanity's age-old drive to define itself through a better understanding of the world we inhabit. At a more down-to-earth level, scientific and technical literacy will provide the gateway to an increasing number of high quality jobs.

Thus, science, both endless frontier and endless resource, is a critical investment in the national interest. Science and technology are tightly coupled, for they both drive and benefit one another. To address the nation's science investment strategy, we must reexamine every element of the enterprise: the research portfolio; the infrastructure needed for world-class research by world-class researchers; and the education of our people in science and mathematics. Each element must be strong, requiring that optimization be done within limited resources. It is essential that we adhere to a long-range and diversified investment strategy: nurture broadly-based fundamental research for the decades ahead, conduct research aimed at today's strategic areas, and undertake vigorous development activities that spring from our accumulated science and engineering "resource base."

While we cannot foretell the outcome of fundamental research, we know from past experience that, in its totality, it consistently leads to dramatically valuable results for humanity. We have every reason to expect that the science investment will continue to yield a very high rate of return.

"Science reveals new worlds to explore, and by implication new opportunities to seize and new futures to create."

Vice President Al Gore
Forum on Science in the National Interest
February 1994

"Strategic research should only be a portion of our overall fundamental science and engineering research portfolio. This is from several perspectives. First and foremost, we need to ensure the continued vitality and support of our most creative people in areas that currently address no identified areas of national need. The spirit of pure discovery needs to be nurtured and sustained especially in our research universities. Furthermore, while it is widely believed we can identify broad areas that can contribute to our national objectives, it is equally sure that we will fail to identify some areas that will. And finally, there is of course those areas where an unanticipated development creates new opportunities that could not be previously identified."

Peter Eisenberger
Princeton University
and Herbert Pardes
Columbia University
Reporting on a Group Discussion, Forum on Science in the National Interest

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Steering by the Satellites

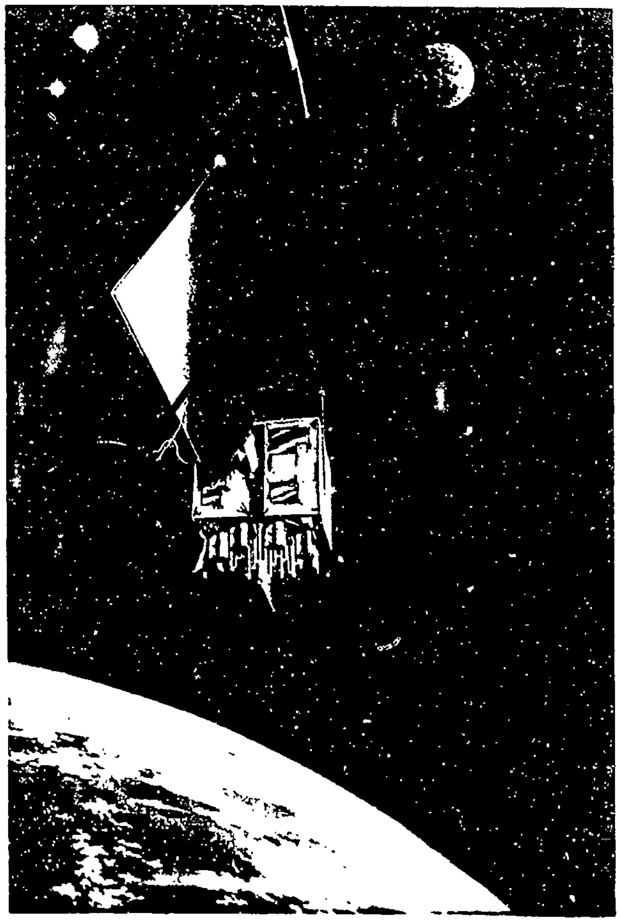
For centuries, mariners used stars and other heavenly bodies for navigation. A modern, hightech version of this technique allowed U.S. troops in the Persian Gulf War to operate in a desert wilderness with pinpoint accuracy. Now it is stimulating an enormous variety of civilian applications—from James Bond-style personal navigators to aircraft avoidance systems—and fueling a huge new commercial market.

This modern navigational miracle, known as the Global Positioning System (GPS), can instantly and automatically tell users their location and altitude to within about 30 feet anywhere on Earth. Instead of stars, the GPS system uses 24 satellites that each circle the Earth in precisely determined orbits every 12 hours. Instead of starlight, it uses radio waves that cannot be blocked by clouds. And instead of a mariner's sextant, the GPS system depends on computer chips, miniaturized radio receivers, and—especially—ultraprecise atomic clocks. Such clocks, carried on each satellite, keep time to within millionths of a second over an entire year. Such accuracy is at the heart of the GPS system, because it allows the satellites to broadcast timing signals. The signals from several satellites can be compared by a receiver and electronically translated into a precise determination of its position.

Atomic clocks were not, of course, invented with such an application in mind. In fact, they arose from efforts to answer fundamental questions about the nature of the universe. Testing the basic laws of physics, such as Einstein's theory of general relativity, turned out to require much more accurate clocks than were available 30 years ago. So university physicists set out to develop them, and succeeded both in verifying Einstein's predictions and in making major advances in the technology of time-keeping. Outside of physics, no great need for ultra-precise clocks was foreseen; but, as so often happens, the advance opened up unpredictable opportunities.

The Global Positioning System was initially developed by the U.S. Air Force for military navigation, for which it has already proved its worth. Many important civilian applications have already emerged—coastal navigation, emergency rescue, tracking commercial vehicles—and GPS use is expanding rapidly. Last year, foreshadowing the impact of the GPS system on aircraft avoidance and navigation, a Gulfstream airplane made a flawless approach to Washington's National Airport using only GPS guidance. Inexpensive receivers to guide backpackers in remote areas or to guide automotive travellers along unfamiliar routes are beginning to appear.

Over 160 manufacturers are developing GPS-based systems worldwide for a new multibillion dollar market. The investment in atomic clocks made decades ago was a seminal part of this development and illustrates the remarkable dividends to society that fundamental research can provide. Today's investments in atomic research, such as trapping and cooling atoms in webs of laser light, have improved precision by orders of magnitude compared with that of GPS clocks. In the laboratory, this basic research is pushing our understanding of physical laws to new limits. In the marketplace, it will undoubtedly stimulate new technologies with surprising societal applications.



The U.S. Air Force is responsible for the Navstar Global Positioning System (GPS) which enables all three military services and civilian users to determine: location in three-dimensions, velocity, and precise time anywhere in the world. The first GPS space vehicles were in orbit by 1978.
Source: Martin Marietta Astro Space

Setting Our National Goals

This Administration stated in February 1993 its over-arching goal for fundamental research—world leadership in basic science, mathematics and engineering. To sustain the leadership position we now hold, we must improve the conditions, capabilities, and opportunities for well-trained scientists and engineers to pursue innovative research; to educate the next generation; and to apply science in areas of importance to the health, prosperity, and security of the country. The agenda is a broad one, and will require the resources of government and the creative participation of industry and academia. Therefore, we set the following goals for our stewardship of science in the national interest:

- **Maintain leadership across the frontiers of scientific knowledge**
- **Enhance connections between fundamental research and national goals**
- **Stimulate partnerships that promote investments in fundamental science and engineering and effective use of physical, human, and financial resources**
- **Produce the finest scientists and engineers for the twenty-first century**
- **Raise scientific and technological literacy of all Americans.**

While we pursue these goals amidst rapid change, we must not lose sight of the core values that have enabled our nation to achieve so much. Over the last fifty years, the United States developed a unique and highly successful system for advancing scientific research in universities, medical schools, and independent research centers, and in Federal and industrial laboratories. Our system rests on a strong commitment to investigator-initiated research and merit review based on evaluation by scientific peers. This system maintains the emphasis on excellence and brings new people and new ideas into the research enterprise.

A significant fraction of research, particularly fundamental research, is performed at academic institutions. This has multiple benefits. Research and education are linked in an extremely productive way. The intellectual freedom afforded academic researchers and the constant renewal brought by successive generations of inquisitive young minds stimulate the research enterprise. A broad range of disciplines are represented in our research universities, providing opportunity for cross disciplinary stimulation.

Federal support of fundamental science and engineering is characterized by a healthy pluralism. All Federal departments and agencies that depend heavily on scientific and technical knowledge and human resources support fundamental research and education in these areas. This improves their capacity to attain their evolving goals as new challenges emerge.

"It is the totality of the enterprise that ensures the ability to keep abreast of important developments throughout the world and is the mechanism for educating and training future generations of scientists and engineers who are able to operate at the cutting edge of science and engineering knowledge. If we compromise our ability to train future scientists or to maintain our fundamental scientific research, we will very rapidly lose our standing in the world arena of technology transfer and economic initiatives."

Lucy Shapiro
Stanford University School of Medicine

"The end of the Cold War provides new opportunities for international cooperation in science. At the same time, the growing ties between fundamental research and economically-vital technologies are creating new barriers to the internationalization of science. It is essential that U.S. science policy be based on a clear understanding of the importance of international scientific communication and cooperation."

Francisco J. Ayala
University of California, Irvine

Several illustrations in this and following sections demonstrate how science has improved and enriched our lives, often in ways that could not be predicted. The broad advance of science and its applications represented in the illustrations originated in the support of science by a multiplicity of federal agencies.

The nature of science is international, and the free flow of people, ideas, and data is essential to the health of our scientific enterprise. Many of the scientific challenges, for example in health, environment, and food, are global in scope and require on-site cooperation in many other countries. In addition to scientific benefits, collaborative scientific and engineering projects bring nations together, thereby contributing to international understanding, good will, and sound decision-making worldwide.

Finally, we must emphasize that science advances the national interest and improves our quality of life only as part of a larger enterprise. Today's science and technology enterprise is more like an ecosystem than a production line. Fundamental science and technological advances are interdependent, and the steps from fundamental science to the marketplace or to the clinic require healthy institutions and entrepreneurial spirit across society. Many of these institutions need attention. Nevertheless, we cannot afford to lose sight of the importance of scientific research and education for sustained progress in the modern world.

Reaching Our Goals

To reach each of the five goals articulated above, this Administration proposes a coherent, integrated set of policies and will work to refine and implement them in concert with the Congress, state and local governments, academia, industry, the research and educational communities, and our citizens. We are all stakeholders in the scientific enterprise, and we now must focus on a shared commitment.

American Presidents have a tradition of strong support for science and technology. This Administration has already taken two key steps to help move us towards our goals. In November 1993, the President established the National Science and Technology Council (NSTC) to coordinate Federal research and development across the government. This cabinet-level group, chaired by the President, elevates science and technology policy discussions to the level of those for national security, domestic, and economic policy. The NSTC will couple research to the fiscal and regulatory structures needed to facilitate application of science and technology to the national interest. In November 1993, the President also established the President's Committee of Advisors on Science and Technology (PCAST). This group of academic and industry advisors will provide valuable community input on major policy issues.

"Since the war years, both Congress and the different administrations have shared the conviction that support of research in the nation's universities and industries represented an investment in the national future."

D. Allan Bromley
Yale University

Goal: Maintain leadership across the frontiers of scientific knowledge

It has seldom proved possible to anticipate which areas of science will bring forward surprising and important breakthroughs at any given time. Therefore, U.S. scientists must be among those working at the leading edge in all major fields in order for us to retain and improve our competitive position in the long term. This means that U.S. scientists and engineers continue to make a significant share of the most important scientific advances. They must maintain our tradition of scientific excellence, produce a scientific, engineering and technical workforce educated at the highest levels in all important disciplines and technologies, and create an infrastructure able to capitalize on and advance key discoveries no matter where they occur. This goal will serve the NSTC as the principal guide to investment in fundamental science and engineering research.

Breadth of scientific excellence is necessary to maintain the enterprise at the appropriate standard. Different areas of science and their associated cutting-edge technologies are tightly interconnected. Advances in one area often have unanticipated major benefits in totally different areas. Furthermore, nature yields her most precious secrets in surprising ways, to those who are well prepared and persistent, and with a schedule not often amenable to detailed planning. Thus, although we can and must do more to identify and coordinate research thrusts aimed at strategic goals,

"World leadership in basic research will confer a competitive advantage if, but only if, it is coupled with world-class performance in the much more extensive set of skills, institutions, and investments that are required for the creation of economic wealth and a rising standard of living. Whether the comparative advantage from leadership in basic research is a modest or a substantial advantage will vary by field and with time; but overall it will be an advantage we would be foolish to forgo in a world where the economic competition is becoming fiercer and fiercer all the time."

John A. Armstrong
IBM (ret.)

A Key to Cancer

Cancer has terrified patients and baffled medical scientists for a long time. Recently, however, a new level of understanding of this dread disease has begun to emerge. Scientific studies initiated using widely different approaches are now unexpectedly converging to provide a picture of the molecular basis of at least some forms of cancer — including colon cancer and melanoma. The resulting insights are certain to have an important impact on the fight against cancer.

Much of this progress has come from untargeted basic research that is aimed at learning how the cells in all forms of life function. One group of researchers was studying the life cycle common to all cells. These scientists knew that their studies were critical to understanding a central life process that operates in all animal cells and hoped that their findings might in some way become relevant to understanding the processes that lead to human cancer. For a decade, they isolated and characterized a group of proteins that interact in complex ways to form the central growth-controlling machinery inside cells termed the cell cycle clock. At the time, the implications of their work on human disease were totally unclear.

Two of the cell cycle proteins they studied, known only as p16 and p21, were first described in a scientific paper published in December 1993. Within just four months, another research team, working independently, found an important and totally unexpected link between the p16 protein and cancer. This team, which had set out to study hereditary melanoma (a deadly skin cancer), found that the gene that directs a cell to make p16 is often mutated (altered) in cancer cells, leading to its inactivation. The mutations can be seen not just in melanoma cells, but in the cells of many other forms of human cancer as well. This indicates p16 plays a critical role in the molecular processes controlling cell proliferation; when p16 is lost, the control of cell growth goes awry, leading to the runaway proliferation seen in cancer.

This discovery complemented a similar, earlier finding which showed that another cell cycle controller, a protein termed p53, also plays an important role in human cancer, being found in mutant form in about half of human tumors. So important was this earlier discovery that Science magazine named p53 as its 1993 "molecule of the year." Strikingly, insights into the cell's growth cycle, which have now become critically important for understanding human cancer, originated from studies of the life cycles of yeast, clam, sea urchin and frog cells.

Understanding the molecular causes of cancer — the triggers that lead to the disease — can lead to the development of new weapons to fight its spread, including the development of novel therapies, new types of drugs, and the use of gene therapy to correct defective versions of growth-controlling genes present within cancer cells. The "road map" sketched by those conducting fundamental research on the cell life cycle will be there to guide researchers who are now beginning to develop these and other innovative approaches to cancer treatment.

Yet another fully unexpected convergence of unrelated lines of research occurred in 1993. Several groups of researchers were studying tumors from patients with a hereditary form of colon cancer. Their published papers describing certain DNA abnormalities in these colon cancers attracted the attention of other researchers who had seen similar abnormalities in the DNA of baker's yeast cells. The yeast cells showed defects in a cellular system — termed mismatch repair — that checks the yeast DNA for errors in genetic text, enabling the cell to repair and hence erase the errors. The yeast cells carried several defective mismatch repair genes. When the human counterparts of these yeast genes were isolated, they were found to be the culprits responsible for hereditary colon cancer. The work on yeast not only showed precisely how such genes operate, but also led cancer researchers directly to find otherwise elusive human genes, saving years of research time.

Finding these colon cancer genes will enable members of families at risk for the disease to take a genetic test that will indicate who among them should receive frequent presymptomatic screening for colon cancer. In addition, as is often the case with untargeted basic research, research on the mismatch repair system will have applications for understanding yet other diseases beyond colon cancer.

Purified DNA fluorescing orange under UV light, is extracted and used for molecular biology studies. This visualization of a single band of DNA aids in the isolation and extraction of the DNA for future molecular biology studies.
Source: Mike Mitchell

we must not limit our future by restricting the range of our inquiry. Vibrant scientific disciplines are best guaranteed by the initiatives of talented investigators and in turn provide the strongest and most enduring foundation for science in the national interest. That quantum theory would lead to today's electronics, or investigations of DNA structure to genetic engineering, could not be anticipated. Countless examples could be provided; the few which accompany this statement are tangible evidence of inspiration, promise, and improved quality of life for our citizens. We can be confident that our children and grandchildren will look back at today's fundamental science and its ultimate benefit with the same surprise and appreciation that we experience today.

"Science cannot live by science alone. Research needs ***education,*** *just as education thrives when it is conducted in an atmosphere of inquiry and discovery. In fact, the separation of education and research makes no sense intellectually. It is an artificial and unhelpful separation caused by how many of us in higher education have chosen to behave."*

Neal Lane
National Science Foundation

Accomplishing this leadership goal will require that the NSTC and PCAST evaluate both the research portfolio and the status of the physical infrastructure needed for research. Coordination of agency responsibilities and commitments in these areas will be essential for appropriate stewardship of the scientific enterprise during this period of fiscal constraint. The NSTC will initiate Presidential Review Directives and Presidential Decision Directives to ensure that science and technology policy decisions are implemented across the participating agencies. Nine NSTC standing committees, including one specifically focused on Fundamental Science, are composed of senior officials from the agencies and from the Executive Office of the President. They identify priorities and prepare technical information, implementation plans, and milestones and measures of progress in support of NSTC priorities. Long range planning and stable support will be important ingredients in this Administration's strategy.

As a result of deliberate and successful long-term investment strategies, a number of countries now possess world-class research capabilities. If U.S. researchers are to sustain leadership and strengthen participation in collaborative scientific endeavors, we must increase our level of interaction with colleagues in other countries. In many important areas of contemporary research, ranging from studies of seismic activity to biodiversity to global change, our scientists can be optimally effective only through international partnerships. In areas such as high energy physics, space exploration, and nuclear fusion research where expensive facilities are required, it is only sensible to share with other countries both the benefits and the costs of constructing and operating these facilities. We should also look for opportunities to engage developing nations more fully in the international science endeavor. As a logical consequence of the North American Free Trade Agreement and long-term policies, we should continue to pay particular attention to engaging the scientific communities of the Americas.

A New Chemistry for Carbon

Until a few years ago, there were two known forms of pure carbon, graphite and diamond. Then an improbable-seeming third form of carbon was discovered: a hollow cluster of 60 carbon atoms shaped like a soccer ball. Buckminsterfullerene or "buckyballs"—named for the American architect R. Buckminster Fuller, whose geodesic domes had a similar structure—is the roundest, most symmetrical large molecule known. It is exceedingly rugged and very stable, capable of surviving the temperature extremes of outer space.

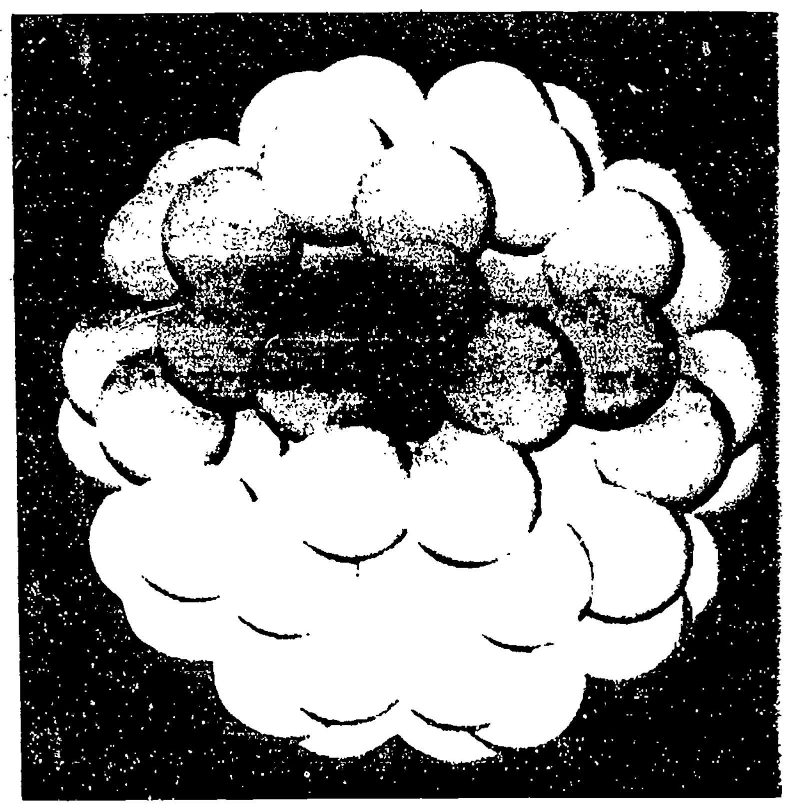
At first, however, the molecule was a mystery wrapped in an enigma. But when a convenient way of making this molecule, also known as C_{60}, was discovered, it set off an explosion of research among chemists, physicists, and materials scientists to uncover the molecule's secrets. Investigators soon discovered a whole family of related molecules, including C_{70}, C_{84} and other "fullerenes"—clusters as small as C_{28} and as large as a postulated C_{240}.

These unusual molecules turn out to have extraordinary chemical and physical properties. They react with elements from across the periodic table and with the chemical species known as free radicals—key to the polymerization processes widely used in industry—thus opening up the fullerenes to the manipulative magic of organic chemists. When a fullerene is "doped" by inserting just the right amount of potassium or cesium into empty spaces within the crystal, it becomes a superconductor—the best organic superconductor known. More important, because C_{60} is a relatively simple system, it may help physicists master the still mysterious theory of high-temperature superconductivity.

Speculation and some hard work on potential applications began almost immediately after the discovery of buckyballs. Possible applications of interest to industry include optical devices; chemical sensors and chemical separation devices; production of diamonds and carbides as cutting tools or hardening agents; batteries and other electrochemical applications, including hydrogen storage media; drug delivery systems and other medical applications; polymers, such as new plastics; and catalysts.

Catalysts, in fact, appear to be a natural application for fullerenes, given their combination of rugged structure and high reactivity. Experiments suggest that fullerenes which incorporate alkali metals possess catalytic properties resembling those of platinum. The C_{60} molecule can also absorb large numbers of hydrogen atoms—almost one hydrogen for each carbon—without disrupting the buckyball structure. This property suggests that fullerenes may be a better storage medium for hydrogen than metal hydrides, the best current material, and hence possibly a key factor in the development of new batteries and even of non-polluting automobiles based on fuel cells. A thin layer of the C_{70} fullerene, when deposited on a silicon chip, seems to provide a vastly improved template for growing thin films of diamond.

It is too early to make reliable forecasts of commercial potential, although the early indications are that buckyballs may represent a technological bonanza when their properties are fully understood. Yet it is important to note that the discovery of this curious molecule and its cousins was serendipitous, made in the course of fundamental experiments aimed at understanding how long-chain molecules are formed in outer space. It is a strong reminder that fundamental science is often the wellspring of advanced technology in ways that are completely unpredictable.



The perfectly round C_{60} "buckyball" cluster.
Source: National Science Foundation

There is already a considerable amount of scientist-to-scientist interaction and collaboration. This is the foundation of international scientific cooperation. However, the government has an important role both in lowering barriers and in supporting large scale collaborations. For example, interoperability of data bases and networks is crucial for enhancing collaboration, and we will continue to work towards appropriate international standards. Strengthened science and technology presence overseas can aid information gathering, identify more opportunities for effective collaboration, and provide the basis for economic relations in technical areas. We must enter international collaborations with clear responsibilities and secure commitments for each partner. For this, we must establish with the Congress mechanisms for prioritizing, committing to, and then sustaining long term support for large projects. This need applies equally well to large American projects with multi-year time scales.

Over the long term, U.S. investment in fundamental research must be commensurate with our national goals. The Gross Domestic Product (GDP) provides the benchmark for total economic activity and thus the most meaningful measure of the R&D investment. Total U.S. support of non-defense R&D is about 1.9 percent of GDP, below that of Germany (2.5 percent) and Japan (3.0 percent). Including all defense R&D (most of which is applied research, development, testing and evaluation), the U.S. total becomes 2.6 percent. The dominant part of the non-defense R&D investment is industrially sponsored applied research and development, that is, activity relatively close to the marketplace. The special responsibility of the Federal investment in sponsoring fundamental research is highlighted by noting that about two-thirds of fundamental research support is Federal, in comparison to about one-third of the applied research and development support (including defense R&D). Still, the Federal expenditure for basic research, the "venture capital" of our national enterprise, is only 0.27 percent of the GDP.

"In conjunction with developing international partnerships the United States must lead the way in training engineers and scientists to meet the challenges of economic development in a global marketplace. We must begin to produce a new breed of engineers and scientists with a broadened view of technology and service to society."

Emir Jose Macari
Georgia Institute of Technology

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Origins of the Information Superhighway

Ten years ago, the information superhighway could not have been built. Many of the core technologies essential to the convergence of computing and communications—a conjunction at the heart of the information superhighway—were simply not ready. The discoveries that initiated or made these technologies possible go back even further—before anyone dared to dream of a world in which scientists could collaborate across continents, in which every school could be connected to the great libraries and museums, and in which ordinary citizens could tap a wealth of digital services and entertainment from their homes.

The true origins of the information superhighway, in fact, include fundamental research on the physics of surfaces in the late 1940s that led to transistors, obscure university work on microwave oscillators in the early 1950s that led to lasers, and a speculative suggestion in an academic journal in the mid-1960s that led to optical fibers. Such research, if proposed today, would be hard to distinguish from hundreds of similar basic research proposals. Yet it produced the seeds of a revolutionary technology that is likely to transform homes and workplaces alike.

Consider one thread in this complex story, that of optical fibers. The idea that laser light could be transmitted over long distances in a glass fiber—and hence used for communications—can be traced to a 1966 article in a scientific journal. The first fibers were relatively crude: they broke easily and defects or impurities in the glass scattered or absorbed enough of the light signal that it couldn't travel very far. But basic research on the chemistry and thermodynamics of glass and on the scattering of light in liquids (glass can be thought of as a cooled liquid) led to steady improvements—purer glasses that reduced losses, for example, and epoxy coatings that made the fibers more flexible and resistant to corrosion. In 1970, Corning Glass Works demonstrated a fiber that could transmit a light signal with losses of only 1 percent per kilometer—a big advance at the time, but not good enough for commercial systems.

Today's fibers have losses of 100-fold less, reduced almost to the theoretical limit, and the result has been an explosion of optical communications. Optical fibers now carry most U.S. long-distance telecommunications and the total traffic over fibers is 1,000 times greater than a decade ago.

But the fiber story is far from finished. Fundamental research into the properties of rare earth elements, such as erbium, has led to a new wave of developments that are transforming fibers from passive to active devices with even greater carrying capacity. When fibers are doped with erbium and powered by a semiconductor laser, they can amplify an optical signal. Spliced directly into a fiber cable, these fiber amplifiers will soon begin to replace the regenerating stations that now detect, amplify, and retransmit optical communications signals every 30 to 100 kilometers. Since the comparatively slow electronic components of regenerating stations are the principal bottlenecks in today's long-distance networks, this change to an all-optical technology will increase the capacity of long-distance communications systems by as much as 100-fold.

The process is a continuing one. Just as commercial deployment of the information superhighway is harvesting earlier investments in the creation of basic knowledge, so the technologies of tomorrow and the commercial competitiveness that goes with them will stem from the science of today.

Hair-thin fibers of ultrapure glass are now transmitting voice, data and video communications in many parts of the globe in the form of digital signals emitted by semiconductor lasers the size of a grain of salt. ***Source: PLG Group***

U.S. Research and Development Funding (FY93) ($ Billions)

Funding Source	Development	Applied Research	Basic Research	Total
Federal Government	36.1	15.5	16.5	68.0
Industry	57.8	21.1	4.6	83.6
Universities/Colleges Other Nonprofits	0.9	3.1	5.1	9.2
Total	94.9	39.7	26.2	160.8
Percent of GDP				
Total Funding	1.54	0.64	0.42	2.6
Federal Funding	0.58	0.25	0.27	1.1

All entries taken from 1993 Science & Engineering Indicators, National Science Foundation, Tables 4.4 to 4.7. The GDP of $6,172 billion is from table 4.1. Individual entries have small uncertainties because of differences in definition of basic research, applied research, and development. Total entries may have roundoff entries of 0.1. Table includes both civilian and defense R&D. Of the Federal R&D total, defense R&D accounts for $41.5 billion (including $1.3 billion in basic research). The civilian R&D total of $119.3 billion represents 1.9 percent of GDP.

We must put into place better mechanisms to evaluate our investment strategy and to make changes as later evaluations and future conditions demand. This Administration's strong emphasis on shifting the character of defense R&D towards dual civilian-military use will help focus our overall R&D investment much more on the marketplace. With steady progress here, a reasonable long term goal for the total national R&D investment (both civilian and defense) might be about 3 percent of GDP. This modest increment should be shared by the Federal government and the private sector. Additional work on how to assess this long term goal will be conducted within the NSTC. In any event, the private sector investment will be driven by the global marketplace in an increasingly technology-based society, with government fiscal and regulatory policies enabling and stimulating investment. As the private sector investment is likely to remain heavily weighted towards shorter term applied research and development, properly so, the Federal investment must further strengthen fundamental research, rebuild the science infrastructure, and strengthen longer term applied research and development, thereby providing the seed funds for long term health of the R&D enterprise.

"The balance of military and civilian activities drawing from fundamental science is the most healthy when each has ways of relying on the other, and learning from one another."

Richard Slansky
Los Alamos National Laboratory

Monitoring the Earth

The increasing scale of human activities on the earth has brought with it increased risk of environmental damage on a global scale. Managing the earth in a responsible manner thus requires monitoring the atmosphere, the oceans, and critical terrestrial ecosystems, so that environmental degradation can be detected in time. Satellites, backed by aircraft and ground observations and by fundamental research on biogeophysical systems, are already playing a major role, and could play an even larger one in the future.

Satellite data helped to confirm the initial discovery of the Antarctic ozone hole and to show that degradation of the earth's protective ozone layer was a global phenomenon. Intensive field and laboratory research, coupled with aircraft and satellite data, soon demonstrated that the degradation was caused by human activities—the industrial chemicals known as chlorofluorocarbons (CFCs), which are degraded in the stratosphere to release chlorine and which, in turn, catalyzes the destruction of ozone. This research led to the signing of the Montreal Protocol and amendments, which committed nations to phase out production and use of CFCs. Subsequent satellite monitoring has shown continued declines in global ozone levels and the presence of high chlorine concentrations over the Arctic, possibly presaging the creation of an Arctic ozone hole as well. Such observations have led to accelerated deadlines for phasing out CFCs, with the result that global production and emissions of these chemicals are beginning to decline. What could have been a major global disaster, with sharply increased levels of ultraviolet radiation harmful to living creatures, is being averted.

Pictures from space have brought global attention in recent years to another environmental problem—the destruction of tropical forests. Astronauts have described seeing the plumes of smoke from space, and nighttime infrared images have shown the Amazon region lit with hundreds of fires. The loss of tropical forests not only threatens the ecosystems that harbor the largest portion of the world's species, but also increases the risk of global warming.

Satellite observations can not only call attention to environmental hazards, they can also help to assess the extent and character of the problem accurately. Recently, for example, careful analysis of satellite imagery from the Amazon region showed that the total area of forest loss over the past decade was less than had been initially thought. However, it also showed that the pattern of clearing and burning had increased the fragmentation of the forest, making an area two-and-a-half times that actually cleared vulnerable to loss of species through disruption of ecosystems. The analysis technique is applicable to other tropical forests as well, and research has already begun to re-examine past satellite images covering other tropical forest regions.

As human populations and industrial activity increase, so will pressure on the environment. Both fundamental research to better understand earth systems and increased monitoring using advanced satellites will be important to detect degradation in time and thus to help preserve our environment for future generations.

This computer generated color composite image, produced from data acquired from the Landsat-4 and -5 satellites, is a representation of deforestation in the Brazilian Amazon region from 1978(a) and 1988 (b). The deforestation represented in these figures is confined exclusively to the forest strata and has been averaged into 10-by 10-mile cells.
Source: National Aeronautics and Space Administration

Our investment budget in fundamental science will be improved in the short term as we examine existing resources and, to match the growing importance of science as a foundation of modern society, increased with future improvements in the Federal government's fiscal condition.

The NSTC will provide ongoing evaluation of America's position in fundamental science, mathematics, and engineering and recommend actions to assure world leadership in all major fields.

Our investment in fundamental science must be accompanied by careful attention to support for international collaborations. The NSTC, with advice from PCAST, will recommend policies for long-term multinational agreements for the support of large scientific projects.

We will work with Congress to find mechanisms for long-term authorization and budgeting commitments for large projects whether conducted exclusively by American scientists or in partnerships with other countries.

Goal: Enhance connections between fundamental research and national goals

Scientific knowledge is necessary for helping us achieve our national goals of improved health, environment, prosperity, national security and quality of life. Equally important are the social institutions, markets and government programs that promote the dissemination of knowledge, technologies, and products. This Administration has taken significant steps, such as strong support of the Advanced Technology Program and establishment of the Technology Reinvestment Program, towards accelerating the development of technologies critical for long-term economic growth and for increasing productivity while reducing environmental impact. Success in this effort demands sustained commitment to fundamental science, the foundation on which technical progress ultimately rests. Truly unexpected technologies, some of which reshape our work, education, recreation, and well-being, generally stem from discoveries of fundamental research which have given us an entirely new way to see how nature works.

This does not mean that the societal benefits of science and technology follow a linear progression from fundamental to applied research, and then development into a product. We depart here from the Vannevar Bush canon, which suggested a competition between basic and applied research. Instead, we acknowledge the intimate relationships among and interdependence of basic research, applied research, and technology,

"Over the last half century, we have achieved spectacular scientific and engineering accomplishments in the service of a Vigilant Society. We now need to enlist our science and technology in the service of a Humane Society where work is meaningful, families are secure, children are well fed and well educated, where prevention is the first line of defense in health care, where the environment is respected and protected for future generations, and where sustainable development becomes the conscience of our progress."

George E. Brown, Jr.
United States House of Representatives

A Virtuous Infection

Genetic engineering turned out to be relatively easy in animal or bacterial cells. Plants, however, initially appeared to be much harder. Fundamental research on a common soil bacterium and its interaction with the plants it infects unexpectedly showed the way. Now genes introduced into plants with the help of that bacterium are poised to bring huge economic and environmental benefits to U.S. agriculture.

The soil bacterium is called Agrobacterium. It infects nearly 10,000 species of plants, causing what is known as crown gall disease. The galls are tumorlike enlargements, and while the disease is harmful to some plants, it is not usually considered a major threat to crops and so is not worth a targeted research effort. Nonetheless, it attracted the curiosity of agricultural scientists in universities and government laboratories as a possible model for cancer; this research led to some fascinating discoveries.

What makes Agrobacterium unique is that when it infects a plant, it transfers a tiny bit of its genetic material, its DNA, into its host — the only bacterium known to do so. It is this foreign DNA that causes the galls or tumors. Further research uncovered the details and showed how to take advantage of this natural genetic engineering agent. The genetic material that causes the galls resides in a small circular ring, or plasmid, of bacterial DNA, a portion of which is incorporated into the plant cell's chromosomes. Scientists were able to snip out the tumor - inducing genes and replace them with genes of choice. Then, when the altered Agrobacterium infects a plant, the new genes are incorporated into its genetic makeup.

Such controlled, virtuous infections have become the method of choice for genetic engineering of many important commercial crops. Genes inserted with this method have led to spoilage-resistant tomatoes, insect-resistant cotton, and a host of experimental varieties of soybeans, rapeseed, popular trees, and roses. Fresh tomatoes constitute a $4 billion market in the United States; a spoilage-resistant variety that can be ripened longer on the vine for greater flavor is one of the first genetically-engineered products in supermarkets. Cotton, the fifth largest U.S. crop, is also the largest user of pesticides, so that insect-resistant cotton will save farmers money and reduce environmental risks.

Although Agrobacterium is no longer the only genetic engineering tool in the plant scientist's arsenal, the fundamental research that uncovered its secrets helped launch the agricultural biotechnology industry. Biotechnology is expected to help produce safer, more nutritious foods and other agricultural products, create crop cultivars needed to cope with changing climates and pathogens, and make feasible alternative farming techniques that can conserve or reclaim fragile soils.

Scanning electron microscopy reveals several Agrobacterium tumefaciens as they begin to infect a carrot cell. In the process, the bacteria's genetic material will enter the plant cell.
Source: A.G. Matthysse, K.V. Holmes, R.H.G. Gurlitz

appreciate that progress in any one depends on advances in the others, and indeed recognize that it is often misleading to label a particular activity as belonging uniquely to one category. All contribute essentially to our national strategic goals. The synergy between science and technology requires coherent Federal policies in both areas. The NSTC will be the Administration's principal instrument to instill coherence in the Federal research and development enterprise. The Council will identify research thrusts of special promise and develop the appropriate investment portfolio across Federal agencies.

Many Federal agencies depend upon and contribute to our science and technology base in pursuing their missions in support of national goals. Federal laboratories associated with these agencies are an important part of our national science investment and infrastructure. For example, in addition to directly supporting agency research and development needs, they operate large facilities for fundamental research by university scientists and develop, maintain, and disseminate critical data bases. In these changing times, their missions and contributions to national goals are changing as well. They must be part of strengthened connections between fundamental research and evolving national goals.

"The federal laboratories were established to provide the capability to meet national research goals and needs, complementary to those existing at universities and industry. Largely, they have been very successful in this task. As goals are reached and new ones emerge, it is necessary and healthy to continue to assess the way the federal laboratories provide these capabilities and address national goals and needs, including the goal of this Administration —World Leadership in Basic Science, Mathematics, and Engineering."

John Schiffer
Argonne National Laboratory and University of Chicago

We understand that the fruit of fundamental research initiatives may not ripen for some time. The time scale can be long, and success may hinge on facilities or interdisciplinary research teams that take years to assemble. Even in the face of current budgetary pressures, considerations about fundamental science, including the social and behavioral sciences, must remain integral to the agency planning activities. We cannot allow a short-term mission focus to compromise development of the intellectual capital vital to our Nation's future.

The NSTC will foster, prioritize, and coordinate major cross-agency fundamental research and education initiatives coupled to national goals.

Each agency that depends on or contributes to our science and technology base will, with involvement of the scientific community, delineate its fundamental research and education missions with respect to the national goals; develop long-range plans for its fundamental science, mathematics and engineering investment; and develop measures to evaluate its contributions.

Seeing Inside the Body

Over the ages, physicians have sought a means of seeing inside the human body without cutting it open. Fundamental discoveries in physics have given us first x-rays and then the more modern diagnostic methods of magnetic resonance imaging (MRI) and positron-electron tomography (PET), contributing to remarkable advances in medical research.

The development of MRI is illustrative of the often complex path to major new technologies. It began as basic research in nuclear physics—in particular, the curious fact that the nuclei of most atoms behave as though they have a tiny magnet attached to them. Physicists soon learned that when they probed the properties of that magnet with a radio beam in the presence of a strong external magnetic field, they could identify which kind of atom it was. As the technique, known as nuclear magnetic resonance, improved, it became possible even to tell something about an atom's interactions with neighboring atoms. Chemists then developed the technique further as a powerful tool for analyzing the chemical structure of a material, including, eventually, biological tissues. This ability to probe the submicroscopic structure of matter—and hence to map the distribution of certain kinds of molecules in a sample or of cancer cells in a body—provided the scientific base for MRI.

Yet MRI also depends on a number of technologies that evolved separately but in parallel with the basic science, and it was the combination of these with the fundamental physics that made MRI possible. Once the idea emerged of using the nuclear magnetic resonance technique to create images, for example, a host of practical problems remained.

For one thing, the technique was initially too slow for medical use. Modern electronics—especially computers-on-a-chip that could be built directly into practical instruments—helped speed it up. So did the mathematical technique known as tomography—synthesizing a composite image from many different "pictures." Superconducting magnets helped to make more compact and powerful MRI instruments.

The result is a remarkable medical diagnostic tool. MRI gives the most precise picture now available of what is happening inside the body and does so noninvasively and safely. Yet it is most unlikely that MRI could have emerged from a targeted effort to design a better imaging technique—who would have thought to begin by measuring the strengths of magnets within atomic nuclei? For MRI, as for many other important technologies, just such fundamental explorations of nature produced the knowledge that enabled a vision of a life-saving imaging technique.

(above) MRI cross-section of brain showing both hemispheres as well as the ventricles (openings).
Source: National Institute of Neurologic Disorders and Stroke

(left) Patient entering a magnetic resonance imaging (MRI) machine for medical diagnosis.
Source: National Cancer Institute

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A cross-agency review of Federal laboratories will give particular attention to their role in support of national goals and their effectiveness in performance and support of fundamental science, mathematics, and engineering.

Goal: Stimulate partnerships that promote investments in fundamental science and engineering and effective use of physical, human, and financial resources

The Federal government can foster the conditions that stimulate private sector investments in fundamental research and in the facilities in which competitive research and quality education are conducted. For industry, these include an appropriate fiscal and budgetary environment, a stable science-based regulatory system, a global trade environment which encourages commercialization of technology, and intellectual property protection. For colleges, universities, and medical schools, the conditions include stable policies on research funding, establishing equitable policies for financing the construction, renovation, and modernization of educational and research facilities, and modernizing the costing principles for academic buildings and equipment.

"What good would I recommend the government do? If I had to pick one prescription to keep our science healthy and productive, it would be: — to nurture the climate that encourages discovery; and — to maintain and enhance the climate that rewards innovation and enterprise."

Virginia V. Weldon
Monsanto Company

Economic competitiveness is rooted in the health of industry at state and local levels. That is where job creation occurs. Thus, we seek to leverage industry-university collaboration using existing state mechanisms and to encourage new state initiatives.

The underlying purpose of industrial and industrially-sponsored research is to stimulate innovation and thereby to create new business opportunity. The principal determinants of success are the quality of the scientists and engineers available to industry and the knowledge base and core competencies which permit both informed decision-making and technological innovations. Thus, the continued health of our major research universities is of utmost importance to our science and technology-based industrial sector. Research is, by its nature, a long-term activity and our industrial managers should be able to plan their commitments with the security that government policies will be reasonably predictable throughout the research activity.

"Some of the most synergistic research coupling of able engineers and scientists in academia and industry will occur via a "bottom up" process: through collaborations established by the individual researchers themselves. In such collaborations, the more mission-oriented inquiries of the industrial researcher will benefit from the less focused outlook of the academic. And the academic researcher in turn will better understand the rich trove of challenging problems that are posed by the strategic objectives of his/her industrial collaborator."

Louis J. Lanzerotti
AT&T Bell Laboratories

"Deferred maintenance of research facilities is a serious national problem. The potential bill is so large that it is unlikely that any single payer will have adequate funds to remedy the situation."

William H. Danforth
Washington University

The heartland of fundamental science and engineering research and advanced education is our unmatched system of research universities and federal laboratories. While fundamental research is declining in much of industry, industrial leaders frequently speak of the value of "people transfer" and "idea transfer" with academic institutions. Faculty and student participation in industrial research and in industrially-sponsored research can have many benefits beyond the research product itself: the educational benefit to the students of learning about the industrial environment; the access of industry to many of our most talented faculty; early identification of the most promising students; possible long-term research collaboration on problems of interest to industry.

Our research infrastructure (the people, instrumentation, information systems, institutions, and buildings) in colleges and universities, in industry, and in Federal laboratories is an enormous national resource. It enables our highly successful research enterprise to continue forward in a leadership position. It is a resource which must be continuously renewed and renovated. Used judiciously, it can also be one of our most effective resources for addressing our national objective of improved science and mathematics education. Stronger coupling between researchers and teachers at all levels—from kindergarten through graduate school—will naturally bring these resources into play to enrich our educational system.

The magnitude of the costs of repairing research laboratories and upgrading research instrumentation indicates a continuing need for government programs to modernize our research infrastructure and policies that will encourage private sector investments. Given the strictures on funding of discretionary government programs for the foreseeable future, and the priority this Administration places on strengthening the support for research funding, it is essential that careful consideration be given to the design of an infrastructure renewal program. The National Science Foundation estimates that the total cost of performing all needed repair and renovation of existing academic research space is in the range of $7 to $8 billion. These figures do not include provision for replacement of space that is of such poor quality that renovation would not be appropriate. Institutions indicated that 13 percent of their existing research space needed major repair to be used effectively, and an additional 23 percent needed limited repair. An additional 3 percent was reported to be in such poor condition that complete replacement would be needed. Further, a survey of academic department heads indicated that high priority scientific instrumentation needs total about $3 billion. The primary justification for the highest priority needs was that of making important frontier experiments accessible to academic researchers, both faculty and students.

Partnerships between the Federal government and states can also be used to develop scientific resources and talent throughout the country. The Federal government already seeds partnerships with participating states, and the states provide matching funds as a demonstration of commitment to increasing their competitiveness for merit-based Federal and private sector research support. Such programs frequently pay other dividends—tying together education and research and strengthening the research infrastructure within states.

We will work in partnership with universities and the private sector to modernize our research infrastructure. To stimulate private sector infrastructure investments in our educational institutions, we will both support elimination of the cap on tax-free bonds for such purposes and re-evaluate allowances for use of facilities and equipment, consistent with industrial practice. The NSTC will develop options for how to implement the Federal investment as a systematic, long-term, multi-agency, merit-reviewed program.

The NSTC, with advice from PCAST and the broader scientific community, will advise on impediments to industry investment in fundamental research and recommend policies to encourage industry investment. The Clinton Administration has supported and proposed making the Research and Experimentation Tax Credit permanent.

The unique assets of the Federal research enterprise will be viewed as a national resource not only for research and post-graduate education but also for enriching the full educational continuum. Federal agencies and their technical facilities will strengthen programs offering research experiences for pre-college and undergraduate college teachers and technical training and apprenticeships for the school-to-work transition and for displaced workers.

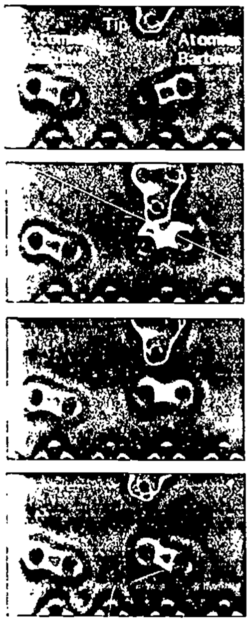
The Clinton Administration will maintain a strong commitment to Federal-state-industry partnerships for forging stronger links between the educational community and the workplace and for seeding merit-reviewed research programs across the nation as important investments in developing research capabilities and associated educational benefits.

"The Federal government should seize the opportunity to initiate and to leverage industry-university partnerships using existing state mechanisms and to encourage other state initiatives."

Catherine Fenselau
University of Maryland, Baltimore

Simulating Reality

The computing revolution is dramatically transforming virtually every aspect of our society—our work, our play, even our national security. This revolution started with the discovery of the transistor, the result of fundamental research in solid state physics and the earlier development of quantum theory. The next stage, development of complex microchips incorporating many transistors, drew from fundamental work in physics, chemistry, and materials science. Now applications such as smart military weapons, delivery of consumer services such as movies on demand, or means of transferring electronic funds in a secure manner are incorporating new discoveries in mathematics, engineering, and computer science.



One important frontier of the computing revolution is found in today's powerful supercomputers, which have the ability to perform hundreds or thousands of calculations simultaneously (so-called massively parallel computers). Within years, this field is expected to cross an important threshold, when the fastest computers will be capable of a thousand billion floating-point operations per second (teraflops). Petaflop computers (capable of a billion billion operations per second) may follow only a few years later.

These advances in computing technology draw heavily on fundamental science. But science and technology are closely intertwined: the technology is also driving forward the frontiers of science—ushering in new fields of research and extending the limits of inquiry in virtually all fields—which will in turn enable new technology. For example, for the first time scientists can now begin to simulate such complex physical and biological systems as the earth's climate, the atomic structure of novel materials, and the molecular structure of living cells. Applications of this new computationally-driven science will include improved microelectronic devices and rational drug design.

Computational studies of silicon—the semiconductor material on which most modern computing is based—illustrate the trend. Researchers are now beginning to simulate silicon-based materials with supercomputers, allowing them to perform "theoretical experiments" and—using new techniques for visualizing atomic scale structure—to "see" the results. Physicists, for example, can now use supercomputers to understand how oxygen impurities influence and impede the electrical properties of silicon wafers—a problem that has plagued semiconductor manufacturers for years. In a simulation, a researcher can introduce oxygen molecules into a silicon lattice and watch how it throws the local electrons into a tizzy—something no microscope can observe. The same approach can be used to study another important problem—the migration and diffusion of impurities within a silicon crystal. Insights from such simulations could lead to improved manufacturing processes.

Exciting results are also emerging from studies of the surface of silicon crystals. The outermost atomic layer seems to consist of pairs of atoms, bonded together in a "barbell" configuration. Theoretical experiments indicate that each barbell can exist in one of two states—up or down, as shown in the top panel of the figure. This suggests the possibility of storing bits of data on an atomic scale—many thousands of times more compact than in present computer memories. Other simulations show that a thin metallic tip, similar to those used in Scanning Tunneling Microscopy, can in principle establish the required orientation of the surface atoms. Thus the supercomputer simulations may lead to the development of revolutionary new information storage technologies.

The synergy between science and technology is crucial for developing the next generation of new technologies. Present computer designs will reach limits dictated by the laws of physics. Can faster, smarter machines be built to model the human brain? Can biological components be built into computer chips? What about using individual molecules as switches a thousand times faster than microelectronic devices? These are the kinds of breakthrough technologies realizable only through fundamental research—research that is itself supported by advanced technology.

(above) A single oxygen atom is made visible as a blue sphere in this supercomputer-generated image of electronic charge inside a silicon crystal. The oxygen atom straddles one of the silicon bonds in the bonding lattice represented by a warm-colored honeycomb. ***Source: IBM Yorktown Heights and The Massachusetts Institute of Technology***

(left) Pairs of silicon atoms bonded together in a barbell configuration exist in up or down states whose configurations could be changed as shown in this supercomputer simulation by a thin metallic tip as used in Scanning Tunneling Microscopy. ***Source: K. Cho, J. Joannopoulos***

Goal: Produce the finest scientists and engineers for the twenty-first century

Our principal resource for maintaining leadership in fundamental science and engineering and for capitalizing on its advances is our talent pool of well-educated scientists and engineers. They are the wellspring of new ideas and new solutions to challenging problems. American colleges and research universities are unmatched in their ability to provide advanced education and to enrich it through forefront research. This system has served the nation exceptionally well, directly coupling post-secondary and advanced education with the unique training afforded by research at the intellectual frontier. These institutions are truly national and international in character, bringing in students from across the nation and the globe, and then sending them out to teach, to do research, to start companies, to branch out into new careers with the creative energy needed to address a broad range of challenges.

"There seems little doubt that prosperity, security, and social well-being of our nation during an era of rapid technological change will require both an adequate supply of well-trained scientists and engineers and a scientifically literate populace."

Bonnie J. Brunkhorst
California State University, San Bernadino

Our goal is to maintain this excellence and to encourage the ongoing reexamination of advanced education in our colleges and universities. The scientifically literate society that America will need to face the challenges of the 21st century will require orientation to science early in life and frequent reinforcement. Because training scientists is a long process, we can not quickly overcome shortfalls in trained personnel in some areas and should not react precipitously in allocating our training support.

We will sustain this tradition of excellence only by engaging the talents of our diverse population. America derives great strength from its diversity, yet the country has not had a coherent policy for developing all our human resources for science and technology. Women, minorities, and those with disabilities are underrepresented in most fields of science, mathematics, and engineering with respect to their proportions in the population. Much of this underrepresentation in science starts very early in the educational process. It will be essential for the future well-being of the country, and specifically of the scientific enterprise, that we educate the twenty-first century scientific workforce by explicitly engaging participants representative of the nation's diversity.

"Orientation to science, mathematics, and engineering must be encouraged early in life and reinforced frequently. Because training for excelling in these fields is a long process, shortfalls in trained personnel cannot be rapidly overcome."

Shirley McBay
Quality Education for Minorities Network
and Linda S. Wilson
Radcliffe College
Reporting on a Group Discussion, Forum on Science in the National Interest

Role models are clearly important. We must also do all that we can to encourage excellent mentoring of individuals in underrepresented groups and access to research experiences. This will be stimulated through awards to be distributed at state and local levels where the nurturing of individuals with interest and talent occurs. We will continue to sponsor research experiences for members of groups who are underrepresented in the sciences. Our Federal laboratories will continue to provide centers for

Plastics that Glow

Ever since the discovery of nylon in the first half of this century, plastics have steadily found more and more uses. Now they are poised to invade one of the hottest areas of electronics—light-emitting diodes. That could create lucrative new markets for such things as computer screens, advertising displays, and even wall-sized video screens.

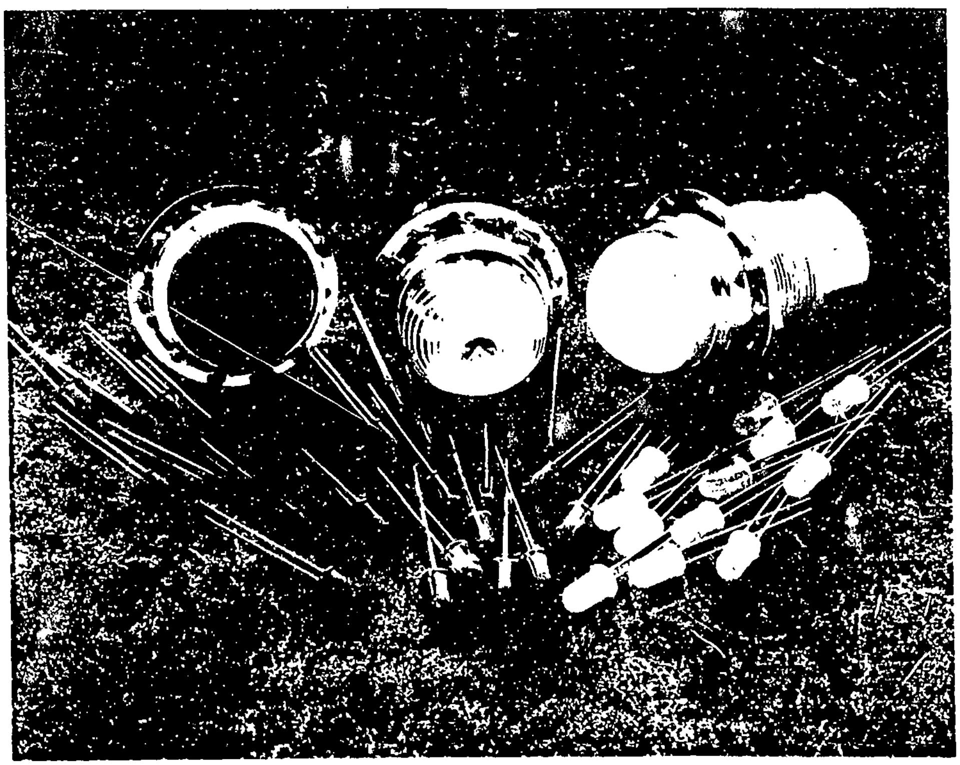
Intriguingly, however, these advances have not come from the electronics industry, as innovative as it is. Instead they come from fundamental university research into the properties of polymers—the long-chain organic molecules formed of repeated units that are the basis of most plastics. This long-chain structure gives polymer plastics the flexibility that makes them so valuable in dozens of applications—from stretch tights to bulletproof vests to kitchenware that doesn't shatter when dropped.

Most polymers don't conduct electricity. But in the late 1970s, researchers at the University of Pennsylvania discovered a plastic that, when "doped" with small amounts of impurities, could conduct. The technique is analogous to the doping of semiconductors that makes possible transistors. Further research led to other conducting polymers, but none found so far conduct well enough to replace metals. In exploring the basic properties of these materials, however, researchers did find something else—plastics that emit light when an electric current passes through them.

The discovery came from investigations of luminescence—the property that makes a luminous watch dial glow after it has been exposed to light—in conducting polymers. Studies of the electronic properties of these materials suggested the possibility of triggering such glows electrically, just as in the light-emitting diodes (LEDs) that form the little red on/off lights on many electronic appliances. Not only was it possible, but scientists rapidly found plastics that would emit in virtually all colors—from red to yellow to blue. Further research has improved efficiencies, boosting the first feeble glows into a source of light potentially bright enough to power a display screen. The key remaining problem is that plastic LEDs don't last long enough for most applications, but researchers are optimistic that this problem, too, will be solved.

Light-emitting plastics have become an area of intense scientific and commercial interest. Scientific articles on the subject were among the most-cited in physics in 1993. Two startup companies have already been formed, and larger electronic companies are paying close attention.

The appeal is that light-emitting plastics are thin and flexible and can even be bent around corners—it is possible to imagine low-level lighting fixtures that would fit any location, or even clothing that would glow. Plastic LEDs could also be made in large sheets, potentially as wall-size, flat display screens—long a key commercial target in consumer electronics. Such potential applications could not have been anticipated in the initial investigations into conducting polymers, but such surprises are not an uncommon outcome of fundamental research.



Three types of specially designed indicator housings. The large indicator products were designed to be replacements for older incandescent lamps, and last 50 to 100 times longer. This type of indicator is now used in many applications including mass transit, heavy equipment, and as market lights on trucks. ***Source: DiaLight Corporation***

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such activities; however, beyond that, we ask all Federal grantees to engage creatively in the process. It is a critical investment in the future of this country.

The NSTC will produce a human resources development policy for sustaining excellence and promoting diversity in the science and technology workforce.

Every Federal agency's educational programs in science, mathematics, and engineering will have, as one measure of success, its impact on increased participation by underrepresented groups.

The NSTC will develop a new program of Presidential awards for individuals and institutions that have outstanding records in mentoring students from underrepresented groups toward significant achievement in science, mathematics, and engineering.

Goal: Raise scientific and technological literacy of all Americans

We must improve the U.S. educational system to give our children an understanding and appreciation of science and the opportunity to compete successfully for high quality jobs and to lead productive lives. Our educational system is the foundation of public scientific and technical literacy. The technology-based global economy of the next century will place a high premium on science and mathematics education, on knowledge of foreign languages and cultures, on facility with technologies, and on versatility and flexibility. Our economic strength will depend more than ever on the ability of the American people to deal with new challenges and rapid change. Yet, we have known for over a decade that the education of America's children, particularly in science and mathematics, has fallen below world standards for a significant fraction of our population.

This Administration's agenda is centered on "Goals 2000: Educate America." This initiative calls for systemic reform of elementary and secondary education organized around the challenging national education goals. Demonstrated competency in mathematics and science by all students leaving grades 4, 8, and 12 is one of the key goals. All students must be prepared for responsible citizenship, ongoing learning, and productive employment in the twenty-first century economy. Responsibility for implementation lies with the states, who will develop their own comprehensive improvement plans aimed at reaching the national education standards. The Goals 2000 process will promote coherence among Federal, state, and local education programs, with Federal resources

"We must remember that the main mission of a university is education. However, we must articulate and rearticulate that the foundation of good education is knowledge, derived from research inquiry and discovery."

M.R.C. Greenwood
Office of Science and Technology Policy

"I strongly believe that we will be providing for our country's future only when a large group of our most talented and energetic young people are choosing teaching careers. To me, this is a far better test of our educational system than any measurement we could design that is based on student test scores. It also has the advantage of giving us an instant, unambiguous reading of how well we are doing in our education investment."

Bruce M. Alberts
National Academy of Sciences

helping to provide comparable tools across the nation for addressing the educational standards. With respect to the mathematics and science goals, we emphasize the special opportunities and obligations of our scientific and technical community to help meet this critically important national challenge.

We are committed to facilitating expanded partnerships between the educational community, the private sector, and government at all levels. America's scientific and technical communities employed in colleges, universities, industry, and government represent an enormous resource for improving the science, mathematics, and technological education of our children. Our elementary and secondary school teachers are also an enormous resource and deserve our support. We need both to stimulate more research into the application of learning technologies and the practice of mathematics and science education, drawing upon the experience of outstanding teachers and successful programs, and to join the science education and research cultures symbiotically. Partnerships built around a common purpose are the key to the systemic reform needed in science and mathematics education. Only a cooperative effort by individuals and institutions will take us to our national education goals.

Our commitment cannot end with high school. The school-to-work transition and lifelong learning opportunities are increasingly important in the workplace because of rapidly evolving technology. Our Administration wishes to learn from industry and from state and local governments how Federal science and technology assets can be used most effectively for these purposes.

The lifelong responsibilities of citizenship increasingly rely on scientific and technological literacy for informed choices. Our scientific community must contribute more strongly to broad public understanding and appreciation of science. Our education system must provide the necessary intellectual tools at twenty-first century standards.

We will work with the research and educational communities to implement mathematics and science education standards to meet the needs for higher achievement, to prepare students for high quality jobs of the future, and to foster excellence in and appreciation of science.

"One idea presently in embryonic form is to work out finance arrangements so that Ph.D. students who enter K-12 education ... and become leaders will have the professional opportunity to return to research groups at Universities during the summers (and periodically for a year during their career) to help train other teachers, run workshops, science summer camps, and prepare new curriculum materials drawing on the resources of the research groups. In that way, they can look forward to a career in which they are not separated from the cutting edge of research, and they are provided with resources that will enable them to become leaders in their professions."

W. Carl Lineberger
University of Colorado

We must involve teachers in career-long professional development where researchers work in partnership with practicing teachers to bring the excitement of research and its discoveries into the classroom.

Federal agencies will encourage research scientists to use their research experiences in support of public understanding and appreciation of science.

This Administration will encourage the development of industry-state-local government consortia and regional alliances to bring telecommunications and other information resources to elementary and secondary schools, two and four-year colleges, and universities. The National Information Infrastructure will play a central role. We must educate our children for the twenty-first century workplace in a twenty-first century setting.

The Human Dimension

Every day, people in many diverse occupations make decisions that have potentially large consequences for human health and safety. Is this plane safe to fly? Given this patient profile, should a physician operate or recommend more conservative therapy? Will this weather pattern develop into a tornado? The answers to these questions have high stakes, and the process of arriving at a decision is often highly probabilistic, involving analysis of ambiguous an often conflicting information.

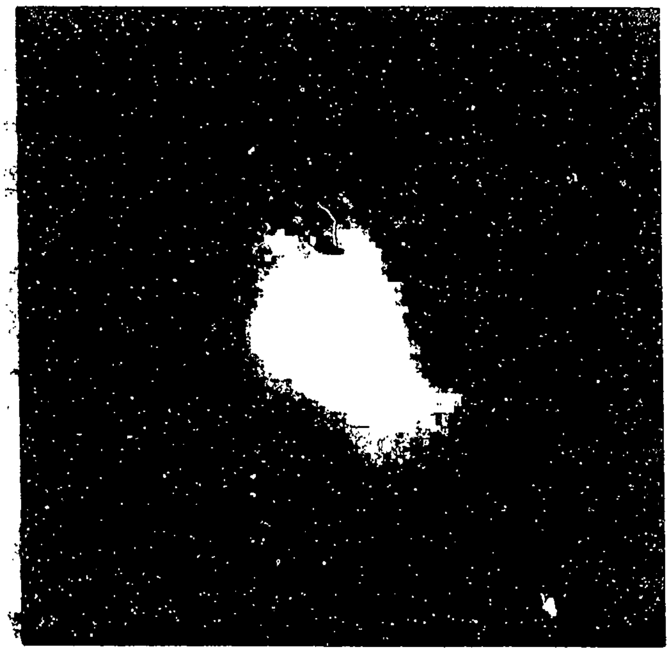
Researchers in the area of signal detection theory study how people, animals, and machines distinguish meaningful or important information from the background "noise" in their environment. From these studies, behavioral scientists are developing methods to help people make better decisions.

The results are known as decision aids, often computer programs that rely on a systematic, standard method that establishes a decision threshold and maximizes accuracy. A decision threshold is the level of evidence deemed necessary to make a decision in the specific situation, e.g. at what probability of a malignancy does one diagnose breast cancer? A fine balance must be struck between a lax threshold which creates many false positives (and their attendant emotional stress and unnecessary surgery), and a strict threshold which misses some positive cases and thereby jeopardizes lives. The decision maker must weigh whether false alarms or undiagnosed conditions are more costly and then must adjust the threshold accordingly. Accuracy can be improved by enhancing the quality of evidence available through basic research and developing better diagnostic tests and instruments. Thus, the methods of behavioral science go hand in hand with the physical and biological sciences.

The practical applications of decision aids are numerous and extensive. Already used experimentally in breast cancer diagnosis, HIV testing, weather forecasting, prostate cancer staging, and testing airplane wings for metal fatigue, the technique promises improved accuracy, and improved public health and safety.

Bringing the Universe into Focus

The razor-sharp images from the repaired Hubble Space Telescope bring the incredible splendor of distant heavenly objects into human view for the first time. Recently, for example, scientists used the Hubble to gather evidence that a massive black hole really exists at the center of a neighboring galaxy. Confronting—and even solving—some of the deepest mysteries of the universe may have no seemingly practical payoff, but it nonetheless appeals to the deep-seated human desire for knowledge of how we fit into the cosmos. Story Musgrave, the payload commander for the recent Hubble servicing mission, put it this way: "I have thought of that instrument as contributing to my personal ideas about what my place in the universe is, what it is to be human."



A NASA Hubble Space Telescope image of a spiral-shaped disk of hot gas in the core of active galaxy M87. Hubble measurements show the disk is rotating so rapidly it contains a massive black hole at its hub. ***Source: National Aeronautics and Space Administration***

The Hubble telescope revealed a pancake-shaped disk of hot gas at the center of the giant M87 galaxy. So sharp was the image that astronomers could see by the pattern of movement that the spinning disk of gas was being sucked down into and swallowed by something at the center. Measurements with the telescope determined the speed of the gas—an incredible 1.2 million miles per hour—allowing astronomers to calculate the mass of the central object. It is equal to 2 to 3 billion suns, so massive for its size that it could only be a black hole—a collapsed condition of matter whose gravitational pull is so strong that not even light can escape. Black holes are predicted by Einstein's theory of general relativity and have been suspected on the basis of other astronomical evidence, but they are such a strange and novel phenomenon that some scientists have remained skeptical. Now the new Hubble observations have provided proof—"the smoking gun," as one astronomer put it.

In addition to such dramatic discoveries, the Hubble is also being used to study the size and age of the universe, the evolution of galaxies from minute fluctuations in the early cosmos, and the details of star birth and star death. There are still plenty of mysteries to unravel about the vastness of space surrounding our planetary home—mysteries that are now in better focus.

The refurbished Hubble Space Telescope is a triumph of technology and human ingenuity, captured in the public mind by the sight of NASA's astronauts unfurling Hubble's new solar panels in space, against the distant backdrop of our home planet. The Hubble servicing mission demonstrated what can happen when scientists and engineers join together to solve a difficult problem. The flawed mirror was discovered soon after Hubble's 1990 launch. A team immediately gathered to examine dozens of possible "fixes". The resulting corrective device, an optical jukebox called COSTAR, was devised and built in only 26 months. Combined with the remarkable ability of the astronauts who installed it and otherwise upgraded the space telescope, the result placed innovative technology in the service of humanity's vision and age-old quest for knowledge about our environment and our place in it.

A Shared Commitment

We have outlined a broad program for advancing science in the national interest. We do so because science and technology depend on one another for continuous advancement and, in turn, are important for the health, prosperity and security of Americans. We do so because research at the frontiers of human knowledge provides unparalleled education for the young scientists and engineers who will help shape the nation's future. We do so to learn more about the world around us and about ourselves.

The public investment is returned ultimately through improvements in the quality of life. We recognize that science is but one part of a larger enterprise, and so our policies in science, technology, education, government performance, environmental protection, health care, international trade, information and communications, intellectual property protection, regulation, fiscal and monetary affairs, and other areas must work together. A thread running through this complex fabric of policy guidance is the pressing need for raising the scientific and technical literacy of the next generation to twenty-first century standards. This is essential for the continued enlightened support of the scientific enterprise by the American people. More important, it is critical for the nation's future.

We must all go forward with a sense of shared commitment to common goals and to excellence. The policies outlined here are only the beginning of a process. Strong federal investment and new partnerships will be essential. Our scientific and technical communities represent an enormous reservoir of talent, dedication and drive. We challenge them to continue their vigorous exploration of the frontiers of scientific knowledge and simultaneously to ensure that all Americans share their vision of the excitement, the beauty, and the utility of science in achieving our national goals. If they, government, and the nation as a whole accept the challenges set forth here and meet them together, our children and grandchildren will have a secure foundation on which to build their futures.

"Colleges and universities must reaffirm their commitment to education, and scientists both in and outside of academia must take seriously their mission to educate in science and science appreciation those who will and will not be scientists."

Vera Rubin
Carnegie Institute of Washington